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Prototyping in the Industrial Internet

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Master's Thesis in Mechanical Engineering

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Abstract

Founded on the pre-master project "Industrial Internet: Sensor Applications and Measurements in a Workshop Setting" (A1) as a starting point for thinking about early stage product development in the industrial internet, this thesis tries to bridge the gap between research and hype on one side and a practical approach to prototyping.

Wayfaring was used as the main method for gaining insights on how an advanced industrial machine were used and how data may be incorporated in feedback loops or repositories. Machine learning was used on a dataset of 165 instances of machine uses to predict familiarity with the machine. The learner was not able to significantly beat always choosing the majority class. Still, insights into how to prototype the data gathering and handling may be used by others to improve the interplay between man and machine.

Data was collected from six sources to monitor usage of a laser cutter. A coding scheme were developed to quantify each user session. This prototype driven-approach allowed for prototyping, testing, and learning in two dimensions – with data and without data. Insights from probing and need finding with users produced a rich description of what users want from a machine and how they are using it.

Further attention should be on using adaptive interfaces and feedback relevant to certain users. This area was only touched-upon and will likely be a promising venue for further research in an industrial internet context.

Sammendrag

Basert på pre-master prosjektet "Industrial Internet: Sensor Applications and Measurements in a Workshop Setting" (A1) som utgangspunkt for å tenke på tidlig stadium produktutvikling i det industrielle internett, forsøker denne oppgaven å bygge bro over gapet mellom forskning og hype på den ene siden, og en praktisk tilnærming til prototyping på den andre siden.

Wayfaring ble brukt som hovedmetode for å få innblikk i hvordan en avansert industrimaskin ble brukt og hvordan data kan innlemmes i tilbakemeldingsløkker eller databanker. Maskininnlæring ble brukt på et datasett av 165 tilfeller av maskinbruk for å forutsi brukerens kjennskap til maskinen. Maskinlæreren var ikke i stand til å nevneverdig slå å alltid velge flertalletsklassen. Likevel kan innsikt i hvordan man prototyper for datainnsamling og datahåndteringen bli brukt av andre for å forbedre samspillet mellom menneske og maskin.

Data ble samlet fra seks kilder for å overvåke bruken av en laserkutter. Et kodingssystem ble utviklet for å kvantifisere hver brukersession. Denne prototypebaserte tilnærmingen tillot prototyping, testing og læring i to dimensjoner - med data og uten data. Innsikt fra utforskingen og brukerbehov ga en rik skildring av hva brukerne vil ha fra en maskin og hvordan de bruker den.

Ytterligere oppmerksomhet bør være på bruk av tilpassede grensesnitt og tilbakemeldinger som er relevant for bestemte brukere. Dette området ble bare såvidt berørt og vil trolig være et lovende sted for videre forskning i en industriell internett-kontekst.

Preface

This master's thesis has been submitted to the Norwegian University of Science and Technology (NTNU) for the degree of Master of Science (MSc). The work has been carried out in the period from January 2017 to June 2017 at the Department of Mechanical and Industrial Engineering under the supervision of Professor Martin Steinert (NTNU). The work has been in collaboration with ProtoMore.

Master Thesis Description

As sensors become ubiquitous, the industry needs to better understand their added value. Aiming to build an educational demonstrator, this thesis will explore how a prototyping machine, for example a laser cutter, can be made «smart» and exemplify how these new data insights may be incorporated into feedback loops and repositories. These feedback loops will be explored in-depth in relation to guiding user behaviour. The prototyping machine will as such touch on topics such as object tracking, user behaviour, data analysis, mechatronics, and reinforcement learning. Possible implications for research, industry, and product development will then be examined.

The thesis will be made in cooperation with the industrial partner ProtoMore with Carl Christian Sole Semb as the contact person.

Acknowledgements

I would like to thank Martin Steinert, for supervising the thesis and for starting TrollLabs at NTNU. Next the group of PhD candidates at the department for contributing with feedback, ideas, and guidance. Especially Heikki Sjöman and Jørgen Erichsen deserve a shout out. At the P314, Even Jørs have contributed in long discussions on prototyping. Truls Nygaard helped out with code to the surveillance camera.

At ProtoMore, Carl Christian Sole Semb has been wonderful and supportive throughout the thesis and pre-thesis work. His energy and interest in design thinking is limitless.

Hans Martin Erlandsen contributed with ideas on adaptive interfaces, methods for designing, and discussions on the chasm between engineers talking about IoT and users living with machines more complicated than they actually want.

And finally, to Elise Dybvig, for encouragement.

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List of Abbreviations

API	Application programming interface
CPS	Cyber-physical systems
FFE	Fuzzy Front End, a course at NTNU
HMI	Human-machine interaction
II	Industrial internet
IoT	Internet of things
KNN	K-nearest neighbours
MDF	Medium density fibreboard
ML	Machine learning
PCA	Principal component analysis
QR code	Quick response code
ROC	Receiver operating characteristics
SCM	Swiss cheese model
SVM	Support vector machine

1 Introduction

The excitement for the industrial internet and internet of things could arguably not be greater. This thesis bridges the gap between some of the ideas and aspirations of II with a prototype-driven approach with roots in early stage product development.

The thesis is partitioned into three main sections: need finding, probing for data, and probing without data. The reader might notice that there has been a compromise between showing the process and strictly separating results and discussion. Because of the iterating nature of probing – probing, testing, and insights are tightly linked together. The need finding part therefore has a section on key insights on users. For probing, some discussion and insights are included were relevant.

One analogues 1991 quote could sum up major parts of the thesis, and which too often is forgotten when designing machines for even technical savvy users:

Personal computers are just too hard to use, and it's not your fault
– Walt Mossberg

1.1 Business Partner ProtoMore

iKuben and ProtoMore are co-located at Molde Kunnskapsparken. ProtoMore is prototyping workshop that has developed its own method and holds product development sessions with companies. iKuben is a cross-industrial cluster that focuses on digital innovation and helping the industry to utilize the industrial internet by information sharing and hosting ProtoMore. To date, 42 entities participate in iKuben. Most of these companies are engineer-to-order and could be categorized as part of the ocean industries.

1.2 Pre-Work: Project Thesis

In the autumn of 2016, work on how sensors could be used, a literature survey of IoT and II, and probing on a workshop setting was performed. Different ideas and insights emerged that later developed into this thesis. The project thesis could be read in full in A1.

1.3 Evolution of Research Questions

Overall RQ:

"How could an advanced machine be made «smart» and how may data insights be incorporated into feedback loops and repositories?"

RQ-1: *What do users need and want from their advanced and complicated machine?*

RQ-2: *What entails a machine being "smart", and what value could the "smartness" add?*

RQ-3: *What user interactions may be quantified, and do the data reveal anything interesting about the users?*

RQ-4: *To what degree can user behaviour and background be determined or predicted by a machine learning algorithm?*

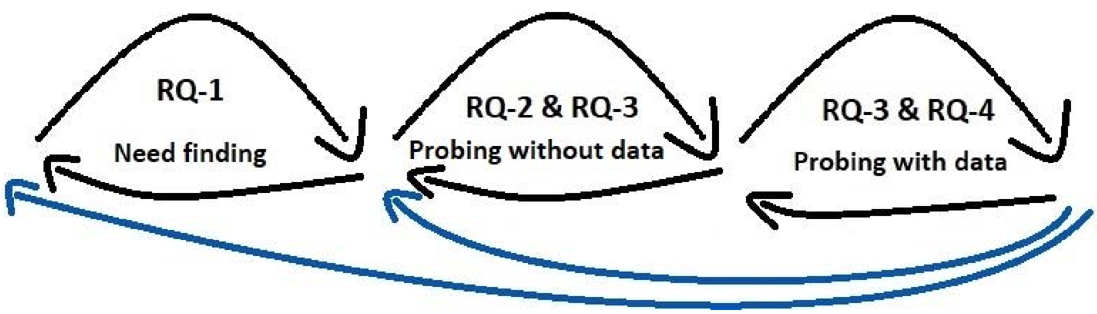

Figure 1.1: Probing in two domains

2 Background Theory

Theory used in the thesis and a framework for understanding will be presented in this chapter. Because of the industrial internet's short lifespan, there will be an empathize on contextualizing by explaining how the term interact with proximate fields and ideas, such as cyber-physical systems, internet of things, industry 4.0, and big data.

2.1 Framework for Methodology

Three models for applying design thinking was used throughout the thesis. Wayfaring was the main framework, with double diamond as a tool for figuring where the process was at. Stanford d.school's work modes and recommended methods were used in specific situations for defining, empathizing, and ideating.

2.1.1 The Wayfaring Framework

Steinert and Leifer (2012) proposes a wayfaring approach to initial stages in a product development process. To develop novel outcomes, they argue that the existing engineering design frameworks are to constrained, and will therefore produce mostly incremental improvements. Gerstenberg et al. (2015) explain the framework through a prototype-driven case study where they deconstruct wayfaring into four core elements. Their method involved simultaneous prototyping in multiple disciplines and involving all domain knowledge from the start. The activity of probing (divergent and convergent activities combined with prototyping and testing) result in abductive learning (Burks, 1946) that leads to changes in design requirements and new ideas.

Steinert and Leifer contrasts wayfaring to navigation, an approach where the goal is already understood and a "fixed grid" for the process may be used. A well-known proponent of the later are Ulrich and Eppinger (2012) who view product development as overlapping and successive phases that could be partitioned in:

1) Concept generation
2) Concept screening
3) Concept scoring
4) Concept testing

Ulrich and Eppinger promotes iteration between the phases, but in a more limited capacity than the wayfaring framework and other methodologies that originate from the industrial design community. Design processes aiming for radical outcomes could be viewed as iterations of divergent and convergent activities (Alexander, 1964). One explanation for why iterations are so important is the need to uncover and solve ‘unknown unknowns’ (Snowden and Boone, 2007).

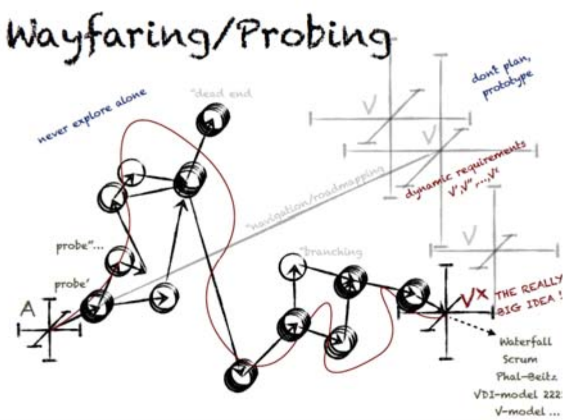

Figure 2.1: Wayfaring ppproach. With permission. (Gerstenberg et al., 2015)

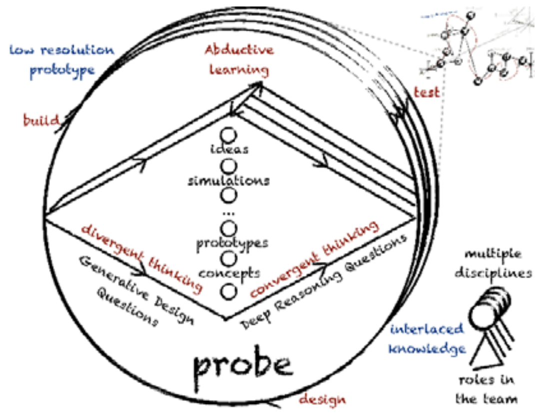

Figure 2.2: Probing as a tool for learning. With permission (Gerstenberg et al., 2015)

2.1.2 Generative Design and Deep Reasoning Questions

Eris (2004) proposes a question-centric design thinking model where generative design questions (GDQ) and deep reasoning questions (DRQ) enable divergent and convergent activates to thrive. His theory states that successful teams will have a balance of GDQs and DRQs. GDQ questions generate divergent thinking by reframing the problem or expand what answers that may be proposed, while DRQ promotes thinking that will combine previous knowledge into answers, and such be possible to dispute. For example, a DRQ will state: “why did the machine break”, while a GDQ would state “how could the machine break”. One is narrowing the thinking, the other expanding it.

2.1.3 The Double Diamond Stanford d.school

Where wayfaring describes an overall framework of describing the process from start to finish, double diamond as proposed by the British Design Council (2005) and the Stanford Design School **(**2010**)** use work modes that are iterated on until the problem is understood enough to be partially or fully solved.

The double diamond separates figuring out the problem and producing a solution into two areas of divergent and convergent activates, or – designing the right thing, and designing things right. In the discovery phase, the emphasis is on unearthing relevant knowledge that can be used in the define phase. Synthesising insights, grouping themes, and finding opportunity areas then produce a define brief or problem description. Then the developing phase is about ideation and producing ideas and concepts that may be implemented through prototyping and testing in the delivery phase.

Stanford d.school has a slightly different approach to the design process. The five work modes activity-centred. 'Empathize' is about understanding the user you are designing for. 'Define' is for synthesizing and unpacking insights to produce a deeper understanding of the problem space and producing a problem statement. In 'ideation', the aim to generate radical design alternatives by exploring a wide solution space. Then in 'prototyping', concepts and ideas are given a physical form that can be 'tested'. This generate feedback that deepen the understanding of the problem or solution.

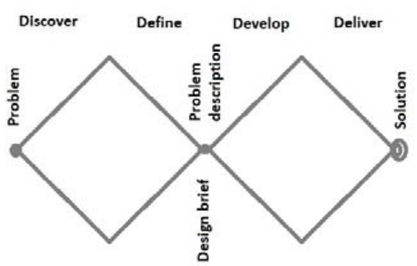

Figure 2.3: Double diamond (British Design Council, 2005)

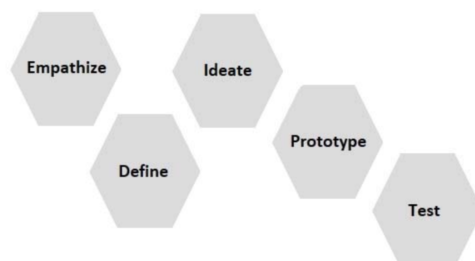

Figure 2.4: Stanford d.schools five working modes (2010).

2.2 Prototype Methodology

Several methods for prototypes and how to apply them have been deployed. This sections goes more into detail to the two most relevant for this thesis.

2.2.1 Houde and Hill's Prototyping Model

Houde and Hill (1997), argues that prototypes are used to answer questions and that developers should have this in mind when planning a prototype. They propose three archetypes of prototypes that relate to value brought to the user (role), how the user would and interacts with it (look and feel), and how it could work (implementation). By separating the prototypes into classes determined by the questions they can elicit or answer, the model fits smugly to wayfaring how wayfaring uses questions and prototypes to learn.

2.2.2 Ulrich and Eppinger's Prototyping Model

Ulrich and Eppinger (2012) define prototype «as an approximation of the product along one or more dimensions of interest». In their view the word prototype is used as a noun, a verb, and an adjective in product development. Further, one may classify the prototype along two dimensions: physical versus analytical and comprehensive versus focused. Renderings and simulations are typical analytical prototypes, while physical prototypes include critical function tests and other prototypes with a bodily component. The other dimension grade the degree of attributes the prototype embody of the product.

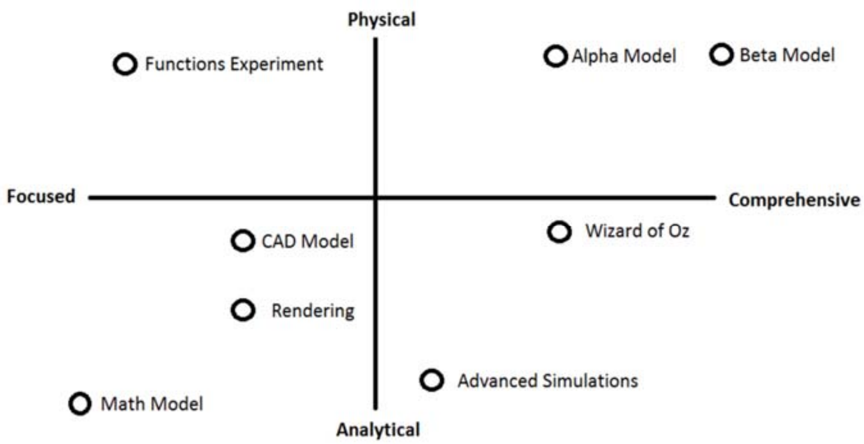

Figure 2.5: The main dimensions of prototypes per Ulrich and Eppinger, where comprehensive and physical models are the most intuitive versions of prototypes for laypeople (Ulrich and Eppinger, 2012).

2.3 The Industrial Internet

To understand the industrial internet, we need to understand the roots and research on the topic, especially since there is much hype and diverging opinions of what it is and it means for companies and researchers.

A common starting point to understanding the trend of smart machines becoming more present in the industry and for consumers is Mark Weiser. He coined ubiquitous computing, sometimes also called pervasive computing, a concept that points to a possible endpoint of IoT. His vision was that cheaper, low powered computers that could interact seamlessly with each other and humans would be common place sometime in the future, and one could say that this already is true in a limited form today. In his own words: “We are [...] trying to conceive a new way of thinking about computers, one that takes into account the human world and allows the computers themselves to vanish into the background” (Weiser, 1991).

2.3.1 IoT

By dissecting the phrase internet of things one may see that it consists of two visions – the first pushes towards a network oriented vision while the latter focus on heterogeneous objects (‘devices’) becoming interconnected. IoT could also be seen as one emerging paradigm from several competing visions (Atzori et al., 2010). Still, some argue that the research field into IoT is highly fragmented and focused on single application domains or technologies (Miorandi et al., 2012). Semantics describe how to establish meaning and logics to the increasing number of connected devices and accumulating amount of information now stored. The idea is to better facilitate for automated processes so to simplify management and recovery of devices. This field is still in its early days, even though initial work has shown some success in accommodating conflicting requirements from stakeholders (Barnaghi et al., 2012).

Some are more sceptical of the ‘IoT hype’, and a literature study from 2014 revealed most IoT-research to be about technology. According to them, business models were written little about, the paradigm was not well represented in management literature, and how to regulate the field was not well discussed. As a consequence, the same study questioned whether or not the IoT is to be an enduring technology, if it will fail to materialize, or if it will only be a stepping stone to another paradigm (Witmore et al., 2014).

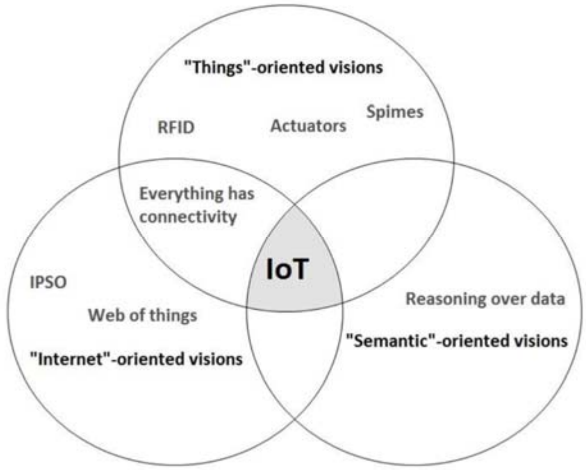

Figure 2.6: Three visions of what IoT is, are merging into one unified understanding of the paradigm (Atzori et al., 2010).

2.3.2 Cyber-Physical Systems

As Lee (2008) defines it: "integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa." Based on the definition of CPS and the section on IoT, CPS can be understood as the 'object' part of IoT, the layer where sensors and actuation are processed, performed, and communicated to the internet of things.

2.3.3 Big Data

Big data is an abstract concept with diverging opinions on its definition, although the importance have been established (Chen et al., 2014). A 2011 definition of the concept is a "new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling the high-velocity capture, discovery, and/or analysis" (Gantz and Reinsel, 2011). With this definition, big data may be characterised by four V's – volume, variety, velocity, and value.

2.3.4 Industrial Internet and Industry 4.0

The two terms industrial internet and industry 4.0 have many similarities, which have caused a lot of confusion. II originated in North America with General Electric as its champion, and was coined in 2012 (Leber, 2012). Meanwhile, Industry 4.0 was first mentioned in Hanover 2011. The latter is closely linked to the German industry with companies and universities heavily invested in it. Since the two terms are so young, and the German version a priori have declared the fourth industrial revolution started, one should take the terms with a grain of salt. Especially since they are closely linked with commercial actors and are used in marketing (Drath & Horch, 2014).

The Industrial Internet Consortium (2015) define the industrial internet as: “an internet of things, machines, computers and people, enabling intelligent industrial operations using advanced data analytics for transformational business outcomes”. While Herman, Penek & Otto (2016) define Industry 4.0 as:

“a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IoS, both internal and cross- organizational services are offered and utilized by participants of the value chain.”

From definitions and explanations above, Industry 4.0 is more centred around production and value-chains, while II take a broader perspective of industrial applications of IoT, data analytics, and organizations.

2.3.5 Adoption of the Industrial Internet in Molde

Research on familiarity and usage of aspects in IoT have been performed earlier by Carl Christian Sole Semb and Lise Lillebrygfjeld Halse, an associate professor at Molde University College, on the Molde-region. Expert users with knowledge to the companies described them to understand sensors, partly understand networks, and lacked knowledge about data filtering and data mining (Semb, 2016). A questionnaire (N=23) done as part of a larger four-year study called Manufacturing Network 4.0 on CEO’s affiliated to iKuben revealed that (Halse et al., n.d.):

- 9/23 companies have sensors for controlling or moving things during production
- 7/23 have online control over processes
- 8/23 have computer controlled preventive maintenance
- 7/23 are using external data in production management
- 3/23 are doing track and trace production

These results indicate that some companies are utilizing data on certain areas of their business, but not on the whole organization. This study confirms that adoption of II has not reached its full potential in Molde.

2.4 Human-Machine Interaction

2.4.1 Classification of Errors

An error can, according to Norman (2012), be classified into a slip or a mistake. A mistake is the result of having the wrong goal or plan for doing something. A slip is the result of having the right goal, but doing something else instead. Experts more prone to memory-lapses (slips) than novices, that are more likely to commit mistakes.

There are many error taxonomies, but a simple model relevant will be presented. The swiss cheese model (SCM) suggests that multiple holes must align for an adverse event to occur. The cheese has slices that operate as barriers, the more slices and design that make it hard for them to align, the more forgiving a system is (Reason, 1990). Other models are more fine-grained and SCM has its drawbacks, but is still commonly used for communicating, analysing, and measuring how errors could become catastrophes (Reason, Hollnagel, & Paries, 2006).

2.5 Data Analysis

Statistics, machine learning, and principle component analysis were used to explore data gathered on usage of the laser cutter. More empathize will be on ML techniques on pre-processing and processing.

To date, no pre-processing algorithm is optimal for all datasets in supervised learning. Kotsiantis, Kanellopoulos, & Pintelas (2006) therefore proposes individually weighting a set of well-known and proven algorithm for data preparation and filtering when working with supervised learning. They divide pre-processing into seven categories: instance selection, outlier detection, handling missing values, discretization, data normalization, feature selection, and feature construction. The most relevant will be explained further.

2.5.1 ML: Outlier Detection and Instance Selection

Kotsiantis, Kanellopoulos, & Pintelas (2006) propose starting with instance selection and outlier detection. By using variable-by-variable filtering one may locate problems such as misspellings and illegal values. For categorical values, sorting similar values to each other or using pivot tables to highlight lone values that be looked at further are recommended. For locating illegal values, thresholds should be constructed if possible and features checked for the number of classes being equal or less to the allowed maximum.

2.5.2 *ML: Handling Missing Data*

Filling missing data can be broadly divided into those that are model based, and those based on quasi-randomization inference (Little & Rubin, 2014). Model based approaches consider the effect the imputed values will have on the population. Data-driven procedures instead assume that the population values are fixed.

Those relevant will be further explained. Before performing a method, one also need to take into account the 'unknownness' (Bruha & Franek, 1996). A value could be:

- missing due to being lost or forgotten,
- not being applicable for the given observation,
- being irrelevant in a specific context,
- not recorded due to the designer of the dataset not caring enough.

In handling missing data, one may per Lakshminarayan et al. (1999) chose from a wide range of methods. Relevant methods are explained further.

- Ignore instances with unknown feature values.
- Mode imputation, fill in the most frequent value of the feature. Often used for categorical data.
- Mode imputation considering the concept, fill in the most frequent value for a subset of a feature. Used in situation where additional information is present.
- Mean imputation, fill in the computed mean of the feature.
- Mean imputation considering the concept, analogous to the one above.
- Hot deck imputation, identify the most similar instance and fill in its equivalent value to the missing one.
- Treat unknowns as a special value, thereby giving them a new and equal value.

2.5.3 ML: Discretization

A comparison between static discretization (binning and entropy-based partitioning) and dynamic methods reveal no significant improvement of dynamic discretization (Kohavi and Sahami, 1996).

2.5.4 ML: Normalization

The two most common methods for normalizing a feature for supervised learning are min-max and z-score (Kotsiantis, Kanellopoulos, & Pintelas (2006):

- z-score normalization: $v' = \frac{v - mean}{standard\ deviation}$
- min-max normalization: $v' = \frac{v - min}{\max - min}(new\_\max - new\_\min) + new\_min$

where v is the old feature and v' the new. Min-max normalization performs a linear transformation on the original data. The value can then be mapped to a new range (new_min, new_max), for example [0,1] or [0, 255]. Z-score instead normalizes the feature using the mean and standard deviation so that the new feature has mean as zero and scaled to have a standard deviation of one.

2.5.5 ML: Feature Selection

The curse of dimensionality has been a major hurdle, and two main approaches have been used to select appropriate features: PCA and correlation-based.

In a survey of contemporary techniques for feature construction, Parikshit (2009) propose using generic constructions methods such as PCA, SVD, and K-means. This approach has been successful in reducing dimensionality. Unsupervised methods are also less prone to overfitting (Guyon & Elisseeff, 2003).

On the correlation based approach. Pair-wise correlations was run on features and evaluated by Hall's (2000) hypothesis that a "good feature subset contains features highly correlated with the class, yet uncorrelated with each other". Categorical features can be one hot encoded to allow for performing a Pearson's correlation (Hall, 2000). Hall's hypothesis is formalized by (Ghiselli, 1964):

$$Merit_s = \frac{k\overline{r_{cf}}}{\sqrt{k + k(k-1)\overline{r_{ff}}}}$$

where $Merit_s$ is the heuristic "merit" of a feature subset S containing k features, $\overline{r_{cf}}$ is the average feature-class correlation, and $\overline{r_{ff}}$ is the average feature-feature intercorrelation. Decision trees where then used to evaluate whether to throw away features with intercorrelation.

2.5.6 ML: Processing

One may choose from a variety of machine learning algorithms. Two common methods of categorizing them are either by the feedback the algorithm is fed or the desired output.

The former separate them into supervised, unsupervised, and reinforced learning (Russell & Norvig, 1995). The latter partition them into classification, regression, clustering, density estimation, and dimensionality reduction **(**Kohavi & Provost, 1998).

In a binary classifier four outcomes for each instance are labelled (Fawcett, 2005):

- TP, true positive examples.
- TN, true negative examples.
- FP, false positive examples.
- FN, false negative examples.

		True class	
		P	N
Hypothesized class	Y	**T**rue **P**ositive	**F**alse **P**ositive
	N	**F**alse **N**egative	**T**rue **N**egative

Table 2-1: Confusion matrix (Fawcett, 2006).

Different metrics for scoring algorithms exist. The most basic is accuracy which is only the percentage of correctly labelled instances:

$$Accuracy\ (ACC) = \frac{TP + TN}{TP + TN + FP + FN}$$

This has been criticised for not considering imbalances in the dataset, and to be to general (He & Garcia, 2009; Stefanowski, 2008). To give more information on the algorithm, more metrics have been constructed. Many based on the receiver operating characteristics (ROC) that use these metrics (Fawcett, 2006):

$$Precision = \frac{TP}{TP+FP},$$

$$Recall = \frac{TP}{TP+FP},$$

$$Sensitivity = \frac{TP}{TP+FN},$$

$$Specificity = \frac{TN}{TN+FP},$$

and area under an ROC curve (AUC) which can be calculated from multiple ROC-points (Bradley, 1997). Different methods for creating ROC-curves exists, and they differ on how conservative they are (Centor & Schwartz, 1985).

An often-used metric for determining if an algorithm is accurate is the F-score, a weighted average of recall and precision.

$$F_1 = \frac{2 * TP}{2 * TP + FP + FN}$$

These metrics are perceived to be commonly accepted for machine learning applications (Sokolova, Japkowicz, & Szpakowicz, 2006; Powers, 2011).

2.5.7 Overfitting

A common problem in machine learning, and especially for decision trees, is overfitting. The algorithm becomes over-trained on the training set, resulting in poor performance. A validation set combined with pruning can be used to cut of algorithm training when the training set gains accuracy on the expense of the validation set (Mitchell, 1997).

Variations of pruning techniques including minimum loss reduction, minimum child weight, and capping max depth for the tree (Turi, 2016**)**

2.5.8 Imbalanced Data

Imbalance between classes of the target feature often produce classifiers with high accuracy on the expense of the minority class(es) (Lewis and Catlett, 1994).

In their review on the work of imbalanced data in machine learning, He and Garcia (2009), propose using assessment metrics such as receiver operating cost curves, precision-recall curves, and cost curves instead of the conventional overall accuracy or error rate. They also divide the approaches to tackle imbalanced data in sampling methods, cost-sensitive learning methods, kernel-based learning methods, and active learning methods.

Sampling approaches have two major problems. Removing samples may cause the classifier to miss important concepts in the majority class. Oversampling appends instances to the data set and identical instances could easily produce overfitting and the authors argues that under sampling therefore is generally better suited (Drummond and Holte, 2003). Thus, the classifier is likelier to perform far worse on the unseen test data (Holte, Acker, and Porter, 1989).

Cost-sensitive methods are therefore recommended to sampling, since associating costs for misclassifying the minority class does not encourage overfitting (Elkan, 2001).

3 Methodology

This chapter explains methods used in the master thesis with an empathize on the topics need finding, probing, and data analysis. The thinking on prototyping and overall methodology are refined from the project thesis in A1.

For all phases a prototype-driven wayfaring approach was used as an overall framework for planning and executing. The double diamond model was used for reflecting on how insights from probing affected understanding the problem or producing a solution. GDQs and DRQs were used depending on the context.

3.1 Need Finding

For understanding user behaviour, needs, and experiences various methods were applied. Literature on need finding from Stanford d.school (2010) applicable for the work modes ‘empathize’ and ‘define’ were frequently referenced. Some of the used methods were:

- Ad-hoc interview, hanging around the laser cutter and asking questions about specific experiences and behaviour.
- Planned interview, one of the groups partaking in FFE were periodically asked questions about their interactions with the laser cutter.
- Immersion, putting myself in the shoes of users by using the laser cutter extensively.
- Journey map, mapping out the workflow and progress of a user’s interaction with the laser cutter.

A white board asking for feedback on how the laser cutter could be better to use and what they felt about different prototypes was used to generate feedback and engagement.

3.1.1 Visited or Learnt from Other Workshops

Other workshops with laser cutters were visited except for Techshop, where I earlier have taken courses on the laser cutter. On the design workshop at NTNU, one users were interviewed. At ProtoMore, the workshop facilitator was interviewed and I had earlier experiences with using that laser cutter.

3.1.2 Questionnaires

A questionnaire was sent out to all FFE students at four-fifth of the semester to quantify statements FFE students earlier had made in interviews. This was done to validate and prioritize needs assumed to be uncovered from observations. They were asked about general familiarity with topics relevant to using a laser cutter, their experience using the machine for the first time, what would make them use it more, and how they felt about being monitored. Also, questions related to which types of problems they encountered and types of

A shorter questionnaire was then sent out to master students and PhD candidates affiliated to TrollLabs. They were asked about familiarity with relevant topics, what would make them use it more, what types of problems they encountered, and how they felt about being monitored.

3.2 Probing

Gerstenberg et al. (2015) propose involving all areas of expertise throughout the project, since I worked mainly alone this could not be followed fully. Instead, doing storytelling and asking for opinions on key insights on domain experts was done as a substitute. This allowed for validating and countering my own domain biases.

Probing is partitioned into two concurrent processes: Probing without data to either generate it or to learn about users, and probing with data to either learn or validate assumptions.

A modular approach was used so different prototypes could be developed to reduce the amount of rework.

GDQs were used to broaden thinking on what could be done. For example, a frequently asked question was "how many ways can we […]". These were used to assemble concepts or ideas that were either prototyped or stored in a repository for later use.

When an interesting concept were prototyped or explored, DRQ were used to troubleshoot and synthesis insights and findings.

A simple concept scoring was done on sensors for the laser cutter, which Ulrich and Eppinger (2012) recommends when it is difficult to select one design.

3.2.1 Prototyping to Answer Questions

Making something "smart" usually means logging data in some way and then either visualizing it or enable the machine to actuate based on its input. Houde and Hill's (1997) thinking were especially helpful in probing. Most prototypes were created to solve some sort of question.

Ulrich and Eppinger (2012) were used a tool for selecting the right type of prototype on the dimensions of analytical-physical and focused-comprehensive.

3.3 Data analysis

Probing was done on each data stream, and on three datasets of increasing sizes. Visualization such as box-diagrams, correlations plots,

Kotisiantis, Kanellopoulos, & Pintelas (2006) recommendations for pre-processing was followed to ensure robustness for the training and test data.

3.3.1 Data Cleaning

Sorting categorical values reveal that there are some deviations of spelling in the dataset, these were fixed.

Illegal values are checked for by determining if numerical values are outside of the permissible range. A couple of values where laser cutting time surpasses the total instance time are re-visited and corrected. The perpetrator was “fat finger errors” from the coding phase, also corrected.

3.3.2 Instance Selection

Instances attributed to the author were removed to avoid undue interference.

In creating a classifier predicting familiarity with laser cutters, the middle values were taken out of the dataset so the classification problem was reduced to two classes instead of three.

3.3.3 Handling Missing Values

For the eight missing values in material type, three different methods for imputations are tested and scored on prediction level. The categorical imputer in Graphlab (Turi, 2017) uses unsupervised clustering.

3.3.4 Imbalanced Data

Cost-sensitive methods in this thesis was based on the built-in class_weight variable in Graphlab Create for decision trees and SVM.

3.3.5 Feature Construction

New features were constructed based on the initial features. The method later used for constructing feature ratios were:

$$Feature\_ratio\_computer = \frac{feature\_raw}{Total\_time - Print\_time}$$

This ratio tried to mirror actions done per minute on the affiliated computer, and therefore remove the effect of varying print times and total instance time.

3.3.6 Feature Selection

Two approaches were taken to reducing dimensionality:

- Pair-wise correlations scored on Ghiselli's merit metric combined with visualization techniques.
- PCA were all features are run and selecting the 12 first principal components.

3.3.7 Processing

The dataset was divided into three separate sets: training data, validation data, test data. The dataset was first split into training and test data (80/20), and then the training data was split 80/20 into training and validation data. Graphlab Create's random_split[1] was used.

Four algorithms were tested on the final dataset:

- Decision tree.
- Boosted decision tree.
- Random forest.
- SVM.

The algorithms were scored on accuracy, recall, precision, f-score, and AUC.

3.3.8 Programmes Used

Graphlab Create[2] was used for data analysis.
Pandas[3] was used for correlation.
Seaborn[4] was used for plots.
Google Forms[5] was used for questionnaires.
Matlab 2016a was used for PCA

[1] URL: tinyurl.com/turi-random-split
[2] URL: turi.com
[3] URL: pandas.pydata.org
[4] URL: seaborn.pydata.org
[5] URL: google.com/forms

4 Need Finding: Understanding Users

This chapter covers two modes in the Stanford d.school (2010) model: 'empathize' and 'define'. The goal was to answer RQ-1: "*What do users need and want from their advanced and complicated machine?*" **A2** is a detailed step-by-step description of workflow on the laser cutter at TrollLabs. **A3** covers typical errors and misuses on the laser cutter. **A4** highlights best practises.

4.1 Interviews and Observations

About 50 people have regular access to the TrollLabs workshop, of those 7 are PhD candidates, about 20 master's students, and about 25 students participating in the fourth-year course *Fuzzy Front End* (FFE) at the faculty of mechanical engineering at NTNU.

TrollLabs may be described as an unsupervised workshop with users ranging from proficient to novice with multiple machines requiring moderate or high know-how to operate. None of the more complicated machines have instructions or step-by-step guides on how to use them. Certain days of the week may be described as supervised because of FFE having a teaching assistant present.

Students and faculty members use the workshop TrollLabs for prototyping and ideation. Most new members join TrollLabs through FFE or writes their project thesis under Martin Steinert. The workshop is separated into two rooms: the green room and the red room. All heavy equipment and tools are in the area with red coloured walls. The red room is divided into different areas: mechatronics area, three 3D-printing machines, laser cutter, shelfs, mill, and work tables. The workshop is designed after principles described in Leifer and Steinert (2011) on how Stanford d.school was designed.

The broad majority of students affiliated with TrollLabs have a classical mechanical engineering background with some knowledge mechatronics and data science. They are likely also specialized in early phase product development. Still, many of the students are not familiar with laser cutters or 3D-printers before joining TrollLabs.

4.1.1 Simplified Workflow

A typical user has already planned the laser cutting job before approaching the machine. Most use CAD-programmes such as NX or Solidworks to design the job, and then do just minor adjustments on the stationary computer affiliated to the laser cutter. This computer boasts a

Windows 7 with the drawing programme Gravostyle 7 by the company Gravograph[6]. Most users profess to avoid using Gravostyle because of unfamiliarity and some describe to never having used its drawing features except for moving and assigning colours to the vectors.

Nearly all jobs are performed using the materials available in the material racket to the left of the laser cutter. The main types of materials used:

- Acrylics (2, 3, 4, 5, 6 mm)
- MDF (3 and 6 mm)
- Plywood (thickness varies, but usually 4mm)

Users then find their materials and power on the external fan and the laser cutter. They then do minor adjustments in Gravostyle before sending the job to the laser cutter. From there they only need to push the green button to start the print job. The Gravograph self-height adjust on default settings.

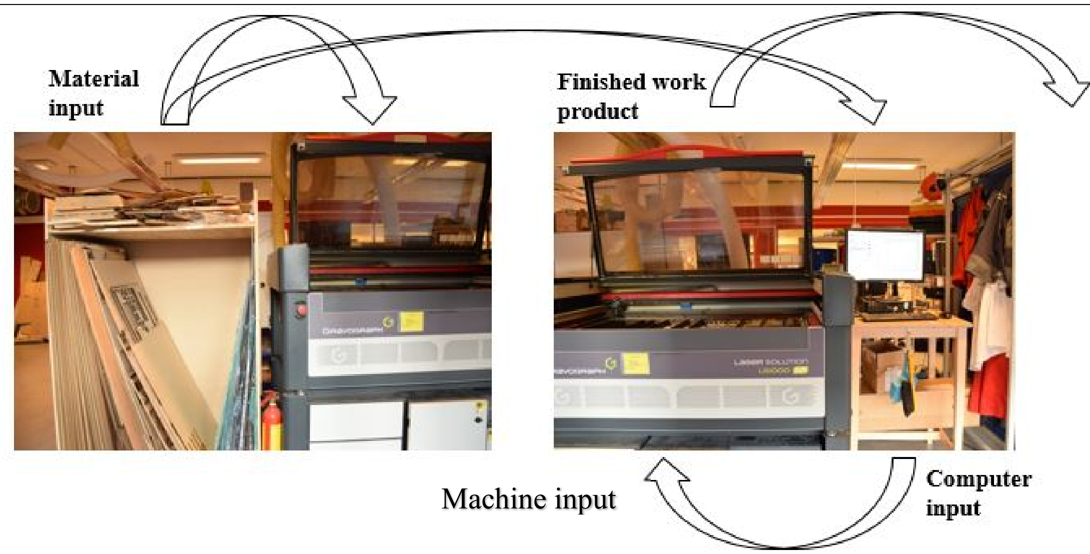

Figure 4.1: Laser cutter workflow (simplified).

[6] URL: www.gravograph.com

4.1.2 Skill Composition at TrollLabs

Different archetypes of users emerged based on usage patterns and familiarity with the machine:

- Novices that are learning to use the features of the machine. They need frequent help in executing the procedural steps and are uncertain of how what parts of the laser cutter that is frail.
- Regulars that know how to use some features and have found workarounds for their typical problems, and uses only a limited set of features.
- Power users, these have experimented with different features and have through trail-and-error found methods of using the machine in different manners.

From observations, the biggest groups at TrollLabs in semester start are novices (one half), regulars (one third), and then power users (one fifth). At the end of the semester, this grading change to be: novices (one fifth), regulars (half), and power users (on third).

4.1.3 A Bar for Using the Laser Cutter

Multiple participants in FFE have described there being a bar for using the laser cutter, and point to different explanations in scheduled and spontaneous interviews:

1. Did not partake in the machine introduction course.
2. There is few formalized rules or guides for using the machines.
3. Did partake in the introduction, but fear of misusing or damaging the equipment was present.
4. The machine is burdensome to use, and the risk of using a lot of time troubleshooting overweight's the benefit of using it.
5. Wanted to learn the machines, but had no "good enough" reasons to do so.

This hindered that FFE students started using the laser cutter in the start of the semester. More students started to use it later in the semester as shown in the questionnaire of FFE students.

4.1.4 Troubleshooting is Time Consuming

At TrollLabs, the laser cutter is viewed as a versatile, fast, and powerful prototyping tool. Knowing how to utilize the versatility and knowing the machine would useful is essential in successful rapid prototyping. But, troubleshooting is a time-consuming activity that often turn 10 minute jobs to two hour sessions if the user has none to ask for help or encounter certain problems. Many students are stopped from finishing a session due to an error occurring that they cannot fix, or they are afraid of damaging something if they do it incorrectly.

4.1.5 Maintenance

Users confessed to not cleaning the lens for multiple reasons. One of the reasons for not doing it was that they never have gotten an introduction to it, and then did not ask for someone to show them. Others just forgot frequently.

4.1.6 Users Work in Teams to Troubleshoot

There was a tendency for users to cooperate on troubleshooting and teaching each other optimal methods for using the laser cutter. Often more skilled people hanging around TrollLabs would contribute with advice if they saw a novice user. This process of helping each other out seems to substitute for TrollLabs not having a rigorous introduction or written guides on the machines.

4.1.7 Expert Opinions

Frequent users that were interviewed explained they had all taken their time learning how to use the laser cutter for their needs. They described having habits that reduced the likelihood of producing typical errors. At the same time, many of the more experienced users admitted in knowing only a fraction of the possible features. It could seem that many just learnt enough to fill their needs, but finding it to time consuming to experiment and learn new features when the essentials were understood. Many described learning to use it properly by repeatedly screwing up, and that they were not happy with the software interface.

Some experts complained on how messy the machine could be, and that scraps often could lay around the machine. It seemed according to them that less experienced users did not follow good practices on machine usage such as:

1. Clean the lens before use.
2. Clean the laser cutter for scraps.
3. Put the materials in the right location.
4. Minimize waste by packing laser cutting jobs.

5. Throw away material scraps.
6. Tidy the computer work station after use.

4.1.8 Teaching Culture at TrollLabs

TrollLabs have an environment were more skilled members take pride in teaching best practises and contributing with advice. At the same time, the more skilled members are PhD candidates and fifth year students with their own tasks to prioritize. They are therefore not available to be ask at all times, and may feel burden by being asked frequently for help. This was a described by one of the PhD candidates as the reason he on days the fuzzy front end course ran stayed away from the workshop: “I am always asked questions on buying things, where things are, and help with basic tasks. I am not able to work efficiently with so many distractions”.

4.1.9 Fixing Something Broken Can Break It More

A reoccurring scenario with the laser cutter was that novice or intermediate users produced errors that they had not previously encountered. Many were unsure whether to ask for help right away or try to fix the problem themselves. It seems from observations that there should be some informal or formal guidelines for when to contact help. The final laser cutter mirror piece and system for moving the mirrors are especially probe to further damage. Worst case outcomes could be replacing parts or hiring a certified technician.

4.1.10 Mapping of Features

A frequent complaint was the software’s confusing layout of core features. Finding which menu item to click on for defining laser colours or setting laser settings were described by many as difficult. Selecting colouring were also perceived to be hard to discover by oneself.

4.1.11 The White Board

Users wrote on the laser cutter regularly in the period is hang at TrollLabs by the laser cutter. Different requests on features and improvements were written down. Some of the request were for the software, such as “how do I remove duplicates”. Others wanted YouTube tutorials and better instructions. A queue system was also created, and seemingly also used on busy days. On busy days, up to three or four people could discuss who should go first depending on job sizes and urgency.

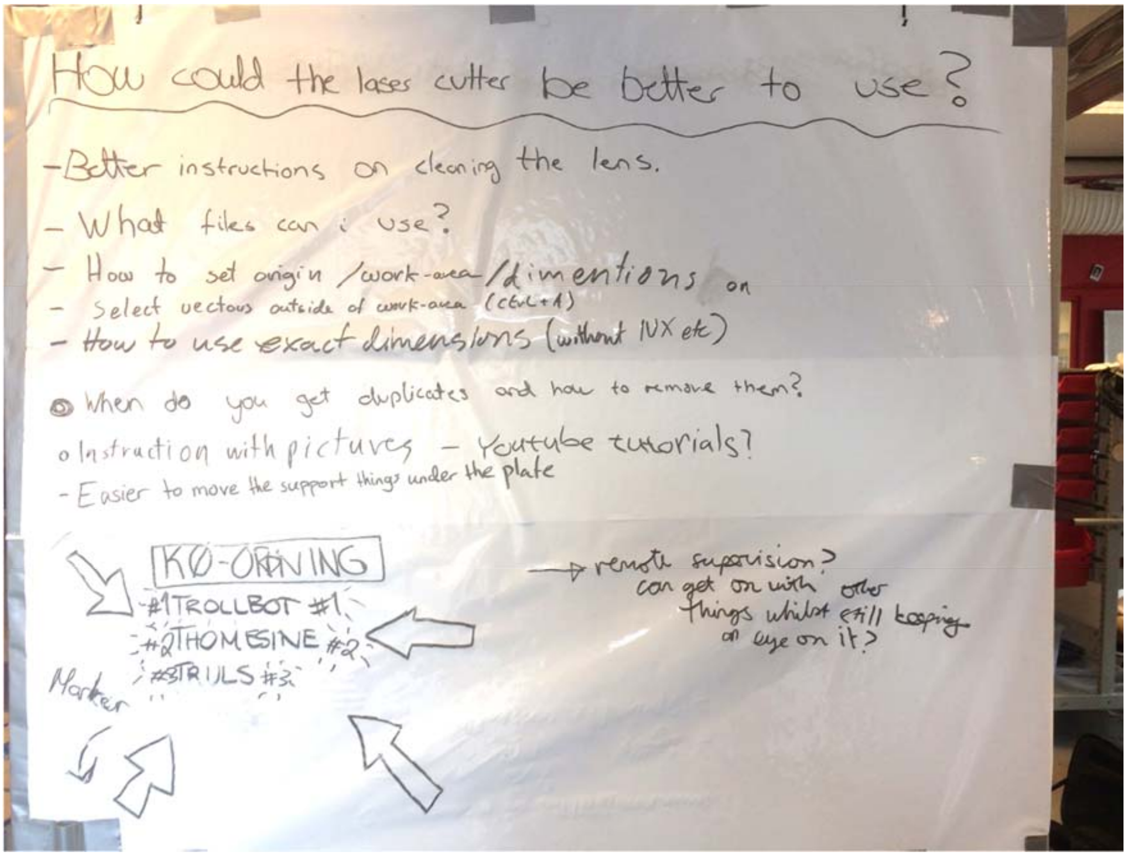

Figure 4.2: White board asking for feedback, opinions, and trivia.

4.2 Different Workflows and Learning Setups for Laser Cutters

The first problem statement was partially answered by looking at existing practises at Techshop, ProtoMore, TrollLabs, and Industrial Design at NTNU.

4.2.1 Techshop: A Two-Hour Introduction, Beginner Project, and User Manual

Techshop is a chain of membership-based maker spaces in ten locations in the US. To use expensive, potentially dangerous equipment Techshop require that members pass a safety and basic use class. These typically take two hours and are done in groups up to seven for Trotec laser cutters. A main component of the course is to avoid misuse by beginners and to learn the minimal needed for using the laser cutter for the first couple of times. Members are introduced to the graphics software’s basic interface and workflow. Adjusting mirror height and cleaning the mirrors are given extra weight and iterated several times. After the initial introduction, the members can design their own dog tags. Each member is also given a manual on best practices, recommended settings for different materials, and a list of allowed materials.

4.2.2 ProtoMore: A Step-by-Step Guide

ProtoMore has an Epilog 60W laser cutter and a workshop supervisor. The workshop supervisor introduces novices to the machine if he has the time. If not, a step by step guide can help semi-novices to overcome procedural slips. The supervisor note that he sometimes is to pre-occupied at workshops that he is not able to help. This is counter to the missions of ProtoMore where learning to combine physical and digital prototyping are a core element of their teaching. Also, members of ProtoMore sometimes forget procedural steps on using the laser cutter. The bar for using it are therefore higher when no one are around to help if issues occur.

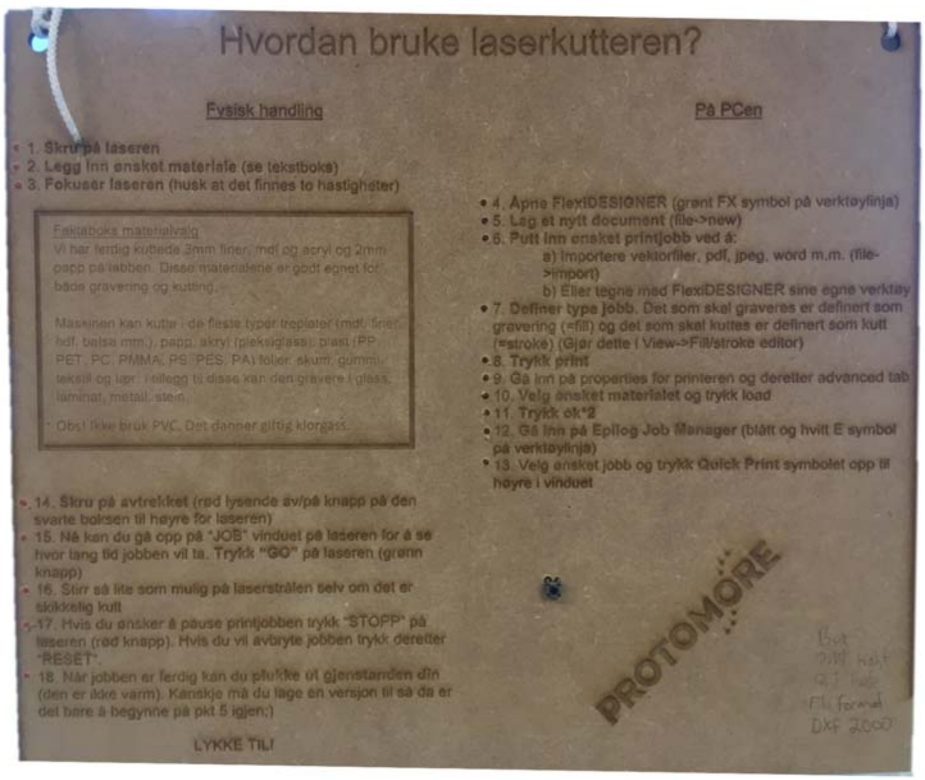

Figure 4.3: Step by step guide to using the laser cutter at Protomore. Courtesy of Carl Christian Sole Semb

4.2.3 Industrial Design at NTNU: Paid Staff, Internet Resources, and Well Defined Workflow

Industrial designers and architecture students at NTNU can from the third grade qualify to use two 1900 x 1000 mm laser cutters. Students must first read about CNC, G-codes, and using the software programme Rhino, before taking a 15-minute-long course.

At the workshop paid technicians are present from 8 pm to 4 am, and check in to see if students know what they are doing. Video tutorials for creating a script and booking the laser were part of the online resources. To create machine readable code for the laser cutters, students run a python script in Rhino that enable them to select material type and unit system. Students then follow a detailed 22-step guide at the workshop (Alto, 2016). The main hurdles students have to overcome are correctly setting the starting position, adjusting the correct height of the laser mirror, and navigating a handheld controller. The processes that are most prone to adverse consequences are:

- Machine start-up, the laser mirror could hit material and as such become displaced. According to the internet recourses this could take from a couple of hours to a week to fix.
- Focusing the laser beam, if it diverges to much from the present 5 mm from the material the likelihood for poor surface quality and fire are increased. Users must manually set the correct height.
- Selecting material profile, if wrong profile is chosen in the python script, a fire may occur. Especially running a plywood profile on a cardboard will result in a fire.
- Turning on the ventilation and filtration system, if this is done correctly before running a job the fire alarm and sprinkles system may be triggered.

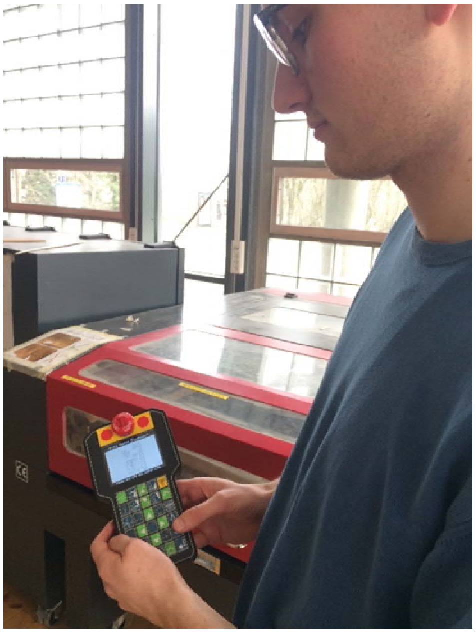

Figure 4.4: Industrial design. The handheld controller is used for setting the starting position and running the pre-made jobs from a server.

Figure 4.5: Industrial design. A 6mm thick MDF-sheet is used for setting the correct laser cutter height when cutting 1mm cardboard. Misfocus could lead to poor surface quality or start a fire.

4.3 Questionnaires

This section summarizes results from the questionnaire taken by FFE students (N=25) of 26 students that completed the course. Not all questions were answered by all students. A questionnaire for master's students and PhD candidates (N=14) were also done to quantify relevant metrics for data analysis.

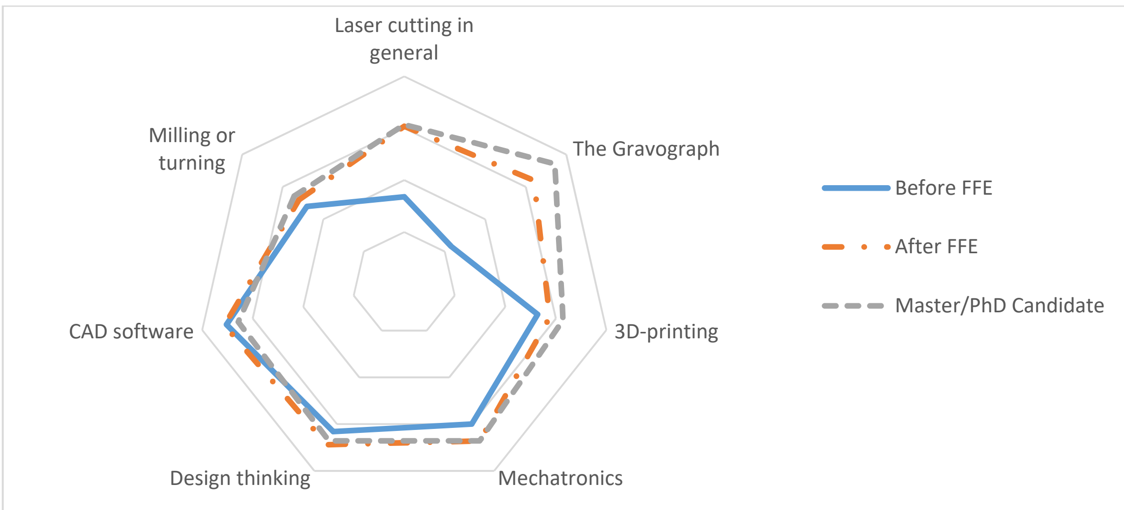

Figure 4.6: Familiarity with key topics relevant to prototyping proficiency.

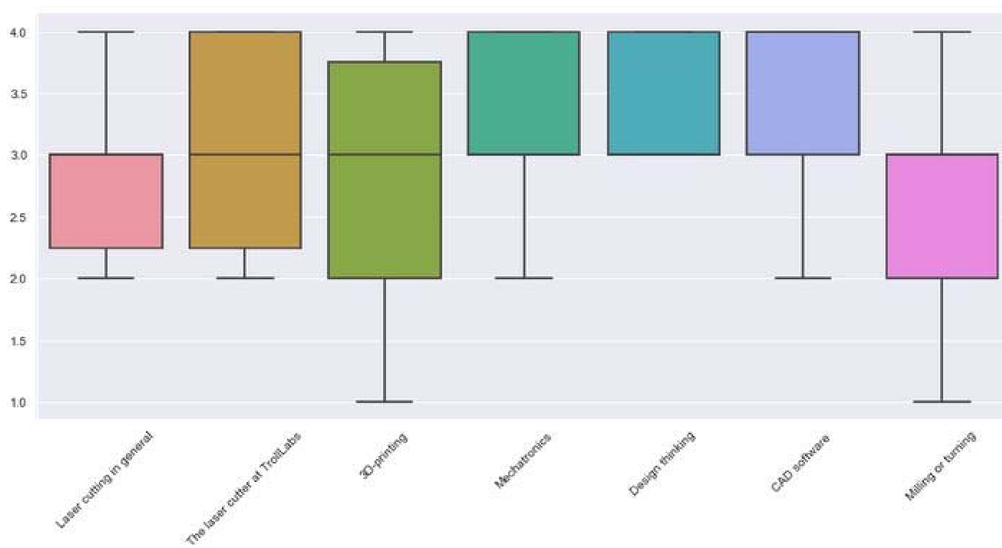

Figure 4.7: FFE students' self-reported familiarity with topics after FFE.

Table 4-1: What stopped or delayed someone from using the machine?

FFE students		
Type of problem	**N.**	**%**
Laser cutter out of order	15	60
Afraid of damaging the machine	14	56
No written step-by-step guide	9	36
No experienced members around to ask for help if necessary	9	36
Problems or lack of proficiency with the hardware components	8	32
Afraid to ask for help	5	20
Forgot procedural actions on the laser cutter	5	20
Afraid to be caught as a novice around the laser cutter	4	16
Problems or lack of proficiency with CAD/drawing software	4	16
Problems or lack of proficiency with the affiliated computer	4	16
Intimidated by the complexity	4	16
None of the above	1	4

Master's students / PhD candidates		
Type of problem	**N.**	**%**
Laser cutter out of order	12	86
Problems or lack of proficiency with the hardware components	5	36
No experienced members around to ask for help if necessary	4	29
Problems or lack of proficiency with CAD/drawing software	4	29
Problems or lack of proficiency with the affiliated computer	3	21
Afraid of damaging the machine	2	14
Forgot procedural actions on the laser cutter	1	7
Afraid to be caught as a novice around the laser cutter	1	7
Intimidated by the complexity	1	7
None of the above	1	7
Afraid to ask for help	0	0
No written step-by-step guide	0	0

Table 4-2: Type of improvements that would increase use

FFE students		
Type of improvement	**N.**	**%**
Easier software	16	64
Better instructions online or close to the machine	14	56
Someone present to help with machinery such as the laser cutter	11	44
Easier hardware	3	12
None of the above apply for me	0	0

Master's students / PhD candidates		
Type of improvement	**N.**	**%**
Easier software	6	43
Someone present to help with machinery such as the laser cutter	3	21
None of the above apply for me	3	21
Better instructions online or close to the machine	2	14
Easier hardware	1	7

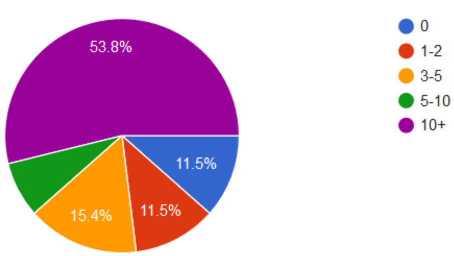

Figure 4.8: Self-reported number of occasions a student used the laser cutter (N=25).

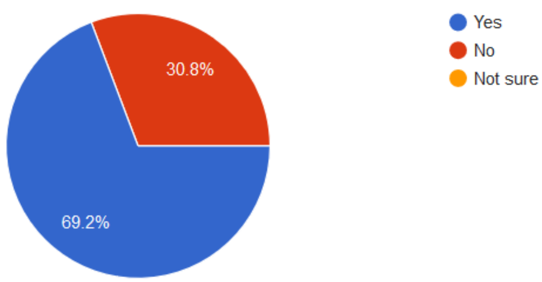

Figure 4.9: Used the laser cutter without someone helping (N=25).

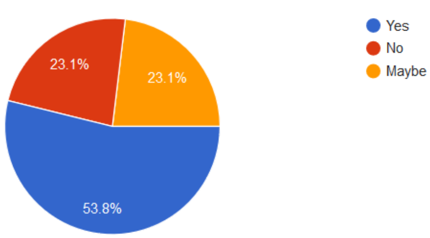

Figure 4.10: Do You Feel You Received Enough Training and supervision? (N=25)

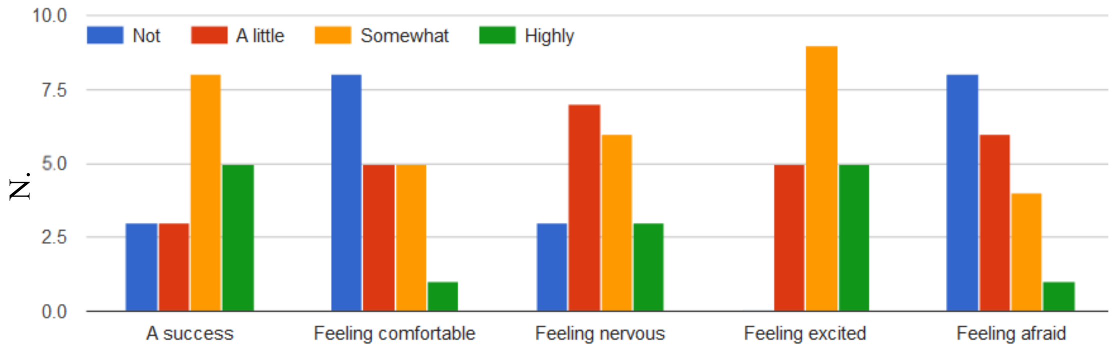

Figure 4.11: If you have used the laser cutter without someone helping you, how would you describe your first time using it "alone"?

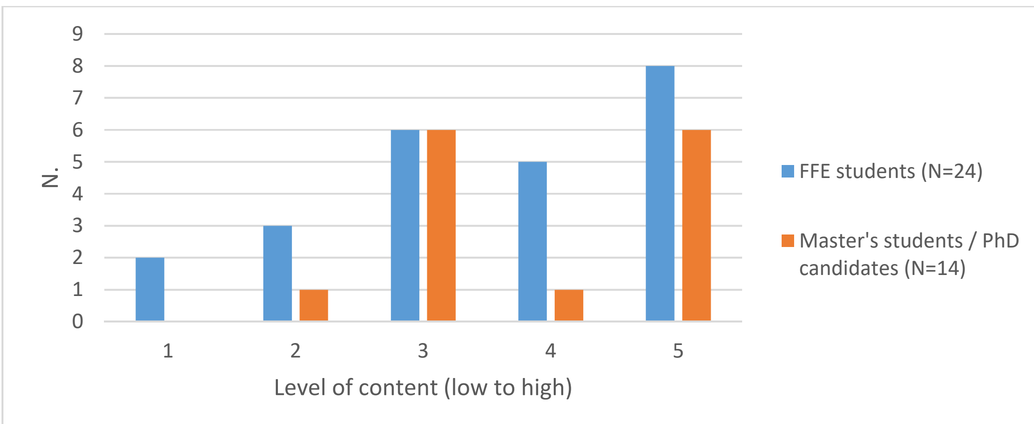

Figure 4.12: How do you feel about there being a system tracking your behaviour and usage of the laser cutter at TrollLabs?

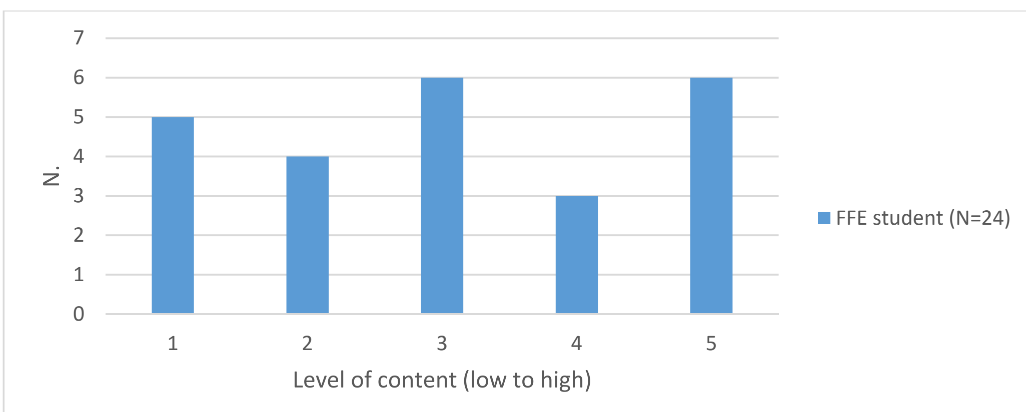

Figure 4.13: Would you mind there being such a system in your future workplace on all machines such as the laser cutter?

4.4 Key Insights from Need Finding

This sections sums up some key insights that influenced the two other parts of the thesis. Insights noted here have also been formed by probing, but belonged more to this part.

4.4.1 What Conceptual Model?

Many users lack a fundamental model of how the laser cutter works. They have problems understanding the workflow since they don't know the major components that go into a successful laser cutter job. Techshop counters this by forcing every user to take a two-hour course to properly teach the underlying concepts. The Industrial design department solves this problem by having a strict protocol for using their machine, and having a detailed online resource.

As Norman (2013) notes, a clear conceptual model could be designed instead of taught by bringing "knowledge inside the head" to "in the world". Mapping, signifiers, and introducing a conceptual model could be used to increase the discoverability of machine.

4.4.2 Out of Order

The machine being out of order was one of the main reasons for people being at least delayed in using it, with a whopping 86% from PhD candidates and master's students. Coupled with the fear many FFE students describe of damaging the machine this area has protentional for being improved. The swiss cheese model propose either applying more layers or reduce holes in each layer to reduce the possibility of severe negative outcomes. Ways to affect user behaviour on these dimensions should be looked into to increase up-time and foster a less anxious work environment.

4.4.3 Learned Helplessness

The current setup is in danger of learning users to blame themselves for struggling to use the laser cutter. Users note that they are afraid of damaging the machine, and that they are unsure of how to use essential features. Norman (2013) notes that poor design may increase the barriers of using a machine, produce negative associations to it that limits use, and could reduce self-believed proficiency. Ways to help users in the novice phase should be looked into, so users faster learn and are less likely to experience strong negative experiences.

4.4.4 Feedback from People and Machines

Users ask each other for help, and are often successful at solving problems with some guidance. There have been negative stories from experienced users reflecting that some may be asked too often. 36% of FFE students describe being at least delayed in using the machine due to not having a written step-by-step guide and one in five describe the same for forgetting procedural actions. This is reflected in what types of improvements FFE students think would increase use where having easier software and better instructions are mentioned more than someone to ask for help.

Ways of reducing the need to ask questions and ways to learn the "expert interface" should be looked into.

4.4.5 Being Monitored is not a First Priority

During the prototyping period, several people contacted me and asked questions about the monitoring of users. Most people were intrigued, asking questions about how it would work and what information would be gathered. Some voiced their concern and discomfort for being tracked. Questionnaire reveals that a majority have few quarrels about the current setup, but there was a modest shift when FFE students were asked about a hypothetical future with monitoring on all similar machines in a future workplace.

Privacy concerns should therefore be considered early in the design data storing and capturing, but will likely not be a major factor in overall adoption.

5 Probing Without Data

This chapter summarizes key phases of the probing not linked to data analysis. The structure is based on figure 4.1 on the workflow of the system. A7-10 explains more detail how the code for the two Arduino modules work, and their respective part lists.

5.1 Reading Material Input

The goal was to find a method for reading one of the main input types in the machine.

Table 5-1: Material matrix

Material Type	Material Category	Material Thickness (mm)
MDF	Wood and glue	3, 6
Plywood	Wood	4
Acrylic	Transparent thermoplastic PMMA.	2, 3, 5, 6

5.1.1 How Many Ways?

RFID-tagging, image processing using QR codes and ML were looked into. Two interesting approaches were tried right after: image recognition and software monitoring.

RFID tagging the material sheets: By having a passive RFID-chip on the sheets and a RFID-antenna mounted directly above the machine should be able to uniquely identify each sheet. Knowing which sheets are used when could be used in tracking inventory as well has how many times each sheet is used.

Optical recognition using QR codes: This type of tracking is frequently deployed in manufacturing and retail, could it have merits in this specific capacity?

Optical recognition of material profile: A camera could be mounted on the laser cutter in such a way that it can picture the material before a laser cutter job. By using machine learning the thickness and surface could theoretically be categorized.

Manually registering material information: Just asking the users to register with an RFID-chip or input to interface.

Monitoring the affiliated computer: To start a job, laser cutting settings have to be determined. Users often use material pre-sets instead of determining by themselves.

5.1.2 Testing: Optical Recognition

To test the feasibility of optical recognition QR codes were engraved on MDF and acrylic sheets. The technology is robust and widely used in retail and manufacturing. Gluing on QR codes on white paper would be robust, but how would engraving the information directly pan out?

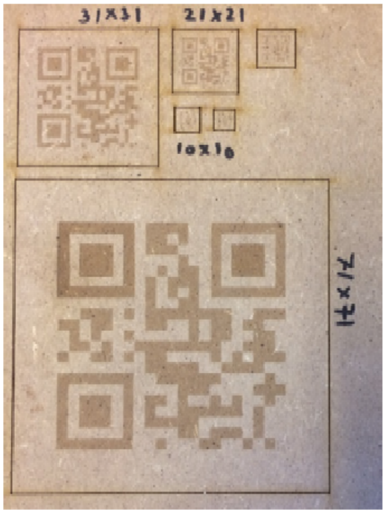

Figure 5.1: QR-Codes on MDF.

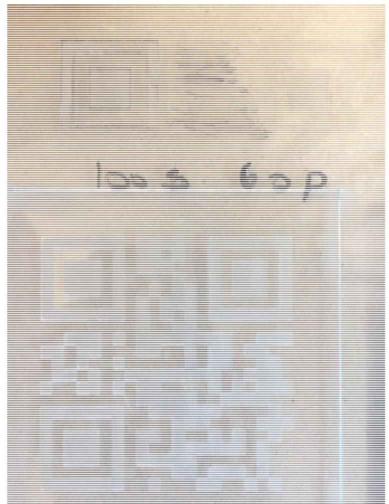

Figure 5.2: QR-Codes on Plexiglass.

The see-through nature of Plexiglas was a problem using a cell phone camera. Using a coloured marker on the QR area before cleaning it up gave a more distinct colour of the etched area, but the same problem reoccurred. The QR was more visible from the opposite side of the material. Etching the Plexiglas mirrored and scanning it could potentially improve recognition. Also, glare from light sources created problems for the recognition. The engraving could be done such that it only penetrates the protective plastic.

Static QR codes were used in the text format. Error correction was set to 15%, level M, the most used setting.

QR codes contains enough information for applying it to the laser cutter. QR codes can also be static or dynamic, which enables for versatility.

5.1.3 Insights

QR and RFID tags need to actively be applied and are therefore too burdensome to use in a continuous manner. Passive tracking such as surface recognition or using user input as proxy, where the user anyway needs to input material pre-setting's are therefore more convenient.

Having users manually register was initially viewed as a sub-optimal solution, but it took little time to set up. Figure 5.7 shows a prototype gathering user ID and material ID by registration. A minority used the prototype for each session according spot tests showing 30 to 50% adoption.

5.2 Monitoring Software

Need finding and observations reveal, the software interaction was a major part of laser cutting with the Gravograph. The Norwegian office of the manufacturer was contacted about the existence of an API or other helpful tools, they declined to aid, stating a wish to protect trade secrets. Different software and hardware monitoring systems were then tested.

5.2.1 Monitor USB Connection

The Gravograph and affiliated communicated through an USB connection set up as a virtual printer. To monitor the data transfer in more detail the USB sniffer USBPcap[7] with Wireshark[8] was tested. Raw data could be read in real-time, but were susceptible to user interference. Users frequently force terminate running programmes, and two preliminary tests were stopped by this. The method was therefore determined to be to unreliable.

Print jobs could be locally stored on the affiliated computer. Information such as filename, size, and time, could be extracted by free optical character recognition tools[9]. A drawback of this method was that the spool could be filled up and create troubles for users, perceived or real. A consequence was that the spool was frequently deleted by users. This made the method less robust for storing data over longer periods. From the print spool the original print files were stored in a proprietary format. The same problem was present combined with a time-consuming method of saving all of them made these files infeasible to record for longer periods.

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[7] URL: desowin.org/usbpcap
[8] URL: wireshark.org
[9] URL: onlineocr.net

5.2.2 *Performance Monitor*

Using built-in monitoring from Microsoft. Performance analytics such as GPU usage, power consumption, which programmes were running etc. could be monitored through Windows 7's built-in Performance monitor. It did not allow for monitoring what happens inside a programme.

5.2.3 *Hardware Loggers*

Hardware loggers for keyboard and mouse were considered. They initially looked promising due to the high resolution of data, and some on-the-self products even allowed for wireless transfer for information. Arduino libraries are available for PS/2 connectors which would allow for data filtering in the capturing phase.

5.2.4 *Commercial Keyloggers*

Multiple commercial keyloggers were benchmarked. Spyrix Personal Monitor PRO[10] and Spytech[11] were tested. Spyrix had specific features of interest that other commercial programmes lacked:

- Saves a detailed report of all actions on the computer every 24 hours locally on the computer in csv-format.
- Takes screen shoots every time a window is changed on the computer. Screen shoots are saved locally in a standardized date and time format.
- Logged mouse clicks and keyboard strokes.
- Actions were sorted in what programme, and in what window in a programme that was used.

5.2.5 *Insights*

The different tests reveal that both the material and computer input could be read using the Spyrix keylogger. That lead to other solutions for reading material input to be put on the self. It should be noted here that speed was prioritized over a better proxy for material input. Tests showed that the material profile most often were collected, but sometimes "flimmer" on

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[10] URL: www.spyrix.com
[11] URL: www.spytech-web.com

the screen capture where the old and new window lay over each other could obscure the material. Also, this approach did not allow for the material profile to be quantified seamlessly. For that to happen, the pictures would have to be run through an OCR or other image recognition algorithm.

5.3 Machine Input

The goal in this section is get metrics on how the laser cutter is used, and to get some idea of which measurements are of value.

5.3.1 Prototyping

A vibration sensor was in the project thesis able to discriminate between four different states: laser cutter powered on, powered off, engraving, and cutting (A1). The ventilation system had since changed, and testing revealed that this approach no longer gave the same results.

An initial prototype using a microphone gave initially good results. The sensor could discriminate between whether the laser cutter was running a job or not. Noise interference from other machines and activities made the method not robust enough.

Different combinations of sensor modules were then applied to different locations to score which combinations could describe the most states:

- Lid: Current sensor, vibration sensor, tilt sensor, SD, RTC.
- Lid: Current sensor, ToF sensor, tilt sensor, SD, RTC.
- Mirror: Photoresistor (2x), ToF sensor (2x), SD, RTC.

Figure 5.3: Quick prototype of having two distance sensors for x and y coordinates, light, and if lid open (hall effect).

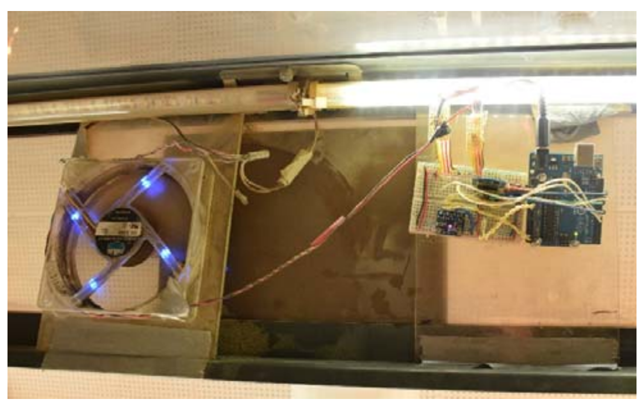


Figure 5.4: Module on Lid. The prototype piggy-back on the laser cutter's electrical system.

Table 5-2: Concept scoring

Sensor\State	Power external fan (On/off)	Power laser cutter (On/off)	Laser cutter lid (Fully Open/partially open/closed)	Laser cutter mirror adjusted manually (Yes/No)	Laser cutter running a job (Cutting/Engraving/No)
Vibration, before change	Blue	Green	Yellow	Red	Green
Vibration, after change	Blue	Red	Yellow	Red	Yellow
Microphone	Blue	Red	Red	Red	Yellow
ToF	Red	Red	Red	Red	Yellow
Tilt sensor	Red	Red	Green	Red	Red
Hall effect	Red	Red	Green	Red	Red
Current sensor	Blue	Green	Red	Yellow	Yellow
Photoresistor	Red	Green	Green	Red	Red
Door,vibration	Red	Green	Green	Red	Yellow
Door, ToF	Red	Green	Green	Yellow	Yellow
Mirror	Red	Green	Yellow	Yellow	Green

Greens: Yes; Yellow: Yes, but with some limitations; Red: No; Blue: Yes, but with sensors on a different module than on the door or mirror.

5.3.2 Choice for Reading Machine Input

Having a module on the door would enable for more precise readings of whether the lid was fully open, partially open, or closed. At the time, the resolution of whether a user was engraving or cutting was not prioritized. The longer wiring and that the sensor module would be more prone to user interference at the mirror location caused a door-mounted time of flight module to be viewed as more robust. With a mirror location setup, the mirror would have been measured on both the x- and y- axis, and the x-axis sensor would not be affected by the lid opening or closing.

5.3.3 Testing

After longer tests of the door module, the code was optimized to remove unnecessary storing of data. Testing the data recorded from sensor module with the software monitoring and RFID reader revealed that more data were saved than necessary. The sensor module was changed from continuously monitoring to only logging changes to the machine. This removed the possibility of knowing when the laser cutter was turned off, but observation of usage revealed this to be of little value in quantifying usage since the laser cutter was seldom turned off for longer periods while in use. Users typically rebooted the laser cutter to reset to default settings, which were logged as “boot”.

Testing also revealed that whether someone was manually adjusting the mirror could be of interest, but were inconclusive of how much value and how to separate this behaviour from running a job.

5.4 Who is Using the Machine?

The goal in this section is to attribute user behaviour to identifiable users. The data analysis also reveal a need for more metrics on how content users were with the process or work product.

5.4.1 First Probing Iteration

The first prototypes wanted to register the unique user identity and material profile for each session. The software and hardware design is based on the Protobooth RFID-reader with two LED-s for showing users when the reader is “ready” and “reading”. Having a similar user interaction were important to avoid misuse.

In testing the designs, different locations were tried out. Close to the monitor, on a side table, mounted to the laser cutter, and mounted to the tools racket. To learn more about the materials used, RFID-tags for each material profile were made. This created an unexpected obstacle: the prototyping machine had 11 material profiles. Storing and using the RFID-tags needed more space than most of the previous solutions had allowed. Locating the reader close to the monitor therefore became unfeasible even though this would be the preferred location since users would stay right in front of it, and it would be close to the screen users were working on.

Figure 5.5: RFID reader on the right-hand side of the computer.

Figure 5.6: Hanging RFID tags close to eyesight on the right-hand side of the computer.

Figure 5.7: RFID tags laying neatly around the RFID reader.

5.4.2 *First Iteration Insights*

The question of whether many users would interact with the system were a main concern, and different methods were considered to encourage usage or blocking the prototyping machine if no RFID were read. Blocking users proved to be a problem due to the old hardware for the laser cutter. A worry was also that an opt-out solution could generate major annoyances if it did not work good enough.

Testing of the software monitoring system, door module, and RFID-reader revealed that:

- More people were using the RFID-reader over time, and that there was a divide between people using it often and not at all. The most cited reason for not using it was forgetting to or not bothering.
- The material profile could be recorded by software monitoring, and therefore not needed on the RFID-reader.
- Users opinions on how their jobs went were not being registered. By removing the material part of the previous system, some type of active input could be added.
- MDF was as expected the most popular material.

5.5 Second Probing Iteration

The goal was to make more users use the system. Add a gauge of whether people were content with their work.

The RFID module was right under the computer monitor to be in line of sight the whole time. A time of flight sensor measured if a user worked on the computer, if the RFID reader or buttons had been used a display started changing frequently to remind people.

Figure 5.8: RFID Prototype.

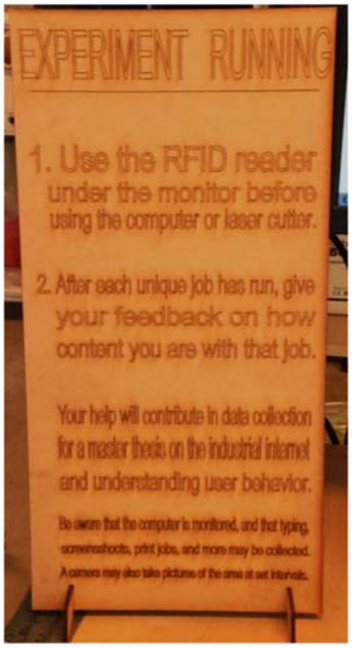


Figure 5.9: Placard Informing Users on How to Use the RFID reader.

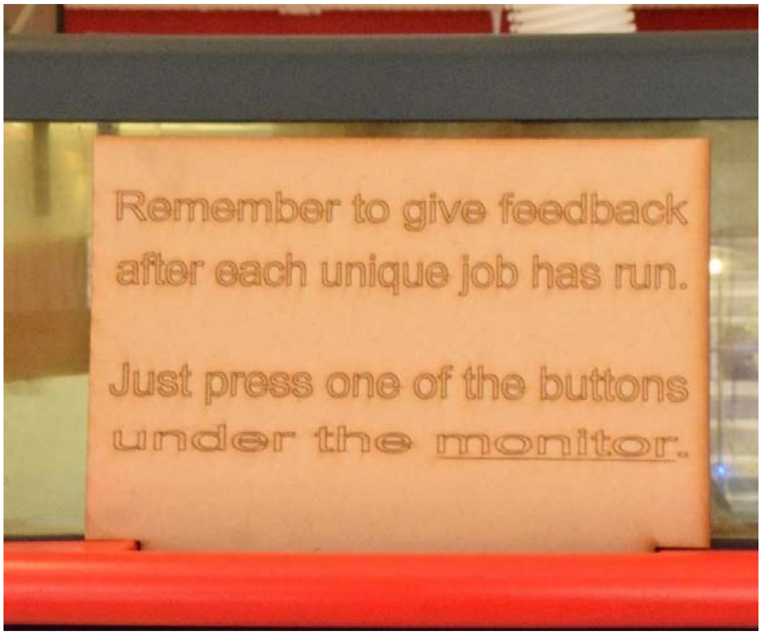


Figure 5.10: Friendly Reminder on the Laser Cutter Lid.

5.5.1 Satisfaction Rate

To get answers on how content users were with the process a question was asked: “are you content with the result” on the prototype. As seen in figure 5.9 and 5.10 users were asked to use either to push a sad or smiling emoji button. See figure 5.8 for overall setup. The hope was that this metric could gain insights to what factors determined a successful job, and could be used as a target function later on.

5.5.2 Testing RFID reader

The data shows that some users give feedback regularly and after each job, some do it infrequently, and others don’t bother to use the reader or the buttons at all. The two latter groups are smaller for the last prototype. This could be attributed building habits over time or the newer prototype working better to encourage users.

The two main reasons for not using the reader from previous prototypes: (1) forgot to, (2) and did not bother.

The new system has a ToF that will trigger a small LCD display to frequently change its message. It was considered to add sounds or distracting lights to dramatically increase the social cost and personal annoyance in later iterations. It was in the end out weight by observing users and previously structured data. Also, prototyping with the data had already started and not changing the hardware setup for a while was prioritized. Many sessions drag on in time, and users doing troubleshooting would be undue affected by adding distracting measures. More encouragement when using the buttons and reader on the display were instead prioritized.

5.5.3 Testing Feedback Buttons

Testing reveal that the buttons were used, but that there was some confusion on when it should be pushed. Some used them after every job, others just when they were finished. The signs (figure 5.9 and 5.10) were changed three times to improve usage. Observations revealed that many users did not bother to read the signs, and did not notice when the messages changed.

Observations showed that users were biased towards a positive outcome with only one fourth tapping the sad button.

Reduced robustness of the experimental setup was accepted since the buttons were used to help define session endings, and RFID to determine session start.

The buttons helped in defining instance endings (see chapter 6) and were used as a tool in developing a coding scheme. As such, the buttons proved valuable in data probing for defining an instance and increasing the richness of the experiment, but where of less value in the final stages.

5.6 Machine Feedback Based on Material and User ID

By monitoring the material profile and person, the two most important variables in a laser cutter job could be determined. This information could feed into an algorithm or programme that could provide interesting information, best practices, and/or tips from earlier sessions. Repository of examples:

- Give novices a conceptual framework of how the laser cutter works.
- Step by step guide for novices, but not experienced users.
- Advice on material properties that could affect prototyping behaviour.
- Previous settings for same material with a positive job outcome.
- Previous settings for an experienced person.
- Inspirational or novel methods for the laser cutter.

5.6.1 Prototypes in Processing

Different mock-ups were made in Processing were material and user ID triggered different displays depending on pre-set rules.

A new user would for example be introduced to more information related to procedural help. Figure 5.11 and 5.12 show a processing interface that was located to the side of the main display. A user could press the black or white button to change between the two processing displays (5.11 or 5.12) that would relate to different topics.

The black screen introduces the user to fact that their identity and material selection is known to the system. Underneath relevant material information is listed. The white screen had some procedural help, showing the two most important toolbar buttons and some helpful tips. A section about reoccurring problem and how to fix them were also listed.

Many users did not bother to register either material or user ID on the RFID reader. Figure 5.13 shows one effort to hinder use without registering user ID. The Resize function in processing allows a display resize when triggered. When the timer reached its limit, an overlay covering the whole screen would force users to scan their ID card.

5.6.2 Testing Processing Prototypes

The affiliated computer has as noted earlier older software and hardware. The first solution worked well in theory, but users had a habit of closing all programmes when the computer had problems. This often resulted in the black/white overlay to also be closed. The prototypes were also tested running dual screens which gave the processing overlay more screen size. This would likely be a better format if more information were to be included.

The processing function related to resizing had combability issues with the affiliated computer which led to the programme crashing.

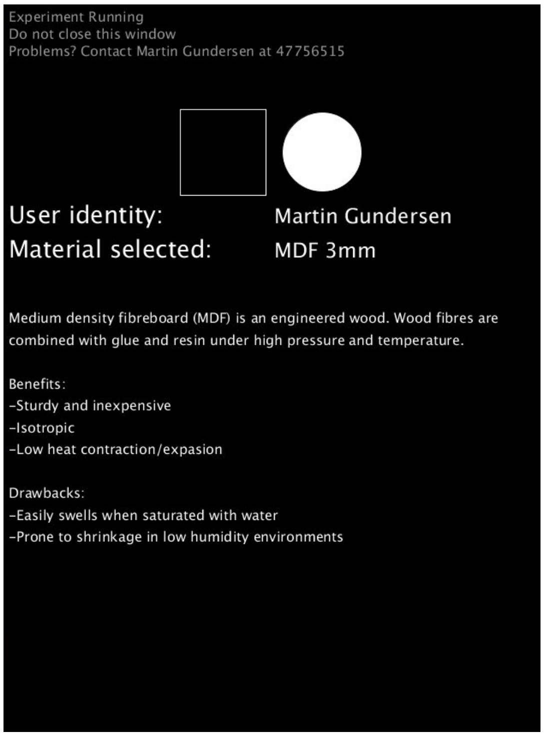


Figure 5.11: Processing Sketch

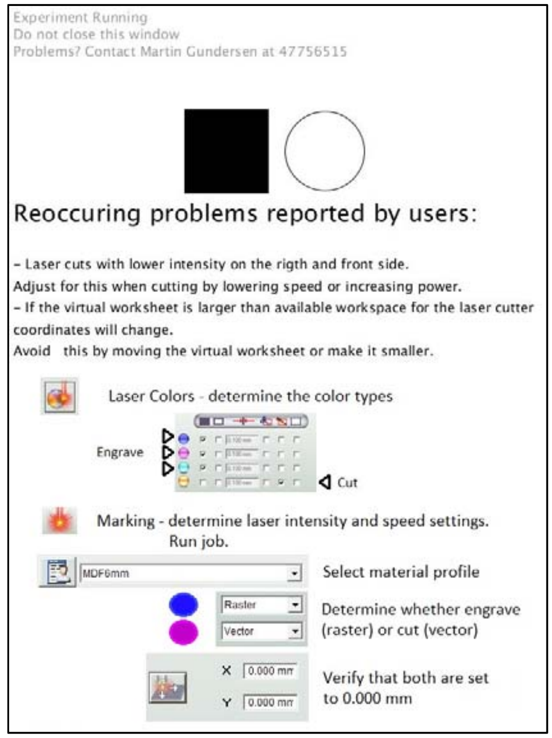


Figure 5.12: Processing Sketch

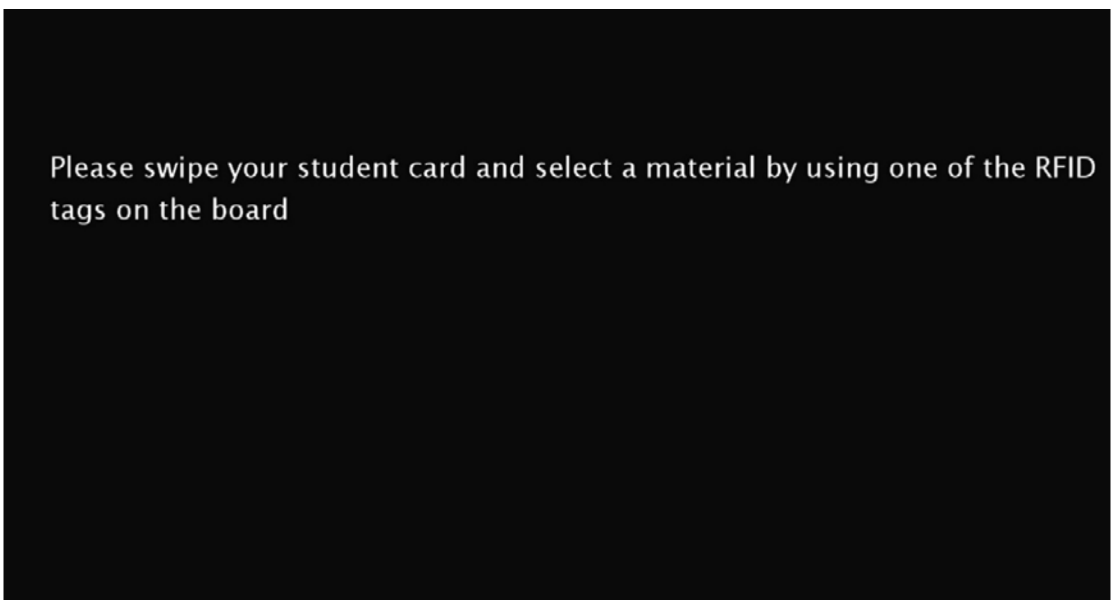


Figure 5.13: Processing Sketch for Blocking Screen

6 Probing with Data: Preliminary Data Preparation

Insights in the probing without a dataset and the need finding phase, led to a setup for analysing user behaviour.

6.1 Data synchronisation

Both Arduino modules timestamped in Unix, while Spyrix stored timestamps in the excel-format 1900 date system. All data were synchronized to the excel format. The Arduino RTC modules also had some drift, typically ± 1 second each day. Difference between RTC module and present time were noted when initiating data gathering and when collecting the data. Then the difference for each day in the period were calculated.

6.2 Structuring Raw Data

The different data steams were merged in an excel document. The data were in the event logging format partly modular such that each column was linked to a certain event types. This allowed excel functions to extract information in a semi-automated manner governed by the coding scheme.

Column	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Origin		Author	Software logger				RFID			Printlist	Laser cutter			
Type	Datetime	Time difference / note to self	Activity	Programme	Window	Action(s)	RFID ID / Material	Positive feedback	Negative feedback	Printed jobs	Laser cutter booted	Lid opens	Lid closes	Laser cutter mirror moving
Format	MDY H:MM	int / text	Text	Text	Text	Text	Text	Text	Text	int (in Kb)	Text	Text	Text	Text
Example	3-31-17 7:18	300 / Session Start 30	KEYBOAR D	explorer.exe	Program manager	<LM><LM><LM><LM>	1300884568	Smile	Sad	98	boot	Lid opens	Lid closes	Mirror moving

Table 6-1: Format of events in Excel.

6.3 Developing Coding Scheme

A method for transforming event data to a series of user sessions in this specific manner was not found. A coding scheme was developed to efficiently perform this process automatically.

The initial assumption that instances could easily be separated and automated were disproven in the first and second pilot dataset. The pilot datasets of 29 and 66 instances were then tested for correlations and tried in different machine learning algorithms with some crude pre-processing to uncovering possible unknown-knowns and to test previously held assumptions from the prototyping phase described in chapter 5.

The initial assumption was that instances could be separated from each other by who had last registered their RFID tag. This proved unreliable for several reasons. Users had varying preferences for when to do it, and a subset never or infrequently used it. Improvement to the RFID reader improved the percentage of registrations, but only moderately. The highest spot test revealed a 61% registration rate.

On busy days, users often worked in parallel. One could be working on the computer, and another finish the on the laser cutting. Instances were cross-work resulted in substantial interference, the episode was noted. Of 165 instances, 11 had a substantial element of contamination from this behaviour. About thirty or more had some cross-work at the start or end of an instance that would make an automated script have problem determining of a new user had begun. Only some of these required extensive works to attribute whom interacted where, and as such required visual verification from screen captures or the overview camera.

Some users performed varied and prolonged work on the laser cutter (more than 60 minutes) and could iterate on their laser cutting designs with minor tweaks. And others completely changed their behaviour throughout one session, by changing materials or working on different projects. The behaviour also made it harder to separate a new user from an existing one, since an assumption that a different job would equal a new user would not hold.

A user session and an instance also differ on what they empathize. Sessions are about the user's interactions with the system, while instances are more narrowly understood in the context of data analysis. An example: a user could use ten minutes to cut two MDF sheets and then clean the laser cutter for twenty minutes. The instance would only count the first ten minutes since the setup did not anticipate extensive cleaning afterwards, or it would count the twenty minutes as some type of troubleshooting or unproductive work.

The resulting definition for an instance were determined to be robust enough for its application:

"A known user interacts with the affiliated computer and sends a job to the laser cutter. If the user takes breaks longer than 10 minutes or substantially changes the types of work performed the instance ends".

Due to the degree of different behaviour and cross work- a fully automated script was not implemented. Instead a semi-manual approach of determining a couple of core variables were coded and then apply excel functions to structure the data. The values manually coded:

- Time of instance start.
- Time of instance stop.
- Time when laser cutter runs.
- Time when laser cutter stops.
- User identity if RFID was not registered.
- Screenshot markings window and virtual worksheet.

6.4 Prototyping Datasets

The first major question to be answered was: What user interactions may be extracted using machine learning, and what data is recorded in a way that enables transformations to machine readable formats. The prototyping datasets were used to gain some initial insights and evaluate if the test setup had any value at all. The short answer: yes. A longer answer highlights major problem with the test setup:

- With close to unlimited features to be constructed, which are interesting?
- What do the different data points tell about human behaviour?

Preliminary exploration revealed that there are significant differences in time used, number of laser cutting jobs per session, and that there seem to be variations in how people interact with the software programme Gravostyle.

Session ID	Is experienced	Is sad	Is power buttons used	Few regrets	Is long session	Is switchy session	Is clicky session	Is imported	Is locally opened	Is using toolbar	Is color adjuster	Is markings adjuster	Is material def adjuster
1	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
2	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
3	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE
4	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
5	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE
6	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
7	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
8	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE	FALSE

Figure 6.1: Example of First Iteration. This extremely crude structured table was used to see if there were differences between users and if they could be grouped. All activity for each feature above average would be set to TRUE, the rest FALSE.

6.5 First Dataset Iteration

6.5.1 Setup

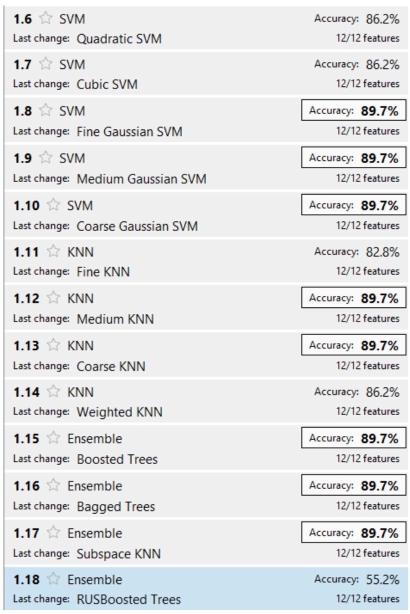
With only 29 instances, limited test was performed to just experience what types of outcomes could be achieved. Four target functions were created to test different classifiers ability to determine outcomes. Fivefold cross validation was used and one fifth of the dataset was kept for validation. 20% set as the test dataset. 11 features were used. The Matlab app "Classification Learner" were used to rapidly test 18 classifiers for each target function. Target functions:

- Is the person content with the result of the laser cutter instance? (Two classes)
- Is the job imported from PDF or locally? (Two classes)

- Does the person view themselves to be more experienced in prototyping than others?[12] (Two classes)
- Does the person use features such ‘F2’ and ‘F7’? (Two classes)
- Can it recognize a person? (11 unique users, 4 frequent) (11 classes)

6.5.2 Results

Results for response “sad outcome”: Decision trees, KNN, and SVM all predict a high accuracy, but the data is imbalanced. This leads the minority class to always be falsely predicted.



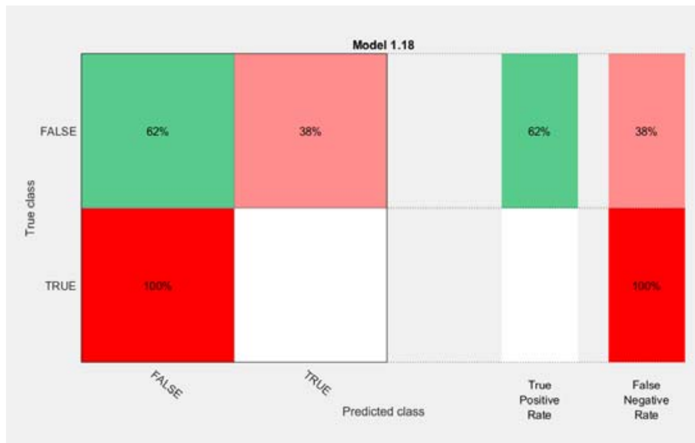


Figure 6.2: Results from "Classification Learner". Overview of performance of algorithms (right), and confusion matrix (left).

“Is experienced”: 55,5% is experience. KNN and logistic regression beats guessing the majority class, but only by 15.5%.

Is the job imported from PDF or locally? 85% correct from Bagged trees.

Does the person use features such ‘F2’ and ‘F7’? Very good response from trees classifiers and SVM’s. SVM gives 72% when time used, number of LM, and number of window changes is counted measured as normalized.

Can a person be recognized? The target function has 11 classes, with four frequent classes, and 29 instances. See figure 6.3 and 6.4 for confusion matrix.

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[12] From the Protoboth database. Users were asked: “How experienced would you describe yourself at prototyping? (scale 0-10)”

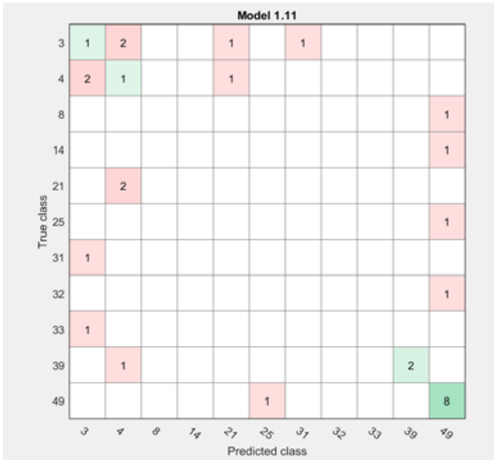

Figure 6.3: Confusion matrix for SVM coarse gaussian. On whether a person may be recognised.

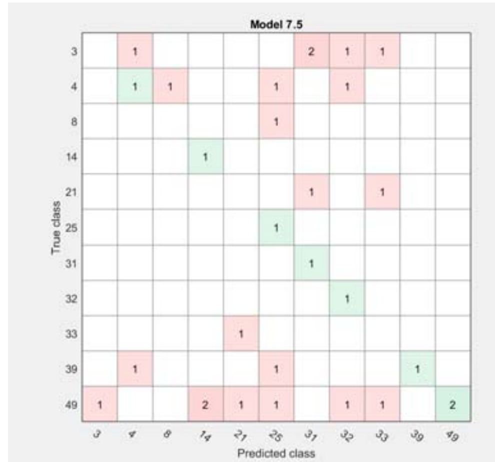

Figure 6.4: Confusion matrix for quadratic SVM. On whether a person may be recognised.

6.5.3 Discussion for First Iteration

This iteration reveal that behaviour is linked together and could be predicted, but are inconclusive about whether experience or outcomes (sad or happy) can be predicted based on behaviour.

The data is imbalanced for some target functions, and patterns looked at through visualisation seems to be correct. There are obvious variations between users in this first iteration. Even though accuracy is not the first concern, it seems possible that a better model can predict if certain behaviour can be linked to a specific user or skill level.

Target feature for pushbuttons (sad or happy) is imbalanced, needs to be addressed. Predicting users is also viewed to have to many target classes to be of value, but could be interesting to look more into in the future.

The most important feature "is experienced" gave poor results, and beat only coinflip by 5 percentage points.

6.6 Second Iteration – Structure and Feature Engineering.

The goal of this iteration is to explore the dataset further with improvement in the coding scheme (see 6.3), and a larger dataset. The dataset is explored with different focuses. Different visualization techniques and pairwise correlations were used to find patterns in the dataset.

The dataset had 66 instances and around 40 features. The questionnaire gave a better target feature for experience with laser cutter, and users were now mapped on more dimensions.

6.6.1 *Correlation tests*

On 40 features, the 39 numerical features were initially checked for correlations. Using correlation were used to find possible relations between features that were later visualized in other manners, see section 6.8.

Pair-wise correlations on raw features: Over twenty pair-wise correlations surpassed 0.60, and three pair-wise correlations surpassed 0.96.

Pair-wise correlations adding ratios: 28 features and 65 instances. Of these 28 features, 14 correlations were stronger than 50%.

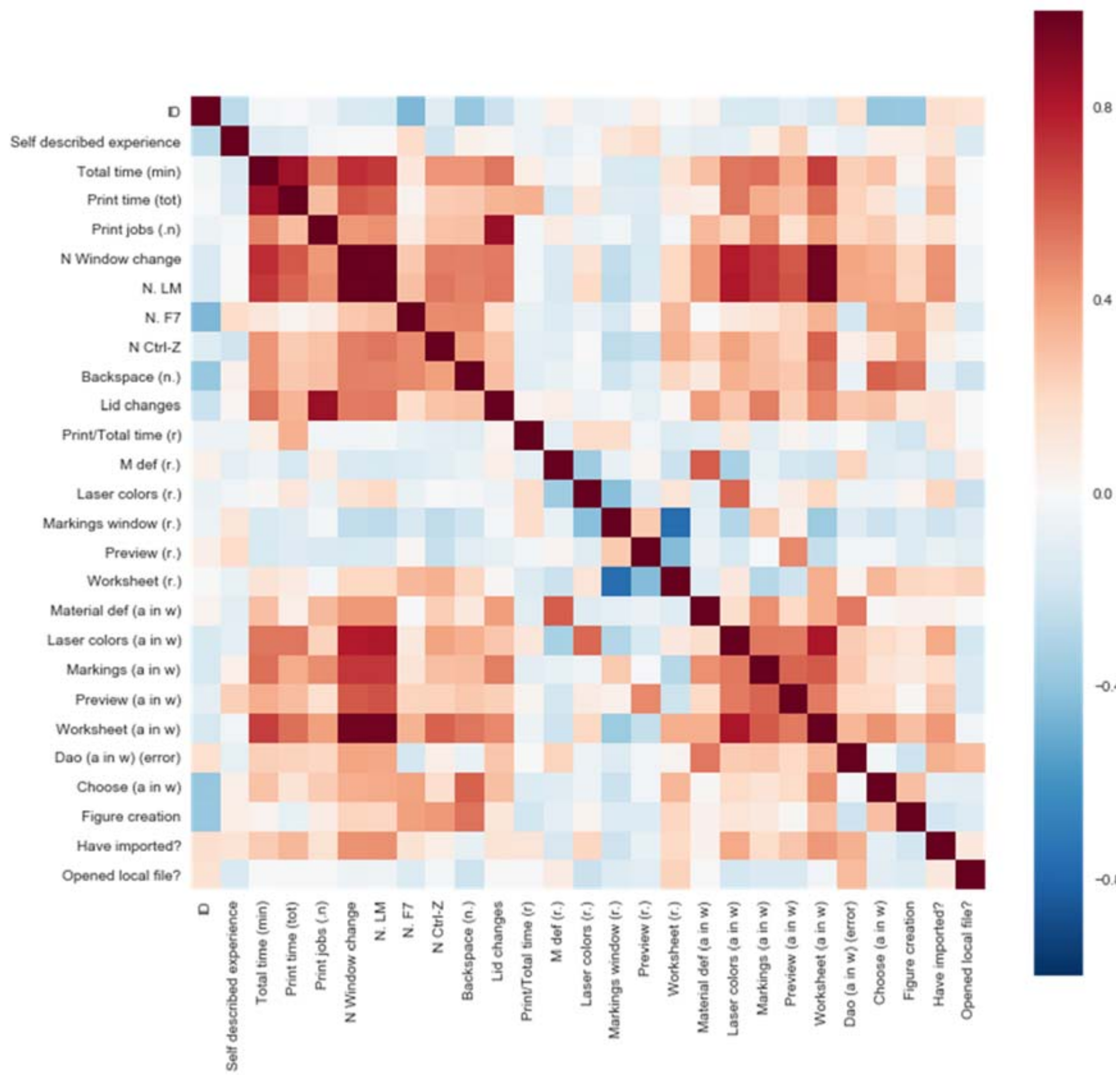

Figure 6.5: Example of a correlation visualisation.

6.6.2 *Insights*

- Need to improves definition of an instance and become more clear on what separates a laser cut from each other.
- Should categorize the job complexity from viewing pictures of the jobs in three classes: low, medium, high.
- Should have a better feature as proxy for experience with laser cutter.
- Should improve the RFID reader to encourage more users to use the pushbuttons.

6.7 Experimental Setup for User Behaviour

The setup has five unique data sources that are used in the data analysis:

(1) RFID reader.
(2) Sensor module on the laser cutter lid.
(3) Event logging running on affiliated computer.
(4) Screen captures taken at window changes on affiliated computer.
(5) A camera run on a Raspberry Pi 3B for overview and validation.
(6) Print log manually extracted by OCR on the affiliated computer.

Experimentation revealed that certain types of data were more important and crucial for doing a robust enough analysis. Through testing (3), and (5) were determined to be essential to the analysis, and all periods where these did not work properly were not considered for further analysis. Data sources (1), (2), and (3) were determined to be important, and missing data were either determined by validation or a missing value was applied. Print logs were deleted to often by users that they were determined as 'nice to have' for validation and learning in the initial phases.

Based on these constraints four periods were thoroughly analysed as the basis for the final dataset:

- 21th of April (08:45) to 24th of April (19:37).
- 26th of April (11:24) to 30th of April (16:25).
- 3th of April (13:32) to 9th of April (20:41).
- 20th of May (10:55) to 25th of May (22:27).

Figure 6.6 A RFID reader, a placard with instructions and information on the experiment, and background screen reminding users of the RFID reader.

Figure 6.7 Overview camera used for validation.

6.8 Breakdown of Final Dataset

The Protobooth designed by Jørgen Erichsen and Heikki Sjöman have 48 users registered. This database was the basis for connecting RFID readings from the system to users. Their question "How experienced would you describe yourself at prototyping? (scale 0-10)" was also used as a feature in the ML dataset. This database was then appended by the questionnaire FFE students, master's students and PhD candidate observed using the laser cutter. In total, 55 profiles were then created. Of total unique users in the final dataset, all have taken one of the questionnaires and four were not registered in the Protobooth database.

The information collected from users can be broken into different categories:

- Familiarity with the Gravograph.
- Familiarity with laser cutters in general.
- Average familiarity on five topics related to prototyping.
- Self-described number of times they used the Gravograph.
- How experienced they would describe themselves at prototyping on a scale of 0 to 10.
- Current position and if they took the Fuzzy Front End course.
- Gender.

Table 6-2: Breakdown of relationship between users and instances

Unique users	27
Total sessions	162
Average instances per user	6
Median instances per user	4
Average familiarity with the machine (1 – 4)	3,5
Instances attributed to top five users	44%
Female users (11%)	3

Table 6-3: Breakdown of user backgrounds

PhD candidates	
Unique users	2
Number of instances	10
Average instances per user	5,0
Median instances per user	5
Average familiarity with the machine (1 – 4)	3,00
Master's students	
Unique users	9
Number of instances	56
Average instances per user	6,2
Median instances per user	4
Average familiarity with the machine (1 – 4)	2,7
FFE students	
Unique users	16
Number of instances	96
Average instances per user	6,0
Median instances per user	4
Average familiarity with the machine (1 – 4)	3,4

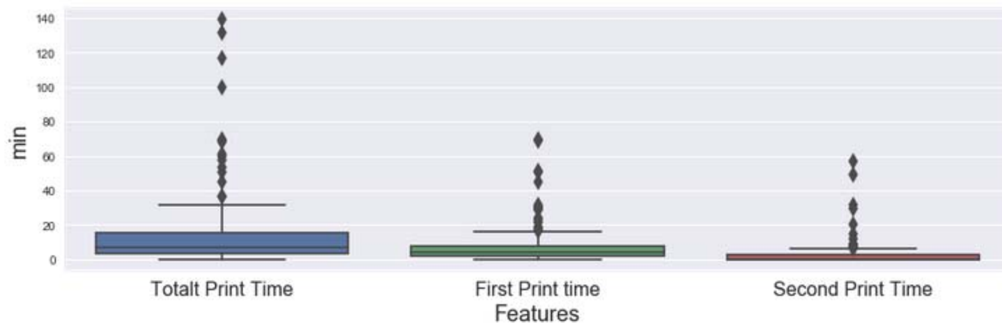

Figure 6.8: Print time.

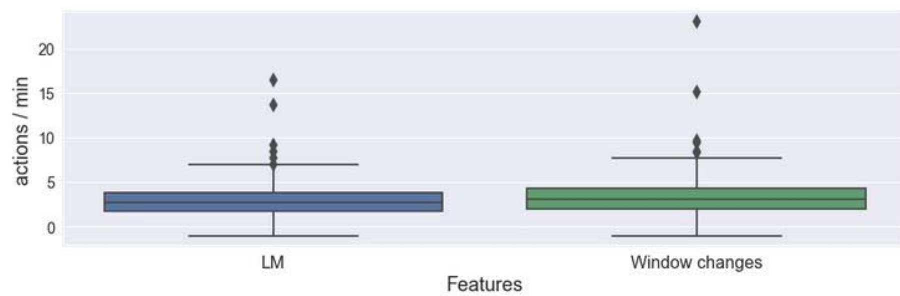

Figure 6.9: Actions per minute.

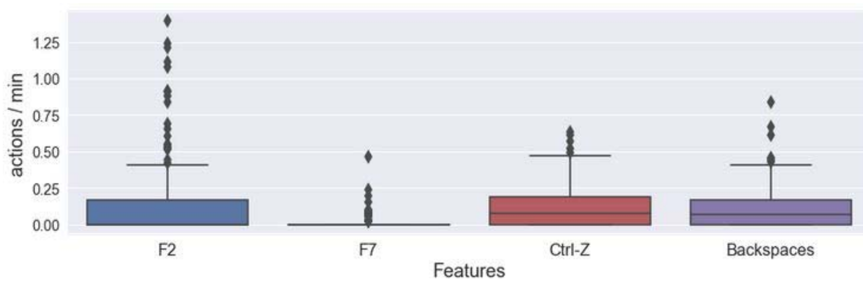

Figure 6.10: Actions per minute.

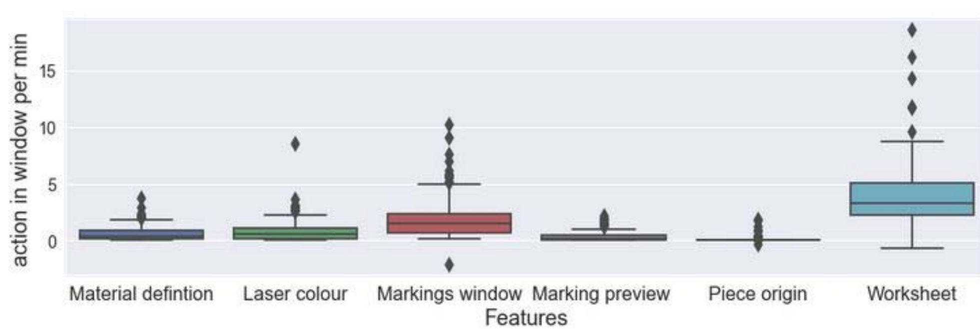

Figure 6.11: Actions in window per minute.

7 Pre-Processing

This chapter shows the results of pre-processing.

7.1 Data Cleaning

Some features had illegal values that were fixed. No instances were removed for being outside the norm.

7.2 Handling Missing Feature Values

In general, the four periods used in the final dataset had few missing values in general, but one instance was removed due to the user being unknown and out of the database.

For missing data on user identity, one instance was removed.

Three feature lack four continuous data points each. These are imputed by the average of the rest, and then rounded to closest integer.

One instance lacks individual print times, but the number of prints and total print time is known for the instance. Individual print time are set to be equal for each job.

7.2.1 Job Complexity Imputation

Nine values for "job complexity" lack, imputation of mode was performed, filling in them with "medium" complexity.

Job complexity (Categorical)	Number (n.)	Percentage (%)
1	35	22.7
2	72	47.7
3	47	30.5

Table 7-1: Job complexity in numbers.

7.2.2 Material Type Imputation

Dataset 7c: 16 reference features in total, 13 related to computer use, to for printing, and one a ratio for print time to total time. All continuous features are normalized.

Dataset c_imputatuon: Five reference features: total time, laser cutting time, number of cuts, job complexity, and first cut time. All continuous features are normalized.

Table 7-2: MDF imputation

MDF			
Dataset 7c		c_imputation_mdf	
Predicted	Probability	Predicted	Probability
MDF 6mm	0.60	MDF 6mm	0.6765
MDF 6mn	0.60	MDF 6mm	0.5263
MDF 3mm	0.53	MDF 6mm	0.6765
MDF 6mm	0.60	MDF 6mm	0.6765

Table 7-3: Plexiglass imputation

Plexiglass			
Dataset 7c		c_imputation_plexi	
Predicted	Probability	Predicted	Probability
Plexi 6mm	0.6316	Plexi 6mm	0.4118
Plexi 6mm	0.6316	Plexi 6mm	0.4118
Plexi 2mm	0.4286	Plexi 6mm	0.4118
Plexi 6mm	0.6316	Plexi 6mm	0.4118

For plexiglass, coinflip (25%) and guessing majority (41%) is beaten by 7c.
For MDF, coinflip (50%) and guessing majority (55%) is beaten by c_impuation_mdf.

7.2.3 Discussion

Material thickness affect how it takes to cut through, and the attribute is likely linked to types of jobs performed. So, even though the thickness may be less important, it could be important to know this value for the later analysis. If not, dropping 11% of instances with plexiglass and 4% of instances with MDF would be unwanted since the dataset is so small. Turi's built-in categorical imputer beats imputation of the mode, and random guessing, but only by a relative small margin. To avoid this problem, removing thickness as part of the feature would circumvent the problem, and could be preferred to imputing with a high error probability. At a later stage, this was not done due to certain material profiles having high correlations to the target function.

7.3 Feature Construction

In deciding which features to use in the final dataset. Several approaches were tried to create features. In all, over eighty different features were tested to some degree. Most were scraped early on, and often after a histogram showed them to either unbalanced or having little variance. The main types can be divided into:

- User – gender, familiarity, number of jobs, position, background etc.
- Job details – material, job complexity, and whether content with job result.
- Actions on affiliated computer.
- Actions on Gravograph.

- Time series.
- Actions per minute.
- Time based, such as time per job and total time per instance.

7.3.1 Discussion

Time series were scraped due to there not being an obvious method of creating them in the established coding scheme. Behaviour on the affiliated computer seemed rich in features, but had many strong correlations. This will be explained more thoroughly in the next section. Typical features were based on counting certain actions such as left mouse clicks. Features based on the Gravograph itself were sparse, but were related to logging time, reboots of the machine, and whether the lid was open or closed.

In section 6.8 (Breakdown of Final Dataset) the sources user features are explained. These will be used as classes and features depending on the situation. What is interesting here is how users behave and how they describe themselves, and if there is a difference. Seven features related to user identity (user experienced and questionnaire).

7.3.2 User-Related Features

Seven user features where analysed using pairwise correlations with one hot encoding for categorical features:

- Gender, categorical, 2 classes.
- Current position, categorical, 3 classes.
- Self-described experience with prototyping, numeric, 10 classes.
- How familiar with laser cutting in general, 4 classes.
- How familiar on seven topics, numeric, 4 classes.
- How many self-described uses, numeric, 4 classes.

Interesting pairwise correlations:

- Familiarity with laser cutters in general correlates 0.60 against familiarity with the Gravograph. And familiarity in general with laser cutters correlate with more features that are related to average familiarity and self-describe prototyping experience. This could therefore be a better class than the more specific case of knowing the Gravograph.
- The number of self-described occasions of using the laser cutter correlates strongly negative for FFE students (-0.87) and more modestly for master's students (-0.31)

indicating that PhD candidates use the machine more throughout the year. It also suggests this to be a poor class.

- There is only a modest correlation (0.3) between self-described experience and average familiarity on seven topics.
- Females self-report less usage and experience, but should be taken with a grain of salt since all females partake in the FFE course.

From these correlations, general familiarity with laser cutters will be used as the feature other features are tested against in accordance with Hall's hypothesis (2000). Since few women (N=3) are in the dataset, this feature will not be used latter on. Average familiarity (Questionnaire) and self-described experience (Protobooth) are in many ways similar, and even though there is only a modest correlation, only average familiarity will be used further on due to the other feature lacking data from four users. Current position will be used further on to test if these can be determined by usage.

7.3.3 Material

Material are categorized by thickness and material category. An example: MDF 6mm.

7.3.4 Job complexity

The highest geometric complexity of a job in an instance were rated on a scale from low, medium to high. This could give some insights into what the geometrical complexity of the jobs performed meant for a user's skills, and if it could be correlated to specific behaviours.

7.4 Feature Selection

Two main approaches were used to reduce dimensionality: PCA and a correlations-based approach.

7.4.1 Correlations and Visualizations

Current position and average familiarity with laser cutters are used as target functions. As mentioned in the method chapter, features that correlate strongly with each other and poorly with the target function are to be removed. Using histograms, correlations plots, lists of pair-wise correlations, and running some decision trees – the dataset were reduced to 12 features.

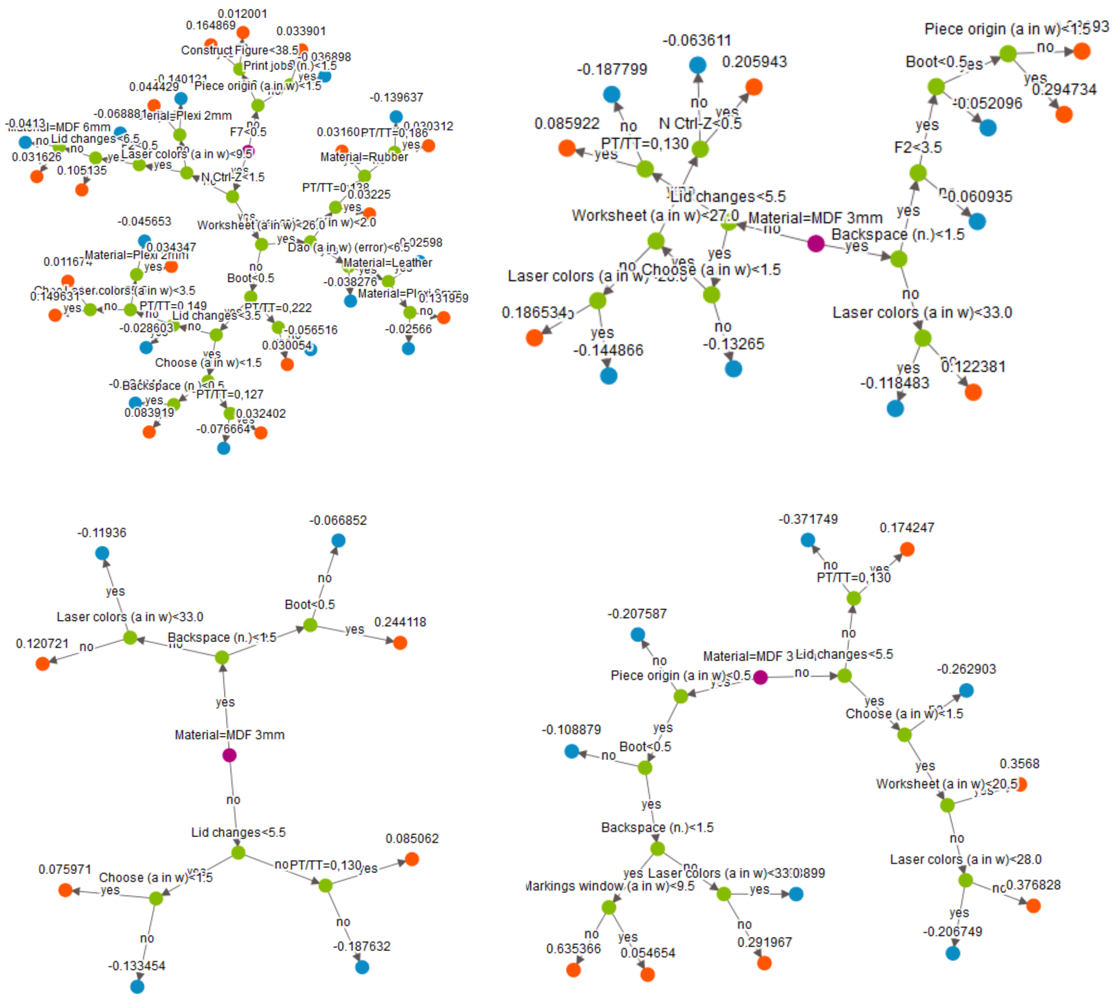

Figure 7.1: Decision trees as a tool for feature selection. Here: Familiarity as target function.

Final 12 features:

- Material profile.
- Job complexity.
- PT/TT, print time divided by total instance time.
- TT, total instance time.
- Number of actions Laser colours window, ratio.
- Number of actions Marking preview window, ratio.
- Number of actions in piece origin window, ratio.
- Number of error pop-ups, ratio.
- Number of files imported, ratio.
- Number of F2 clicks, ratio.

- Number of Ctrl-Z clicks, ratio.
- Number of backspace clicks, ratio.

Table 7-4: Ghiselli's merit metric

Feature-feature intercorrelation	-0.0255
Class-feature correlation	-0.01455
Merit	0.123

7.4.2 *Reducing Dimensionality by PCA*

In total, 63 features were feed into PCA in Matlab. Of these, 49 were initial features; two features were divided by total instance time; and 12 were ratios for computer use. All features were normalized except categorical features that were one hot encoded. 12 first features explain 90% of variance, the rest is discarded.

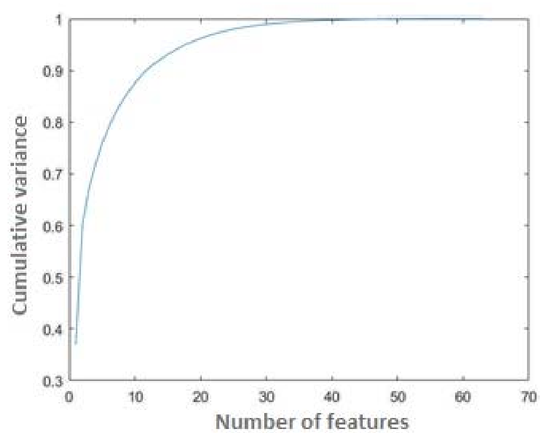

Figure 7.2: Cumulative variance versus number of features.

8 Supervised Machine Learning

This chapter shows the results for supervised machine learning with familiarity to the laser cutter as the target function. The class somewhat familiar is removed to have only two classes that are less similar.

Table 8-1: Alternative accuracies

Class	N	
Low familiarity	24	23.8%
High familiarity	77	76.2%
Coinflip	50.0%	
Guess majority	76.2%	

Table 8-2: Dataset partitioning

Correlation-Based Dataset	N.		*PCA-Based Dataset*	N.
Dataset	101		Dataset	101
Training data	58		Training data	64
Validation data	17		Validation data	16
Test data	26		Test data	21

Table 8-3: Results correlation-based dataset

Decision Tree				
Accuracy	0.714	**Confusion matrix**		
Recall	0.667	Target label	Predicted label	Count
Precision	0.933	3	1	7
Log loss	0.643	3	3	14
AUC	0.762	1	3	1
F-score	0.778	1	1	6
Boosted Decision Tree				
Accuracy	0.714	**Confusion matrix**		
Recall	0.667	Target label	Predicted label	Count
Precision	0.933	3	3	11
Log loss	0.616	1	3	2
AUC	0.823	3	1	2
F-score	0.778	1	1	3
Random Forest				
Accuracy	0.787	**Confusion matrix**		
Recall	0.809	Target label	Predicted label	Count
Precision	0.895	3	1	4
Log loss	0.600	3	3	17
AUC	0.823	1	3	2
F-score	0.850	1	1	5
SVM				
Accuracy	0.75	**Confusion matrix**		
Recall	1.0	Target label	Predicted label	Count
Precision	0.75	3	3	21
Log loss		1	3	7
AUC				
F-score	0.857			

Table 8-4: Results PCA-based dataset

Decision Tree				
Accuracy	0.762	**Confusion matrix**		
Recall	0.765	Target label	Predicted label	Count
Precision	0.929	3	3	13
Log loss	0.628	1	3	1
AUC	0.757	3	1	4
F-score	0.839	1	1	3
Boosted Decision Tree				
Accuracy	0.762	**Confusion matrix**		
Recall	0.765	Target label	Predicted label	Count
Precision	0.929	3	3	13
Log loss	0.477	1	3	1
AUC	0.938	3	1	4
F-score	0.839	1	1	3
Random Forest				
Accuracy	0.810	**Confusion matrix**		
Recall	0.826	Target label	Predicted label	Count
Precision	0.933	3	3	14
Log loss	0.553	3	1	3
AUC	0.816	1	3	1
F-score	0.875	1	1	3
SVM				
Accuracy	0.809	**Confusion matrix**		
Recall	0.8235	Target label	Predicted label	Count
Precision	0.933	3	3	14
		3	1	3
		1	3	1
F-score	0.875	1	1	3

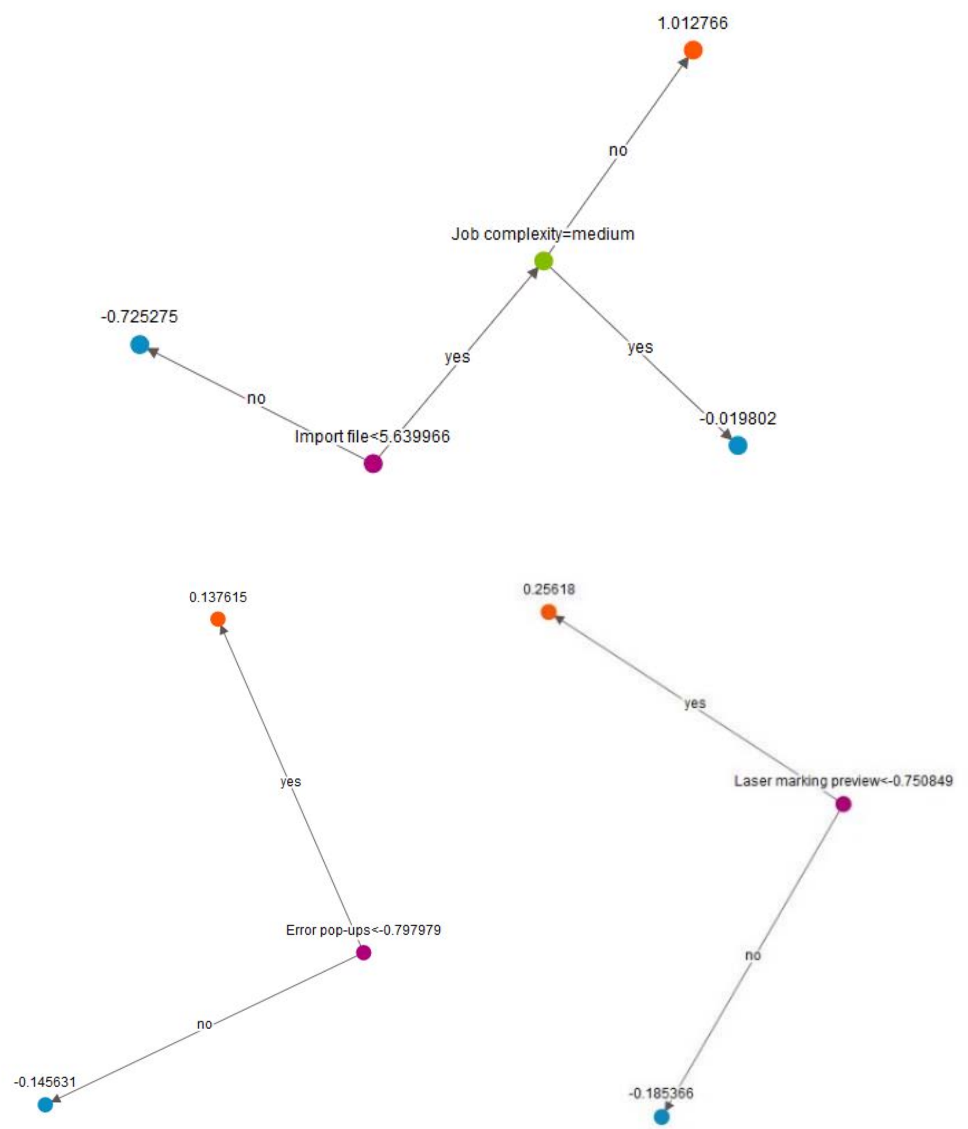

Figure 8.1: Correlation-Based Trees: Random Forest (top), boosted decision tree (left), decision tree (right).

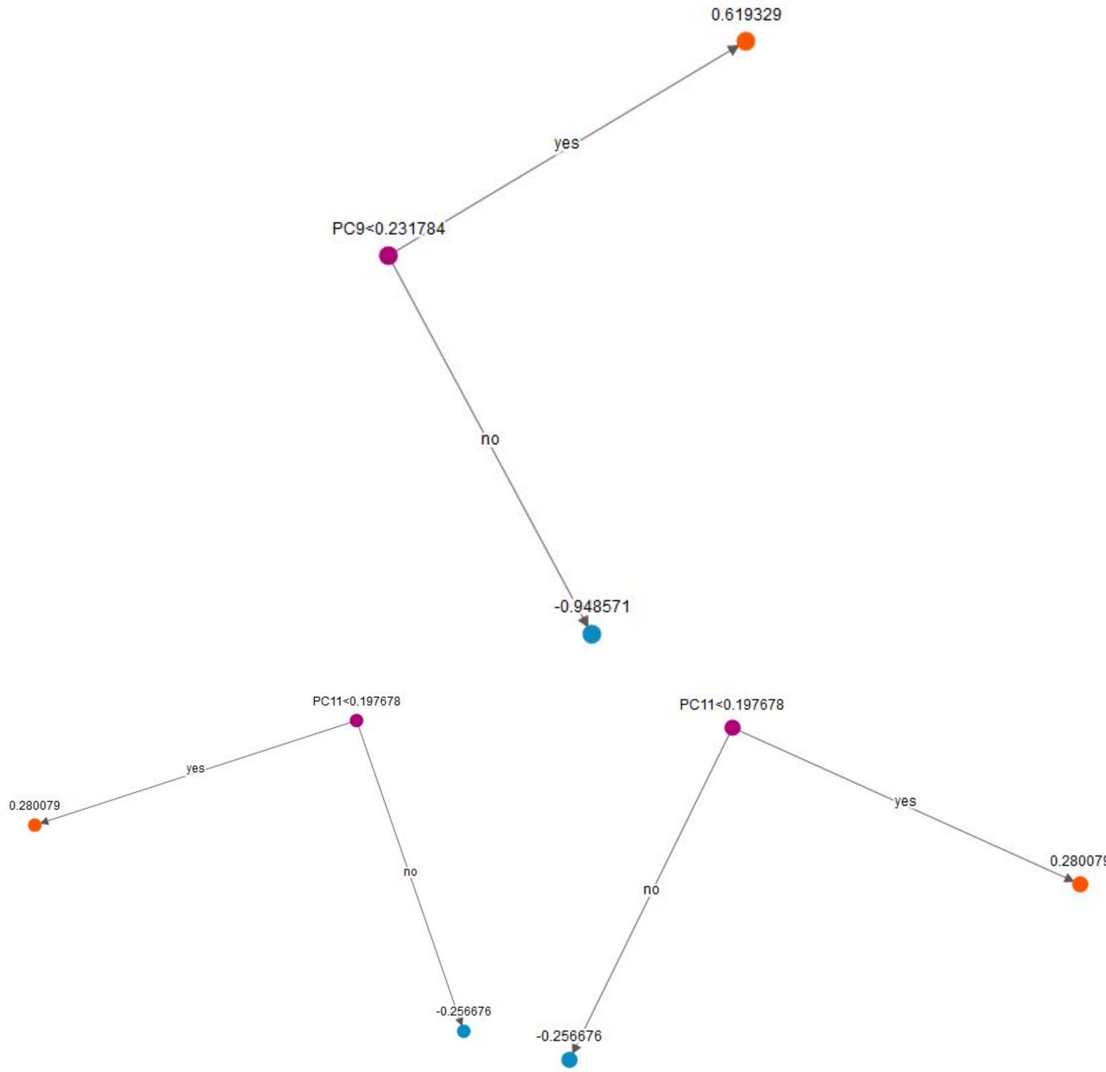

Figure 8.2: PCA-Based Trees: Random Forest (top), boosted decision tree (left), decision tree (right).

9 Discussion

This chapter reflects on the work process and results.

9.1 Method

9.1.1 On Including All Knowledge Domains from the Start

The results explained earlier have a variety of methods behind them, and different areas of domain haven been utilized. As stated in Gerstenberg et al. (2015) all background relevant to the project should be included from the start. I believe this insight to be one of the most important for probing in multiple disciplines simultaneously. To produce insights, I had to verify and talk to experts outside of my domain.

This process of synthesising knowledge is second-rate to having these domain-knowledges inside the core team. When probing to produce data or user-facing prototypes one should know which tools are available in the data analytics domain. If not, prototypes for data will be less optimal in its first iteration, and maybe take more iterations to triangulate which value the data could have.

9.2 Need Finding

Combining a quantitative and qualitative approach helped in synthesising experiences picked up from observations. The five core insights from the need finding phase evolved over time and reflect some relevant discussion held today about human-machine interaction. Machines are often designed for expert users with the idea that training is needed for newer users. This fact is also a reflection of already experienced users not wanting too much to change between every product iteration.

For experience users or people familiar to a machine, the idea of learned helplessness seems foreign. I would argue that laser cutters in general require too much needless training and are to focused on pleasing already familiar users. Misuse increase the strain a machine is put through and troubleshooting could easily produce severe negative outcomes if frails parts are tinkered on carelessly.

9.3 Probing

9.3.1 Bias Towards Existing Hardware and Wanting Robustness

When probing without data, one is more free to experiment. But when the project already has modules capturing data or interfacing with user, the bar for changing the physical setup increases. If one were to change the setup too much, all previous data could be without value. In addition, existing prototypes have stability issues and drawback that could be fixed. Optimizing existing hardware will improve the data collected in the present, but could in my opinion impede future experimentation. Also, better robustness is helpful in probing with the data later on. Thus, on has to prioritize a balance between having enough robustness so the present data is useful and remaining agile.

9.3.2 Rate of Acquired Valuable Data

The main types of data captured in this thesis revolved around a user interaction. The problem with these types of interactions is that users vary in motivation and behaviour as a group and as individuals. Capturing enough data is therefore a problem for multiple reasons. There is a limit of how much a specific machine is used over a period of time, and there is a limit how many users are involved with the machine. In addition, a laser cutter is versatile which generate multiple use scenarios for each user.

In this case, between zero and twenty sessions a day with the median of maybe five sessions would only produce 100 instances over a twenty-day period.

9.3.3 Modularity, Simplicity, and Standardization

Modularity, simplicity, and standardization are three core design principles that in my opinion reduced the amount of rework and sped up discovery of design faults.

By building multiple cheap modules that had specific tasks, some data could always be acquired even if some parts of the systems were upgraded or failed. Stability issues for Arduino modules running quickly prototyped scripts or hardware are prone to fail for a multitude of reasons. By checking regularly if the modules are working, and troubleshooting their reasons for failing to measure something specific or measure at all, one may more rapidly uncover design faults.

By striving for simplicity were possible, scripts and hardware become easier to troubleshoot since there are fewer possible reasons for failure.

When working iteratively standardization of generic components reduce the time to design newer modules. There are drawbacks of course, standardization will incur some effort to create in the first place, and it may narrow the solution space due to the sunk cost fallacy.

9.3.4 Use Cases

In my opinion there are two main use cases for an II system - (1) To give users relevant feedback based on behaviour or user identity, or (2) generate a data repository.

For this thesis, the second route were chosen. The main reasons for this was to see if user characteristics could be determined by analysing machine interaction.

The first route would produce a more tangible outcome. It could also have been prototyped faster due to not needing many user sessions for testing. Without access to the drawing programme on the affiliated computer and with the stability problems on the computer, this approach had its hurdles. Some simple prototypes were created and a better interface for the programme were sketched out, but were never implemented.

9.3.5 Systems Integration

A grand idea of integrating multiple sub-systems were scraped midway through the thesis. The reason is connected to the rate of acquiring valuable data, and that the need at the moment did not involve near real time monitoring.

Another reason for not integrating more systems were the instability of the affiliated computer. Some modern programmes and crowd-sourced tools had problems even running, while others were prone to being shut down by users. This will be explored more in the limitations chapter.

9.4 Discussion on Data Analysis

The final dataset suggest that the dataset is in the lower bound of what machine learning may handle, but as Oates and Jensen (1997) show on 19 datasets – this size is often enough to reach as good accuracy as having 500 instances.

That said, the results clearly demonstrate that the final classifier did not achieve any significant gains to primitive methods such as coinflip and guessing the majority class. The results shown were just a set of many similar and failed efforts to classify users based on behaviour.

I am unsure why the classifier did not surpass 5% of guessing the majority class. Different explanations could be:

- More instances should have been thrown away to reduce noise.
- Poor choice of target function.
- Another method for dimensionality reduction.
- Another method for feature construction.
- Too much variations in the dataset compared to number of instances.

9.4.1 Overfitting

As seen in the bare-bone tree models, the classifiers overfitted after just a few nodes. A different test was run with 162 instances guessing whether the person was very, somewhat or a little familiar with laser cutter in general. Those models were less prone to overfitting, even though they did not achieve meaningful gains.

9.4.2 Reduce Noise and Instance Selection

In screening instances, I could have been stricter on what types of behaviour on the laser cutter that should have been thrown away. Certain kinds could have been excluded if they were to, for example, exceeded five times the mean on any feature. This type of screening was not performed and more work on removing deviant instances could have been performed.

9.4.3 Cross-Work

It is possible that overlapping work was not coded well enough, and as such added noise to the dataset. A problem could also be that when users work in team, they behave differently than if they would do it alone. From observations, teams solve problem on the laser cutter quicker than if they were alone. Experienced users hanging around the laser cutter could also have helped more novice users without it being noted.

An added camera above the laser cutter could have been used to record how many people are present around the laser cutter, and if that affects behaviour.

9.4.4 Target Function

The target function was chosen as the best of available metrics for experience with the laser cutter. In hindsight, a scale from 1 to 10 should have been used to have a bigger span to work on. A method here could have been to remove the middle four or only use odd numbers.

A different discussion is whether a questionnaire is the right way to gauge a user's skill. If this approach were to be re-tried, a method for baselining self-reported proficiencies could have been used.

The data used in the analysis were gathered in the later stages of the FFE course. Thus, the users would likely have had some experience with the laser cutter before being monitored, and as such be closer to the skill level of other members of TrollLabs. If the users are too equal in skill level, the metric may be a poor target function or their behaviour may be too similar to distinguish.

10 Conclusion

Results from need finding and probing shows that prototyping in an industrial internet context is feasible. Even for one person, major insights may be extracted and expanded on later.

Creating a system mainly focused on gathering data has its drawbacks for rapid prototyping in that it requires time to capture, analyse, and verify the data. Energy that could have been used on iterating on feedback between machine and user, where capturing data is less important and testing far faster.

The data analysis is inconclusive on to what degree behaviour may predict proficiency or user certain user characterises. A larger dataset, improved target function, or improved system for gathering behaviour could all contribute in improving the accuracy of machine learnt predictions.

That even mechanical engineering students have problems using a laser cutter reveals that many expert-focused products are way too hard to learn.

10.1 Future work

Even though no significant came out of the data analysis, there have been many lessons on how to conduct probing over multiple domains and ideas of where to focus if a next project in this project were to be started.

I would propose focusing on feedback between machine-user and having in mind the possibility of analysing the generated data later. Prototyping for data produces longer iterations when interactions typically have longer duration than ten minutes and there is infrequent use.

10.1.1 Attribution

An improved system where the user does not need to manually register should be developed for a next iteration. Using RFID antennas above the different places users are located could automate some attribution. Computer aided vision or biometric markers could also aid in understanding who does what on the machine.

10.1.2 Adaptive Interfaces

Adaptive interfaces could be used in several ways to improve the user interaction. Either the interface could be adaptive between experienced and novice users, or the interface could display relevant feedback, tips, or other information during an interaction.

Especially adding a novice interface that uses progressive disclosure and introduces a conceptual model could reduce the amount of misuse, lower the barriers of use, and contribute to faster learning.

10.1.3 Usage Analytics

Already today, a basic supervision system could be created from the existing data and sensors with minor adjustments. This system could be used to track key usage metrics such as time used every day, what types of work is performed, what materials are used, and which users are using it. The analytics could be use by facility managers or be display to all users to spark curiosity, for gamification, or influence social norms.

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Industrial Internet: Sensor Applications and Measurements in a Workshop Setting

Martin Gundersen

Understanding and utilizing the industrial internet is becoming more important to established companies as the IoT-paradigm becomes more pervasive. This report explores how to apply sensors in a workshop setting. Several repositories on industrial internet show the width of sensors and applications available. Two prototypes prove how sound and vibrations can be used to meaningfully monitor an object or room. The report proposes more research on connected sensors measuring a workshop simultaneously, and two possible use cases are described.

Keywords: internet of things; industrial internet; sensors; frequency domain analysis

THE NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

PROJECT WORK FALL 2016
FOR
STUD.TECHN. Martin Gundersen

Prototyping industrial internet

The challenge is to understand how to fast prototype potential industrial internet solutions in an existing company environment. TrollLABS and ProtoMore will act as test platform.

- generate concepts,
- build prototypes
- build test setups
- test and compare alternatives
- judge and evaluate concept

Also, it is expected to contribute to one or more scientific publications during the project/master thesis.
Supporting coaches are Heikki Sjøman from NTNU and Carl Christian Sole Semb from ProtoMore.

Formal requirements:

Students are required to submit an A3 page describing the planned work three weeks after the project start as a pdf-file via "IPM DropIT" (http://129.241.88.67:8080/Default.aspx). A template can be found on IPM's web-page (https://www.ntnu.edu/ipm/project-and-specialization).

Performing a risk assessment is mandatory for any experimental work. Known main activities must be risk assessed before they start, and the form must be handed in within 3 weeks after you receive the problem text. The form must be signed by your supervisor. Risk assessment is an ongoing activity, and must be carried out before starting any activity that might cause injuries or damage materials/equipment or the external environment. Copies of the signed risk assessments have to be put in the appendix of the project report.

No later than 1 week before the deadline of the final project report, you are required to submit an updated A3 page summarizing and illustrating the results obtained in the project work.

Official deadline for the delivery of the report is 13 December 2016 at 2 p.m. The final report has to be delivered at the Department's reception (1 paper version) and via "IPM DropIT".

When evaluating the project, we take into consideration how clearly the problem is presented, the thoroughness of the report, and to which extent the student gives an independent presentation of the topic using his/her own assessments.

The report must include the signed problem text, and be written as a scientific report with summary of important findings, conclusion, literature references, table of contents, etc. Specific problems to be addressed in the project are to be stated in the beginning of the report and briefly discussed. Generally the report should not exceed thirty pages including illustrations and sketches.

Additional tables, drawings, detailed sketches, photographs, etc. can be included in an appendix at the end of the thirty page report. References to the appendix must be specified. The report should be presented so that it can be fully understood without referencing the Appendix. Figures and tables must be presented with explanations. Literature references should be indicated by means of a number in brackets in the text, and each reference should be further specified at the end of the report in a reference list. References should be specified with name of author(s) and book, title and year of publication, and page number.

Contact persons:

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Introduction

The original need from the ProtoMore, the industrial partner, was to create a tangible manifesto of the industrial internet so their customer companies could gain more understanding of concepts, business models, solutions, and technologies that are enabled by it.

The overall challenge was to understand 'how to fast prototype potential industrial internet solutions in an existing company environment' with two workshops as testbeds. Different approaches were applied to better define what factors influence prototyping in the industrial internet.

The report covers three main parts: (1) literature and context of the report, (2) repositories, and (3) probing. These parts act together as a funnel from wide (1) to narrow (3) on how to understand the concept of the industrial internet. In addition, the report should be read as a preliminary study for a possible master thesis on this topic.

The concepts of internet of things (IoT) and industrial internet (II) are used interchangeably in the report to reflect how IoT as a paradigm covers the II, and that they share many of the same driving technologies.

The research question 'how can industrial internet be applied in a workshop setting and what are the promising venues of exploring it?' is answered in thematic sections. Section 1 lays out methods and prototyping frameworks. Section 2 explains the internet of things paradigm and its relation to the industrial internet. Section 3 gives context and background to the Molde region and the industrial partner of the report. Section 4 concerns how the author explored the industrial internet by: making repositories, creating concepts, prototyping, and performing experiments. Section 5 summaries key findings, and possible problems to tackle next.

Method

The overall inspiration for the methods used have been Leifert and Steinert (2011) who argues that radical innovation requires flexibility and 'dancing with ambiguity'. In a follow-up paper they propose a subjective model of thinking about early stage product development (PD) – the hunter-gatherer model where abduction, prototyping, and exploration are used as tools to increase the chance of novel discoveries (Steinert and Leifert, 2012). These techniques have been used with the help of the Institute for Design at Stanford list of seven mind-sets; five work modes: define, ideate, empathize, prototype, and test; and 41 example methods for human-centred design (Stanford, 2010).

The Stanford approach is inspired by the belief that changing external requirements can be off-handed by organizational knowledge generation (Nonaka & Takeuchi, 1995) and that failing through probing is needed for solving complex problems with unknown unknowns (Snowden, 2007). This in contrast to viewing PD in distinct and successive phases (Ulrich and Eppinger, 2012):

1) Concept generation
2) Concept screening
3) Concept scoring
4) Concept testing

The latter, and other traditional PD-textbooks, were viewed to be too late stage in most of the project, although its advices on concept generation have been utilized.

Another inspiration has been the «Agile Manifesto» who introduces four values to improve IT product development (Beck et al., 2001):

- Individuals and interactions over processes and tools

- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

Rigby et al., (2016) argues that the agile ultimately has a mechanical heritage in Bell Labs and a 1986 paper called the «New new product development game» by Takeuchi and Nonaka. In that light, the agile and scrum approach to early phase product development has been a natural fit for work partitioning.

Ulrich and Eppinger (2012) define «prototype as an approximation of the product along one or more dimensions of interest». In their view the word prototype is used as a noun, a verb, and an adjective in product development. Further, one may classify the prototype along two dimensions: physical versus analytical and comprehensive versus focused.

Houde and Hill (1997), argues that prototypes are used to answer questions and that developers should have this in mind when planning a prototype. They propose three archetypes of prototypes that relate to value brought to the user (role), how the user would and interacts with it (look and feel), and how it could work (implementation).

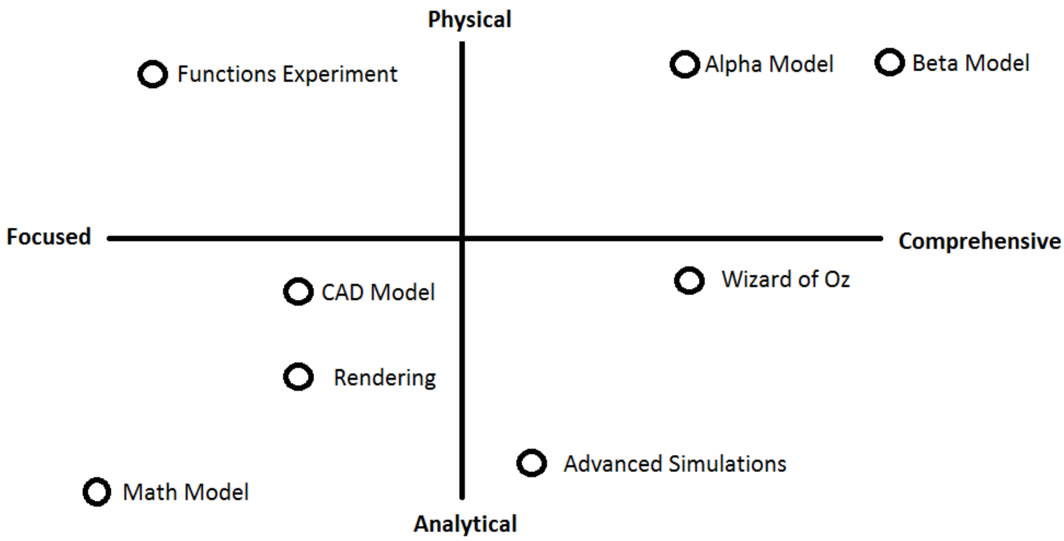

Figure 1: The main dimensions of prototypes according to Ulrich and Eppinger where comprehensive and physical models are the most intuitive versions of prototypes for laypeople (Ulrich and Eppinger, 2012).

Internet of Things – Background and Overview

In order to understand IoT we need to understand the roots and research on the topic, especially since there is much hype and diverging opinions of what it is and means for companies and researchers.

A common starting point to understanding the idea of smart devices is Mark Weiser. He coined ubiquitous computing, sometimes also called pervasive computing, a concept that points to a possible endpoint of IoT. His vision was that cheaper, low-powered computers that could interact seamlessly with each other and humans would be common place sometime in the future, and one could say that this already is true in a limited form today. In his own words: 'We are [...] trying to conceive a new way of thinking about computers, one that takes into account the human world and allows the computers themselves to vanish into the background' (Weiser, 1991).

By dissecting the phrase internet of things one may see that it consists of two visions – the first pushes towards a network oriented vision while the latter focus on heterogeneous objects (‘devices’) becoming interconnected. IoT could also be seen as one emerging paradigm from several competing visions (Atzori et al., 2010). Still, some argue that the research field into IoT is highly fragmented and focused on single application domains or technologies (Miorandi et al., 2012).

Semantics describe how to establish meaning and logics to the increasing number of connected devices and accumulating amount of information now stored. The idea is to better facilitate for automated processes so to simplify management and recovery of devices. This field is still in its early days, even though initial work has shown some success in accommodating conflicting requirements from stakeholders (Barnaghi et al., 2012).

Some are more sceptical of the ‘IoT hype’, and a literature study from 2014 revealed most IoT-research to be about technology. According to them, business models were written little about, the paradigm was not well represented in management literature, and how to regulate the field was not well discussed. As a consequence, the same study questioned whether or not the IoT is to be an enduring technology, if it will fail to materialize, or if it will only be a stepping stone to another paradigm (Witmore et al., 2014).

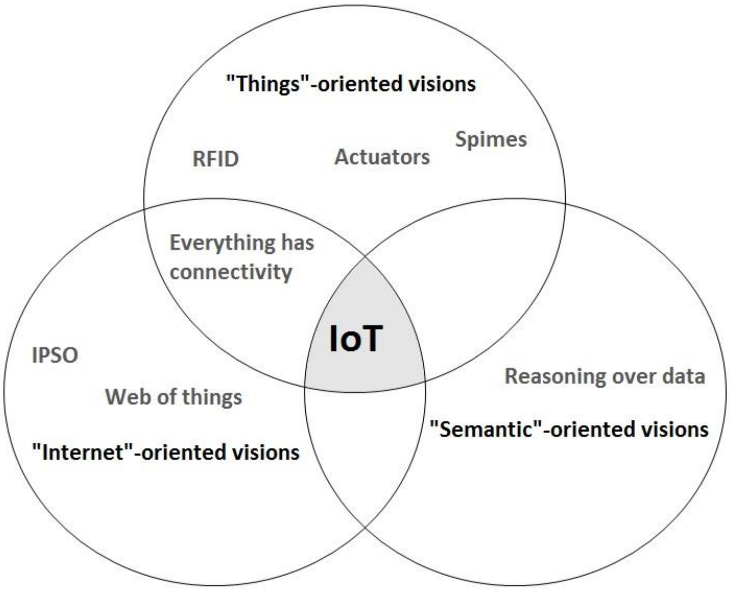

Figure 2: Three visions of what IoT is are merging into one unified understanding of the paradigm (Atzori et al., 2010).

An interesting concept that emerged aside IoT is spime, a combination of the words ‘space’ and ‘time’. It is defined as an object that can be tracked through space and time throughout its lifetime and that will be uniquely identifiable (Sterling, 2005). Today it is seen as a neologism, but it reflects an idea to address devices from cradle to grave that many already are try in their own way.

Another engaging concept is networks that combine sensors and actors (SANETs) that was first introduced in 2004, and describe how heterogeneous sub-systems could interact to also process and respond to sensor data. SANETs if applied correctly could reduce the amount of information that needs to be communicated outside of the sub-system, and increase the overall robustness of the sub-system (Akyildiz and Kasimoglu, 2004; Dressler, 2008).

The concepts of Big data, Industry 4.0, Industrial internet and Industrial internet of things (IIoT) all share some characteristics and are often linked to IoT, but diverge somewhat on how they interact with the paradigm. For the sake of clarity, these will be described in short.

A definition of Industrial internet is: 'An internet of things, machines, computers and people, enabling intelligent industrial operations using advanced data analytics for transformational business outcomes'. As such, the Industrial internet could be viewed as a sub-category of IoT. Likewise, Industry 4.0 and IIoT describe the same general idea and could be placed under the umbrella of IoT (Industrial internet consortium, 2015).

The Industrial internet consortium (IIC) lists the industries: energy, healthcare, manufacturing, smart cities, and transportation as promising areas (IIC, 2016). This list points to possible starting points for the likely industrial IoT-revolution.

Big data is an abstract concept with diverging opinions on its definition, although the importance have been established (Chen et al., 2014). A 2011 definition of the concept is a "new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling the high-velocity capture, discovery, and/or analysis" (Gantz and Reinsel, 2011). With this definition big data may be characterised by four V's – volume, variety, velocity, and value.

Economic Impact of and the Molde Region's Affinity to IoT

In understanding why iKuben/ProtoMore focus on IoT and why established companies see value in the paradigm one has to understand its rapid and massive introduction to the marketplace.

Several reports on IoT have in the last years been published. The consulting company Mckinsey estimated that linking the physical and digital worlds could generate between $3.9 to $11.1 trillion a year in economic value by 2025 (Manyika et al., 2015). While analyst from the American research and advisory firm Gartner predicts that there will be close to 26 billion interconnected devices by 2020, a 30-fold increase from 2009 (Rivera and van der Mulen, 2013). Traffic monitoring of a cellular network in the U.S. also showed an increase of 250% for machine to machine (M2M) traffic volume in 2011 (Safiq et al., 2012).

Combined with the knowledge that the number of connected devices in 2010 surpassed the human population (Evans, 2011), connectivity could be a trend on the scale of how smartphones penetrated the cell phone market. And it could be predicted as Miorandi does that within the next decade, the internet will exist as a seamless fabric of classic networks and networked objects (Miorandi et al., 2012). In short – most reports and research points to an exponential increase in usage and monetary value the coming years.

In Norway, the two powerhouses for product development Eggs design and Inventas, have recently launched departments into connected devices. With Smartlab and «Connected World» the companies want to expand into a space where more of the new product development happens in the cross-over between expertise in design, electronics and mechanics.

In 2017 the mobile operator Telia will launch a LTE-product marketed for IoT-interested in Norway. The product will utilize their 4G network, and are already in limited use in Oslo for locating parking and in agriculture for automated watering

(Telia, 2016). From this one may see the contours of experts in the marketplace (Inventas and Eggs design) and infrastructure investments as the first signs of mass introduction to the Norwegian market.

iKuben and ProtoMore

iKuben and ProtoMore is co-located at Molde Kunnskapsparken. iKuben is a cross-industrial cluster that focuses on digital innovation and helping the industry to utlize the industrial internet by information sharing and hosting ProtoMore. As of now, 35 companies participate in iKuben. Most of these companies are engineer-to-order and could be categorized as part of the ocean industries. Seven employees are currently affiliated to ProtoMore and iKuben. ProtoMore is prototyping workshop that has developed its own method and holds product development sessions with companies.

iKuben was awarded «Arena status» in 2012 the lowest level of the programme «Norwegian Innovation Clusters» administered by Innovasjon Norge, Norges Forskningsråd and SIVA. This program will continue until the summer of 2017 if it is not renewed again as in 2015.

Research on familiarity and usage of aspects in IoT have been performed earlier by Carl Christian Sole Semb and Lise Lillebrygfjeld Halse, an associate professor at Molde University College, on the Molde-region. Expert users with knowledge to the companies described them to understand sensors, partly understand networks, and lacked knowledge about data filtering and data mining (Semb, 2016).

A questionnaire (N=23) done as part of a larger four-year study called Manufacturing Network 4.0 on CEO’s affiliated to iKuben revealed that (Halse et al., n.d.):

- 9/23 companies have sensors for controlling or moving things during production
- 7/23 have online control over processes
- 8/23 have computer controlled preventive maintenance
- 7/23 are using external data in production management
- 3/23 are doing track and trace production

These results indicate that some companies are utilizing data on certain areas of their business, but not on the whole organization.

Early Phase Product Development

By working iteratively and deploying a range of techniques to produce repositories on industrial internet as basis for decision making is made.

Empathize

In order to learn more about the context of the project, ProtoMore, and local practitioners of the industrial internet, Molde was visited on two occasions. On these visits local entrepreneurs, CEO’s, engineers, designers, Innovation Norway, politicians, employees of ProtoMore and iKuben, and a researcher on industry clusters were interviewed.

On the first visit, learning about iKuben, ProtoMore, affiliated companies and local entrepreneurs were prioritized. On the last visit, ProtoMore and iKuben rebranded themselves and invited key stakeholders in the region including some national figures working with innovation or politics. Due to time limitations, participation in a workshop seminar was unfortunately not done. This could have shed light on how companies work and think about the industrial internet and prototyping in a different setting. To offhand this, both of the two main facilitators were interviewed on how they performed the seminars, how the participants behaved at and in-between the seminars.

Figure 3: Jan Tore Sanner equipped with VR-googles tries to fix a robot in the Portal video game universe at the last Molde visit.

These visits revealed several aspects of ProtoMore and its ecosystem which were used as a foundation for the later work:

1. Workshop seminars run in collaboration with Inventas were one of the main services provided to companies. In these sessions companies specialized in IoT meet with traditional manufacturers. Through these sessions new concepts and ideas are also developed in-between. ProtoMore have established a framework for these sessions.
2. Few companies and entrepreneurs took regular use of the workshop outside of the planned sessions.
3. Most of the employees at ProtoMore are focused on business development or other non-technical work.
4. Most of the prototypes were of the same fidelity and there was no permanent installation of higher fidelity on the industrial internet.
5. There was a strong wish to have one or more working prototypes to explain key concepts in the industrial internet.
6. It seems like CEO’s and entrepreneurs were more involved with ProtoMore than heads of development in mature companies.
7. Entrepreneur and business development courses are regularly held in the workshop. These sessions are scheduled long in advance and limited availability of prototyping tools, and could increasing the bar for dropping by the workshop.

Ideate

To produce a wider array of solutions several ideations techniques were deployed.

Sessions with ProtoMore

Together with the ProtoMore co-supervisor, Carl Christian Sole Semb, a session was held on the different applications of sensors. With pink coloured post-it notes ideas were written down on objects and rooms in ProtoMore. This approach tried to include rethinking how different objects and spaces could apply in an IoT-setting.

Different groups of ideas emerged and were later loosely evaluated based on novelty and feasibility. This exercise was partly held to get the most obvious solutions on the table to move into interesting ones. From this ideation session some underlying principles emerged which were used later on in talking about value generated by II:

- Measure usage
- Monitor harmful/unwanted usage
- Trace objects in space and time
- Give feedback to users
- Increase knowledge on maintenance needs

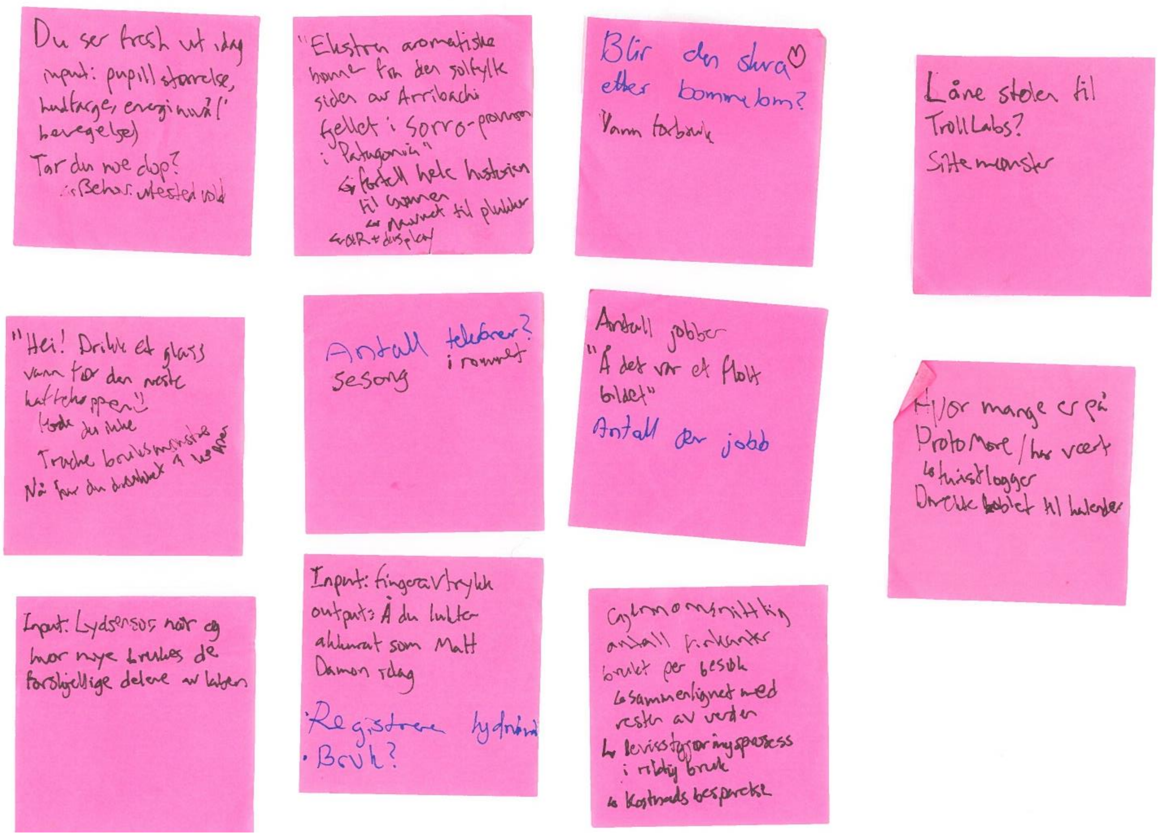

Figure 4: Some of the post-its achieved from the sessions and used later on. Some of these are incorporated in the repositories.

Sessions with TrollLabs

Following a learning cycle on how companies are using sensors and more knowledge about their usages, fellow student Even Jørs joined in for an ideation session at TrollLabs. Through storytelling on earlier ideas and concepts a new brain storming sessions helped further develop two ideas:

- Using audio to say how and when a room is used.
- Using sensors to say how and when certain small tools in the workshop were used.

Based on ProtoMore's explained needs and an interest in measuring and quantifying usage, a concept of using audio to determine room usage was developed. As seen in figure 5 and 6, ProtoMore could be partitioned in smaller areas. The idea was to show visitors of ProtoMore an IoT system from sensors to visualisation, and such help to explain some of the main problems and opportunities in the IoT space. Tracking small tools usage is explained in the repositories.

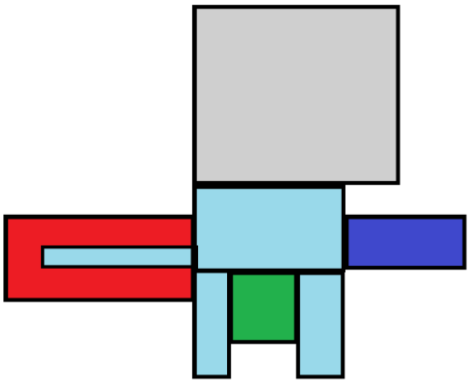

Figure 5: These two figures show a simplified overview of ProtoMore. On the left the rooms are coloured after type: red – offices, light blue – halls and common areas, blue – wardrobe, gray – workshop, green – conference room.

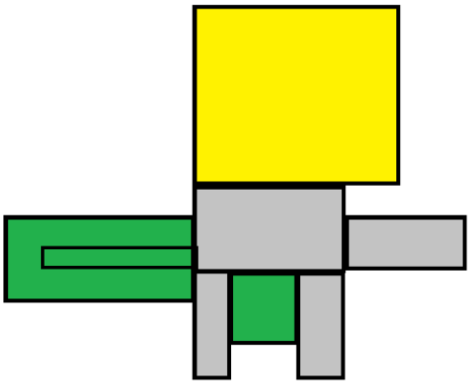

Figure 6: The rooms are now coloured after usage. The workshop is yellow signalling usage of machines while green means there is talking or background noises associated with work.

Repositories

The repositories are a result of ideation sessions, interviews and work done throughout the project period to archive findings. The five principles mentioned above worked as a rough tool for categorizing some solutions, but have not been explicitly noted in the repositories.

Repository 1 – Sensor Applications Already Implemented:

This repository notes some of the companies and implemented solutions that are available online and could be used for inspiration:

1. Passive RFID-tags have been used by different retailers with some success. One example is venture backed Byte Foods that uses passive RFID-tags inside commercial refrigerators to track stock and sales. Every item sold through Byte Foods has a tag, which enables the refrigerators to be located unsupervised in offices and commons areas (Pantry Retail, 2016).
2. The Fiber Bragg Grating (FBG) optical sensing technology is being used in the maritime industry to track hull fatigue and stress in real-time. When the optical sensors are stretched specific wavelengths are reflected back to a sensor (LightStructures, 2015).
3. Tiny integrated circuits with battery life up to 15 years are being introduced to the market. A Norwegian company called Disruptive Technologies have introduced three sensors for the commercial and consumer segment that allows for one specific task each. The sensors then communicate with a router connected to the world wide web. Examples of sensing are temperature measurements, proximity, and touch (Valmot, 2016).

4. For analysing group interaction Alex Pentland of MIT Media Labs has developed a sociometric badges that measure the amount of face-to-face interaction, conversational dynamics, physical proximity to other people, and physical activity levels using social signals derived from vocal features, body motion, and relative location (MIT, 2011).
5. The smart home market is growing with some mature companies. Typical sensors are temperature and smoke detectors.
6. A portable system for detecting gluten have been made by a venture-backed American company. Uses Bluetooth and needs three minutes to determine if there is more gluten than 20 ppm (Nima, 2016).
7. An autonomous sensor drone has been developed to monitor conditions in fish farms. Oxygen, temperature, light levels, and salt concentrations can be measured by repeatedly sinking down and floating up to the surface to transmit data (Vasenden, n.d.).
8. A robot equipped with ultrasonic and camera sensors is able to measure water pipe leakage (Sæter, n.d).
9. Wearables in different shapes and forms. Fitbit, smartwatches, and smart headsets are just some of the smart devices people are starting to wear. Kickstart has in the start of the year close to 500 fully funded projects with the phrase “wearables”.
10. In monitoring food intake, a variety of factors starting from the diet composition to frequency, duration and speed of eating, can be relevant health issues. Most measures of food intake are done by self-reporting, and a study wanted to get a better understanding of what people ate since there are large discrepancies in self-reporting studies. By using a microphone in the ear canal, the scientist could differentiate between a small pre-defined range of food types (Amft et al., 2005).

Repository 2 – Objects That Could Be Measured in a Workshop Setting

Things one may measure in the workshop of ProtoMore, TrollLabs and/or Realiseringslaben, a mechanical workshop at NTNU, that could reasonably add some value:

1. Laser Cutter
2. Mill
3. 3D-printer
4. Paper printer
5. Window and/or walls used for project work
6. Ventilation canal
7. Small tools racket(s)
8. Elevator connected to TrollLabs
9. Entrance doors to workshop
10. Soldering station
11. Electrical socket(s)
12. Dremel rotary cutting tool
13. Moveable squares or chairs
14. Table(s)
15. Storage shelfs
16. Copy machine – paper (ProtoMore)
17. Coffee machine (ProtoMore)
18. Lathe (Realiseringslaben)

19. Welding station for MIG/MAG/TIG (Realiseringslaben)

Repository 3 – Possible Sensor Applications in a Workshop Setting

List of possible sensor types and usages that could be applied in a workshop setting. See the literature case on mill for repository on examples of measuring a single machine or process.

1. Microphones are widely used for recording how machines are used. Many machines and tasks generate repeated and similar sounds when used. This attribute opens up for using frequency domain analysis to register whether anomalies occur. See prototyping on audio for more explanation.
2. Microphones may be used for measuring human activity in the workshop.
3. Vibration sensors operate in the space between accelerometers and microphones. A frequent method is to generate electricity in piezo elements that could be further amplified. See prototyping on laser cutter for more explanation.
4. Current sensor - power consumption for the entire workshop or one machine may contribute in revealing usage patterns or activities such as tool usage and total prototyping activity.
5. Machine vision – could be used to measure movement in the lab, tool position, and the number of people present.
6. Oxygen sensor and/or air contamination sensor – in for example the ventilation canal intake to possibly measure tool (miss)use or people present. A caveat is the amount of possible unknown variables such as open windows or doors that could affect the result.
7. Current drawn from electrical sockets for soldering or small tools could monitor usage or potential failure. See section on mills for ore explanation.
8. Weight sensors have been used successfully by several companies to monitor inventory and produce meaningful analytics for resupply. Measuring variations in of storage or small equipment rack(s) could say something about activity and usage.
9. Photoelectric sensor for light usage as a proxy for activity. Monitoring when lights are on could work as one of many sensors to monitor facility usage.
10. Motion detector for movement in the workshop or at specified points such as doors to measure activity in general or traffic into or inside the workshop.
11. Infrared sensor – measure heat from tools or people as a proxy of activity and usage.
12. Proximity sensors can be used on multiple objects and locations for checking if something is open or closed.
13. Humidity, moisture, oxygen, and air contamination sensor could monitor working conditions and be paired with metrics for productivity or wellbeing.

Repository 4 – Enabling Technologies

This list is not exhausting of protocols and technologies that allows for communications between nodes of an IoT installation, but these cover some the most important bases (Want et al., 2015; Al-Fuqaha et al., 2015):

1. Radio frequency identification (RFID) was considered in the early 2000s as one of the most likely components of IoT (Want, 2004), and a new standard called UHF RFID was developed. Due to poor performance in retail trails where not all

RFID-tags could be read the technology is now less hyped, but it is still regarded as a key enabler.
2. Near-field communication (NFC) is rooted in RFID and are becoming more widely used for contactless payment and reading NFC-tags. One of the main reasons for the NFC-optimism is the increase in smartphones that are NFC-enabled.
3. Optical tags also compete in the low-cost tagging space with the quick response (QR) codes as the most popular 2D optical standard (Kato and Tan, 2007).
4. Bluetooth low energy (BLE) could be viewed as more high-end tagging technology than those RFID-rooted. In its most scaled down version, BLE can be used as a low-power electronic tag that could operate up to a year on a lithium coil cell battery. All modern smartphones come with BLE-hardware.
5. New wireless infrastructure protocols that require low energy. Two promising protocols are the 6LowPAN and the Routing Protocol for Low Power and Lossy Networks (RPL) also based on IPv6.
6. ZigBee is a communication technology that is based on IEEE 802.15.4 for low-rate wireless private area networks. Has a relatively low power consumption, low data rate, low cost, and high message throughput while maintaining a high level of security, encryption and authentication services.
7. Long Term Evolution—Advanced (LTE-A) is a set of cellular communications protocols that is well suited for machine-type communication (MTC) and IoT infrastructure (Hasan, 2013).
8. Z-wave is low-power communication protocol for Home Automation Networks (HAN), and operates up to 30 meters. It is specified for applications using tiny amounts of data.

Prototyping Audio: How does Sound Describe Room Usage

Following the ideation sessions, it was decided to learn more about audio since it has been applied in many situations for analysing machines and could possibly be used to describe room usage.

A regular acoustic assumption is that rooms smaller than a regular classroom may ignore the directional property of sound. Since most of the rooms in ProtoMore and at TrollLabs fulfils this criterion one microphone should be able to pick up approximately all sound generated, but one should have in mind that sound strength decrease with distance.

At first the plan was to use an Arduino-based prototype for recording and archiving the sounds. The system works well with BLE and could easily be interconnected if the first tests worked well.

The first iterations showed the signal to be too poor to be properly analysed due to its low amplitude. To amplify the electret input-signal a LM358 operational amplifier was used to some success.

Due to the Arduinos low sampling frequency, said to be 9165 Hz (Stackexchange, 2014), it was decided to instead use a stereo handheld microphone with 44 100 Hz sampling frequency to get more data points and better resolution than the Arduino's 1024. The new approach lacked the Arduino's scalability, but sped up the data gathering phase and had more flexibility when analysing in both the time and frequency domain.

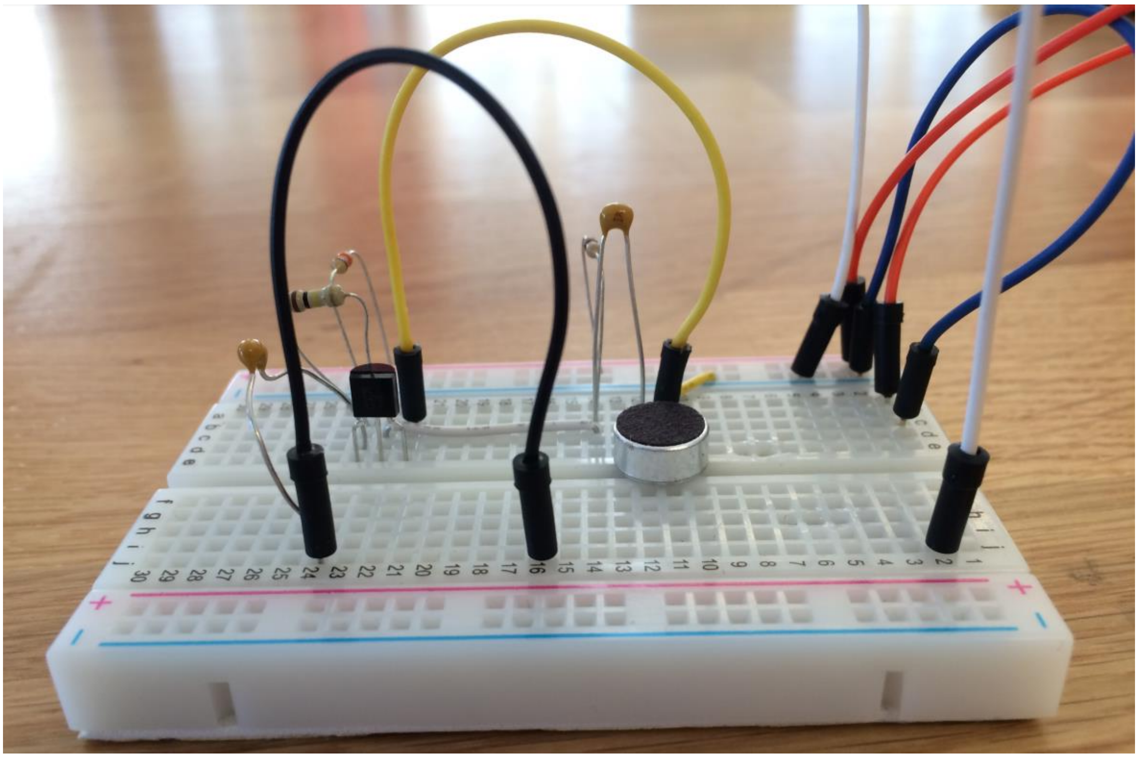

Figure 7: An electret microphone setup that was connected to an Arduino Uno in an earlier build.

Signal Processing

The handheld microphone recorded six different sound settings that then were compared using a free sound visualizer (Accattatis, 2016). Most of the graphs are in the 0 to 8 000 Hz-range due to frequency staying on a far lower level and will therefore most likely have less value in further analysis. These values below -120dB can therefore be removed by a low-pass filter since few data point above 8 000 Hz contributes in a meaningful way. Note also that the y-axis is in decibel which means that for every ten dB the power of the signal increases by a magnitude of ten, alas: 30 to 40 dB equals 1 000 to 10 000 in signal strength.

The two main approaches to signal processing of sound and vibration is whether to analyse in the time or frequency domain. Simplified one may say that machines are best described on the frequency spectrum, while speech is often understood in the time domain.

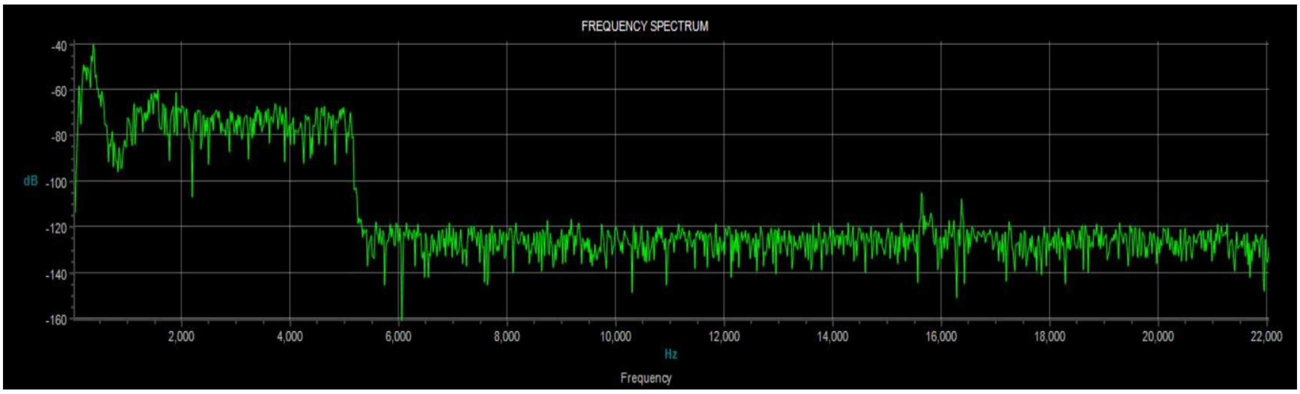

Figure 8: Full frequency spectrum of an active laser cutter. All sound recordings showed a similarly large drop in signal strength around the 5 000 to 8 000 Hz. Later graphs are therefore cut-off at their respective cut-off points. Smoothing windows used: Hanning. FFT sample size 4096. Sample taken at a random place in sound recording. Same parameters for three following figures (Accattatis, 2016).

Figure 9: Laser Cutter frequency spectrum from only 0 to 6 000 Hz.

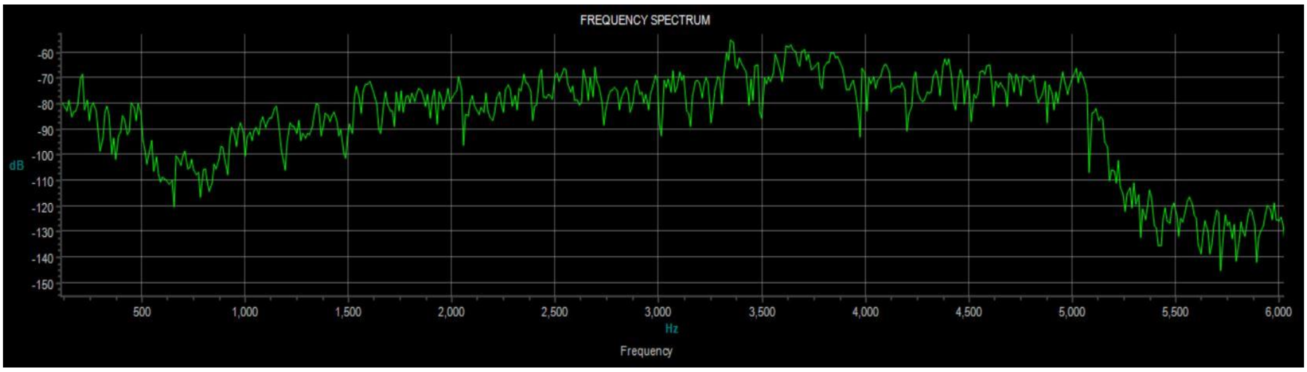

Figure 10: Dremel rotary power tool on the frequency spectrum 0-6 000 Hz.

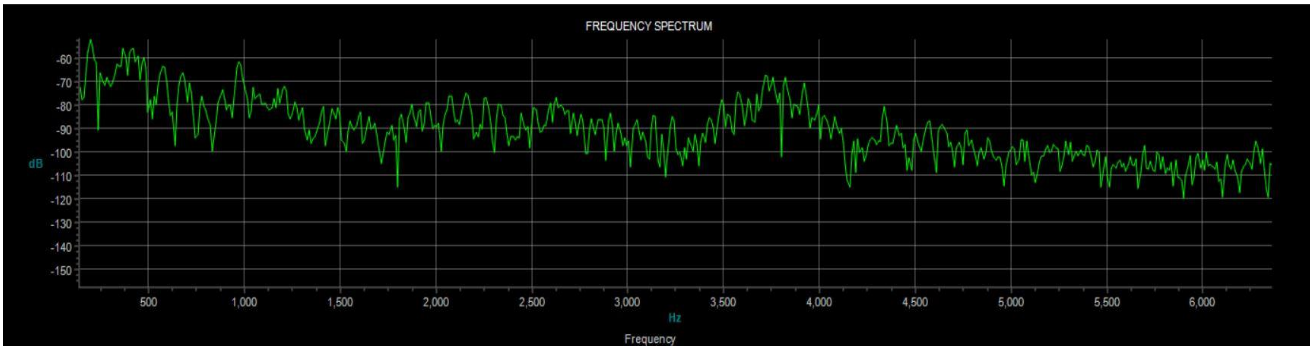

Figure 11: Conversation on the frequency spectrum 0-6 500 Hz.

Test setup for the Audio Experiment

The handheld microphone was used on several locations and on different activities. The four audio recordings were analyzed in Matlab using the signal processing and neural network toolbox (A1). These sound settings were used:

1. Milling aluminium
2. Laser cutting on MDF
3. Conversation
4. Office work without conversations

Using a frequency analysis, the hope was that (3) and (4) would have larger variations in frequency pattern than the two machine samples. As such, a machine learning algorithm could then classify to be distinct. The thinking behind this assumption is that state (4) has far less signal strength, less changes than state (3) and that speech tends to repeat certain frequencies.

Sampling frequency were 44 100 Hz on all recordings, and when combining both the right and left microphone 140 to 284 snippets of sound with length of 40 000 data points (~ 1 second) were made for each recording. After performing a fast fourier transformation (FFT) using the pwelch Matlab-function the frequency range is 0-8 000 Hz.

Matlab's neural fitting tool (nftool) was used with 10 hidden layers, 8 000 inputs (frequencies), 880 samples, and four outputs. Samples were partitioned to have 15% for validation and 15% for testing.

Results from Audio Experiment

An initial test revealed as expected that four random mill samples had come overlapping frequency spikes (figure 12). The same could be said for the laser cutter (figure 13). In figure 14, both the conversation and background noise hint to some type of repetition that could be quantified in a machine learning algorithm.

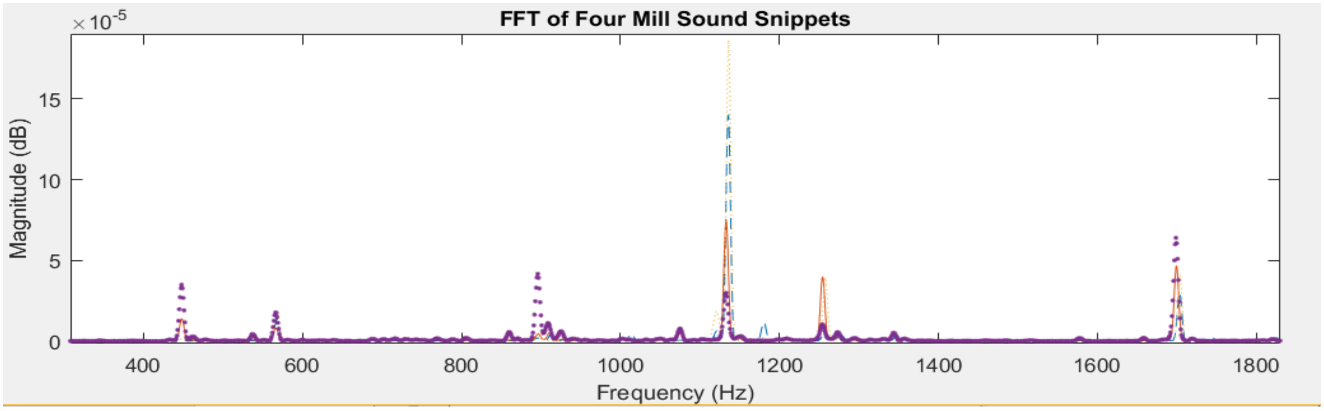

Figure 12: The two largest frequency peaks (1150 and 1700 Hz) seem to be similar for all four samples. Each color corresponds to one sample.

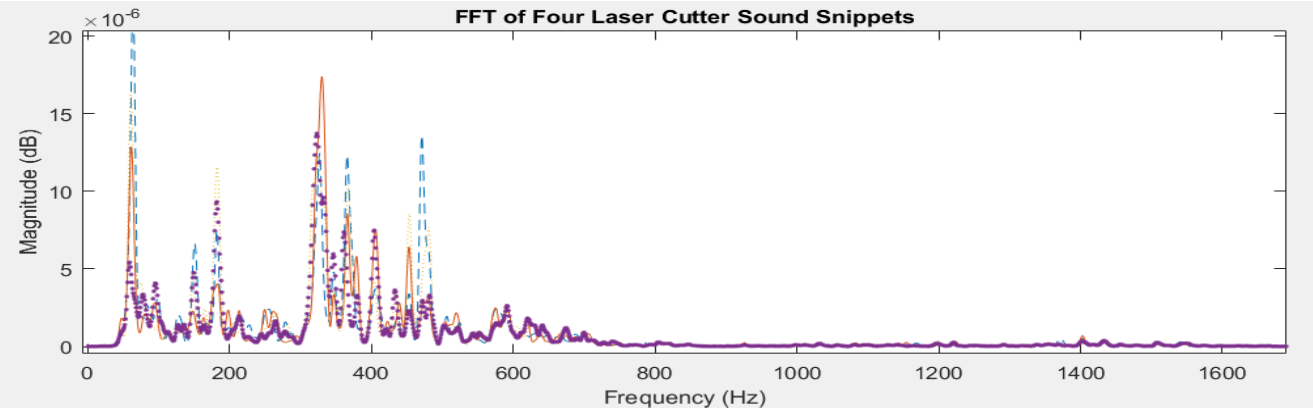

Figure 13: Frequency peaks are located in similar areas and far away from the mill. Each color corresponds to one sample.

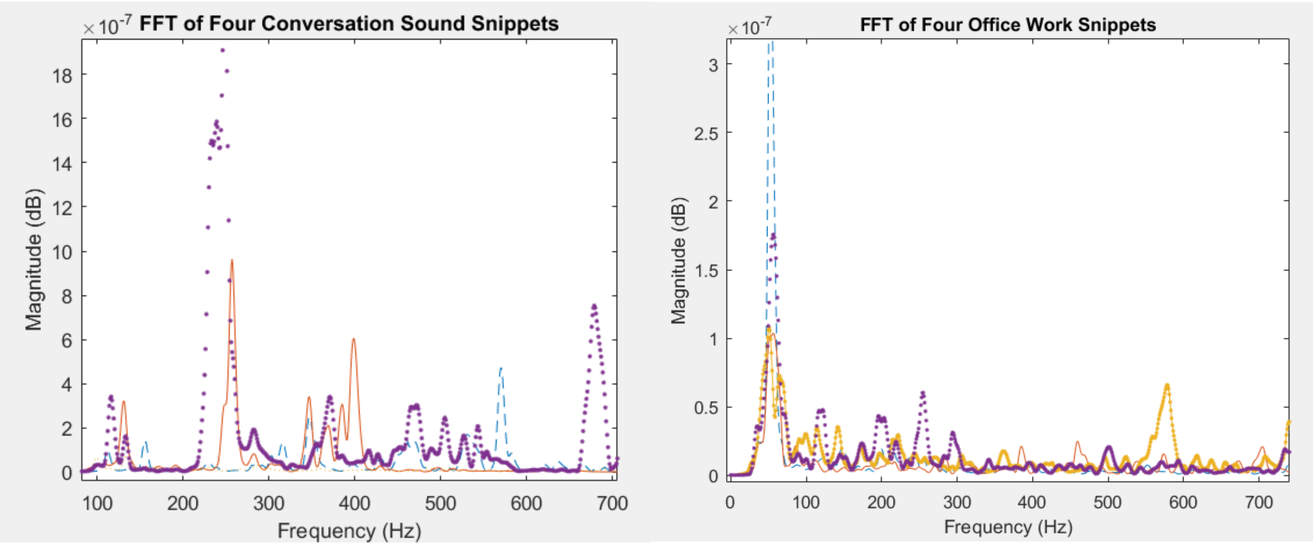

Figure 14: Conversations and background noise at the office is far lower than the machine noise and distinct from each other. Each color corresponds to one sample.

The neural network and simple illustrations show that machine sounds, conversations, and office background noise can be classified reasonably with a microphone. At the same time, only one conversation between three people was used and there is a 13% misclassification error between the audio recordings of conversation and background noise.

Combinations of sounds and sound directional property would all make a setup less likely of working in semi-real time. Normalizing the data set to accord for distance to sound source has also not been done which could be a problem when generalizing the setup.

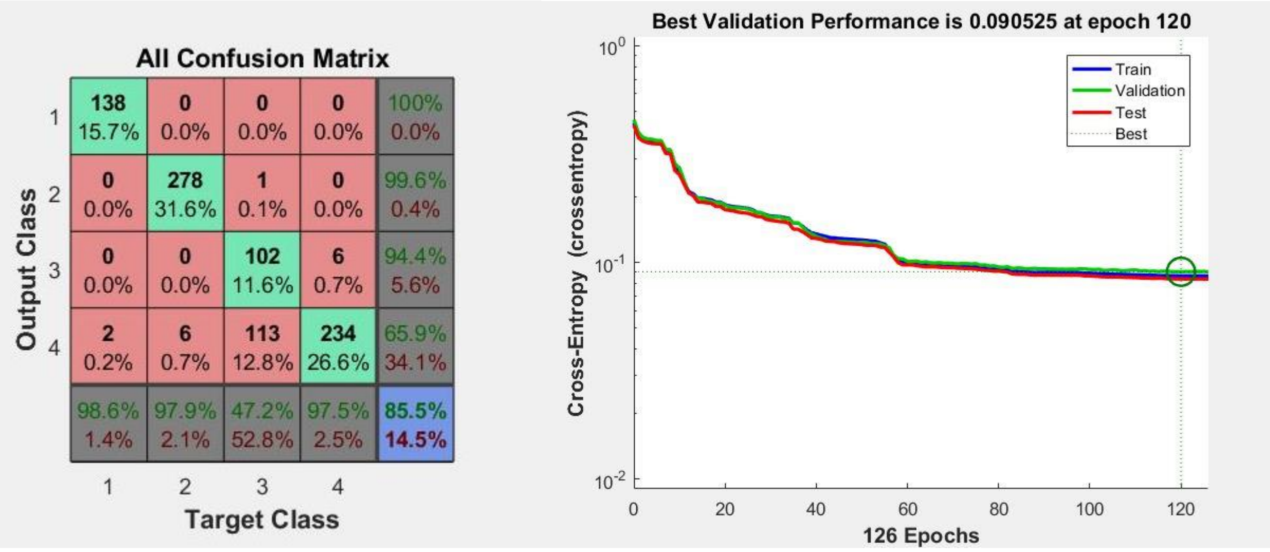

Figure 15: The confusion matrix and the cross-entropy graphs shows that the data set did not over fit and had an error percentage of 14.5%.

Implications

The prototype shows that frequency domain analysis works for classifying speech from background and machine noise. A setup as described above could be made to visualize an activity which is easily registered when present, but burdensome to monitor over time. A groups of Raspberry Pis with off-the-shelf microphones could be interconnected and produce near-real time monitoring of a facility like TrollLabs or ProtoMore.

How Have Sensors Been Used on Mills?

Sensors have on multiple occasions been used for analysing specific machines for failure in different forms. Focusing on one machine enables for more limitations and therefore depth. The mill was chosen due to its rich literature and availability at NTNU if practical work were to be done.

To learn more about what values sensors could create, workshop technicians and a professor at the Department of Production and Quality Engineering at NTNU were interviewed and research literature on the topic reviewed.

Børge Holen, and experienced workshop technician at NTNU, describes sound and vision to be his most important senses. For monitoring machines, sound is the main way of picking up anomalies and he speaks of four different regular misuses: machining too hard, too fast, too dry, or with tools near failure. These produce sounds he recognize even from afar.

In literature, a natural first stop is the introduction Intelligent Machining Modules (IMM) in the industry that enables manufactures increased real-time analysis of machining operations. IMM run digital signal processing boards with analogue sensor signal processing capabilities. This allows for simultaneously running tasks as adaptive control, tool condition monitoring, chatter detection, process control (Altintas, 2012).

One paper shows how one may indirectly measure cutting force by analysing the currents drawn by AC feed-drive servo motors. As such, they were able to produce and implement an adaptive cutting force controller (Kim and Kim, 1996). Also utilizing currents drawn, one paper presented a method for detecting tool breakage in milling within one spindle revolution by filtering the average current signals at tooth passing periods (Altintas, 1992).

Chatter may occur due to machining vibrations which degrade the workpiece surface and could damage the machine. One strategy is using a microphone to detect chatter by analysing the sound spectrum (Smith and Delio, 1989). Their work was expanded on, and a later study showed that stable milling results in a distributed spread of frequencies compared to unstable milling that had certain far higher frequency spikes. Usually the chatter frequency was over 400 Hz, and could have several smaller spikes on higher frequencies. Their setup was sampling five times the frequencies measured (0-3600 Hz), which resulted in an 1800 Hz frequency range (Altintas and Chan, 1992).

Other methods are eddy current type gap sensors and plate dynamometers under the workpiece analysed in the time and frequency domain (Hashimoto and Marui, 1992) and using a laser displacement sensor analysed in the time domain (Gradisek et al, 1998).

Laser Cutter Experiment: How does Vibrations Describe Machine Usage

The case study above reveals that there is ample research on specific machines, especially those closely related to traditional machining. Searches on Google Scholar revealed no research on the laser cutter fitting this experiment.

For a first quick iteration a standard Arduino script made for detecting knocking was used (Arduino, 2015). One 1M ohm resistor was used in combination with a piezo vibration element. The piezo vibration sensor transforms vibrations into voltage.

To improve sensitivity, different resistors was tried out before introducing an operational amplifier. Due to needing only magnitude and frequency, an inverting amplifier setup was used. To tune the operational amplifier, the built-in serial plotter tool in the Arduino software (version 1.6.13), was used on different surfaces with different input. Of the three possible sensor, a small enclosed piezo sensor was chosen mostly due to versatile mounting capabilities (see figure 18).

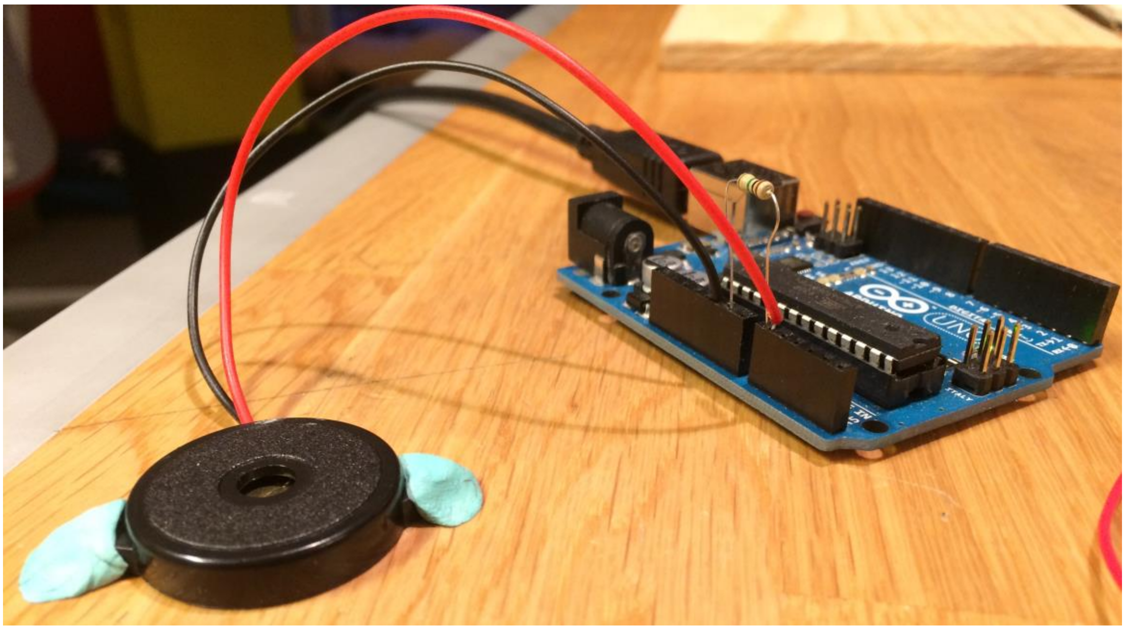

Figure 16: First iteration of test setup. Lightly modified knock example script and the least complex wiring was used to test three different sensors, their sensitivity and,

possible types of mounting to surfaces.

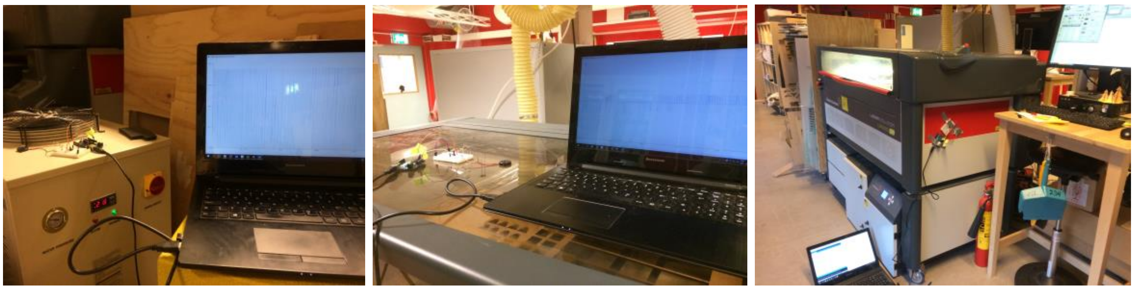

Figure 17: The laser cutter external fan, lid, and right-hand side were tested to better understand of expected amplitudes and what types of data one could acquire by using the built-in serial plotter. On the right-hand side, the red area was of a metallic material which did not reduce vibrations like other plastic surfaces.

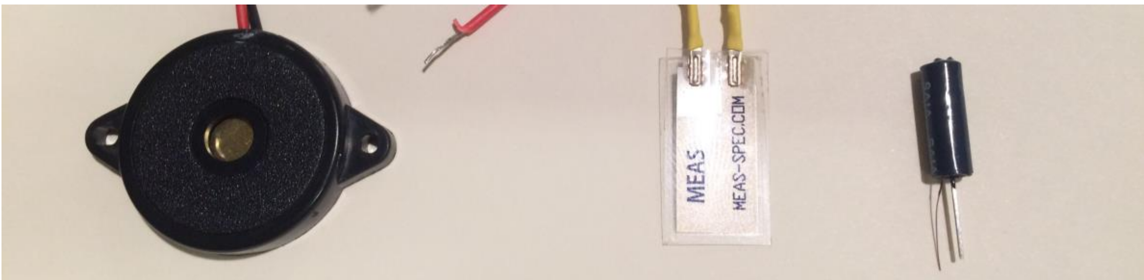

Figure 18: An enclosed piezo vibration sensor (left), a piezo film sensor (middle), and a fast vibration sensor switch (right) were tested.

Test setup for Vibrational Output

For the experiment an inverted operational amplifier with 2.13 gain, piezo sensor, and Arduino Uno was used (A2). The goal of the experiment is to determine whether five different machine states can be measured by a vibration sensor. The experiment is partitioned in two: How does power states affect vibrations, and how does machine activities as rastering and cutting affect vibrations. The sampling frequency is the same for all readings, and should be close to 1 000 Hz.

Signal Processing and Visualization

One data point logged as the value 627727 to 627 to reflect the most likely input. All data was then changed from 0-1023 to 0-4 999 mV to better reflect the voltage generated by the piezo element. For visualization and further analysis, the data set was inverted again with 3077,2 mV (628) as the zero-value, to better show when vibrations generated current.

Results from Laser Cutter Experiment

As seen in figure 19 and 20, laser cutter activity is possible to measure with one vibration sensor. When the laser cutter is powered on, internal systems seem to generate consistent vibrations. In this experiment, there was no significant difference between having the external fan on or off, which suggests that the laser cutter does not pick up its vibrations from neither the floor or ventilation cannel.

Foot movement close to the laser cutter and touching of the machine affects measurements in a significant degree. This phenomenon could be viewed in figure 19 for the state «fan on, laser cutter off» were at least two samples produce the maximum sensor output.

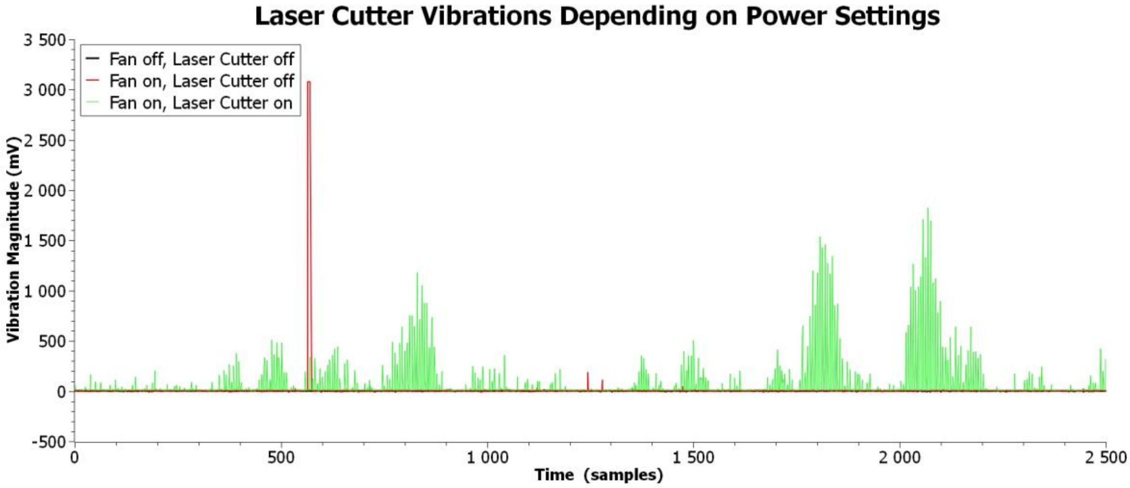

Figure 19: With the power of the laser cutter off, few readings stray away from 0 mV. When the laser cutter is turned on, periodic and somewhat similar vibrations occur.

In the experiment, the circuit was tuned to laser cutting, and not rastering which explains the amount of measurements that surpasses the experiment scale. Since this is an initial experiment where the goal was to determine whether different states could be measured, this is less important. If a later iteration is to be made, a weak lowpass filter could be mechanically introduced to increase the richness of the data gathered. Sensitivity should also be adjusted to meet desired outcome and could easily be higher with the introduction of a non-inverting operational amplifier that allows for 0 mV when there is no electricity generated by the piezo element.

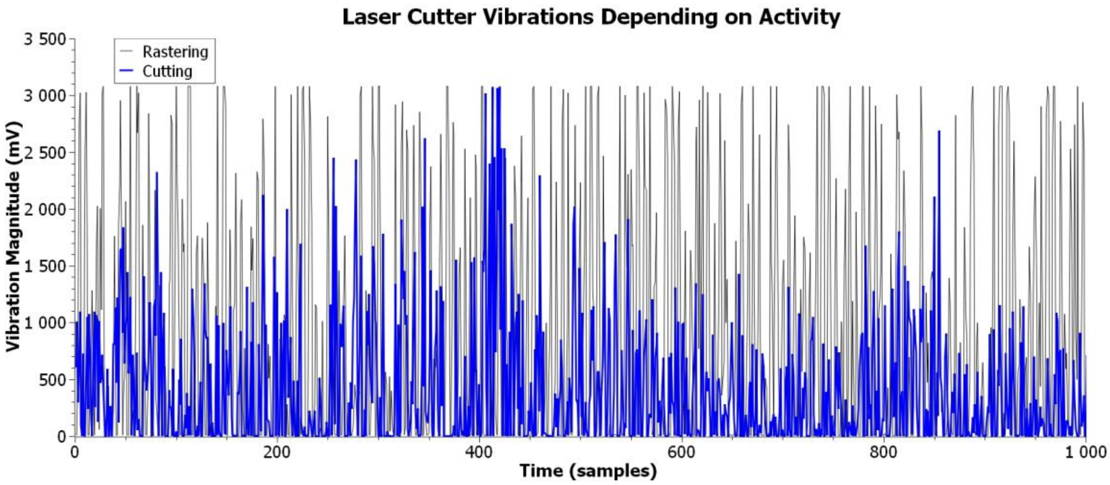

Figure 20: Rastering generates in general more vibrations, and it is more consistent than laser cutting. Setup for rastering: speed 100%, power 13%. Setup for cutting: speed 13%, power 100%. Material cut: MDF 6mm.

From the fast fourier transformation (FFT) one can see that rastering has two distinct amplitudes in the area 0.2 and 0.8 samples which is far larger than any measured for laser cutting. The finding fits well with observations of machine use. In rastering the mirror moves repeatedly from left to right to engrave the surface. This reoccurring activity is the likely reason. For laser cutting, the machine moves slower while the laser beam is on, which creates a significant speed difference between movement. This change could be reflected in FFT for laser cutting.

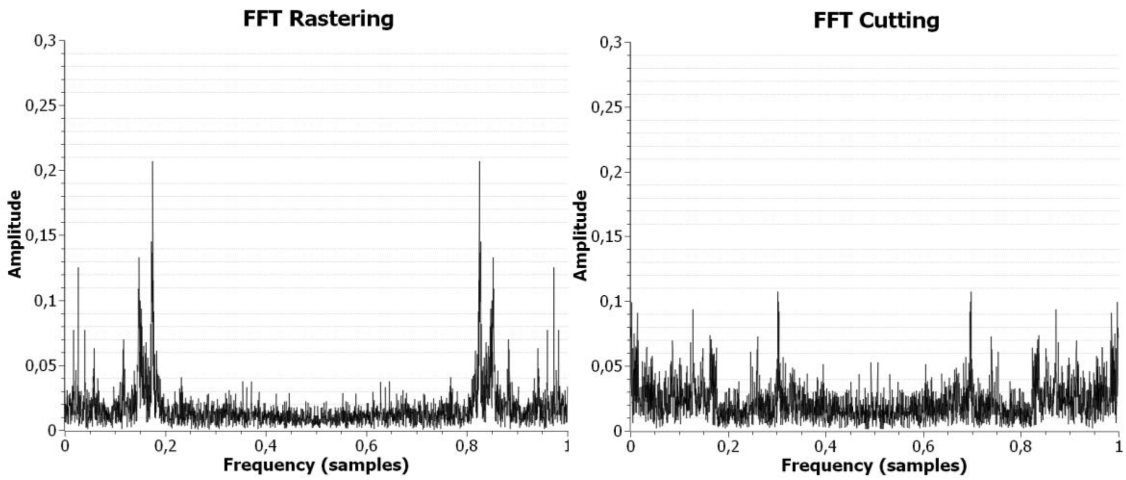

Figure 21: Fast fourier transformations (FFT) for raster and cutting. 2500 samples were used and the amplitude and frequency was normalized to 0-1.

Implications of Laser Cutter Experiment

The prototype shows that the five different states can be differentiated which open up for further experimentation. A logical next step would be to check if all rastering and all cutting can be differentiated, and if categories of these two could be further differentiated. At the moment this prototype could be connected with Bluetooth to allow for semi-real time recording.

When applying different methods for classifying laser cutter activity, a machine learning algorithm should be suitable. From the results, using both dynamic time-warping and frequency domain analysis look promising.

Conclusion

This report has looked into the industrial internet with a focus on how to apply sensors in ways that create novel technical solutions. Methods such as interviews, empathizing, ideation, and prototyping have answered the question of ‘how to fast prototype potential industrial internet solutions in an existing company environment’.

The approach has created a series of repositories and findings that can be summarized as:

- IoT, and in extension II, seem to become more important the coming years.
- iKuben affiliated companies have yet to fully utilize the industrial internet.
- Sensors could be applied to workshops in a value-adding way.
- Sensors can easily be connected by a range of enabling technologies, and rapid prototyping of the sensor module is proven.
- Vibration and microphone sensors can be used to perform monitoring tasks that are burdensome for humans and some use cases are described.
- There are interesting opportunities in combining sensors of different types to produce richer data sets that can further analyzed.

Further Work

Vibration and sound seem to perform well in monitoring machines and facilities. A further study on how to use these sensors, or expand into a new sensor type mentioned in one of the repositories could gain more insight into the industrial internet.

Repository three lists several possible concepts that could be further developed and that would make a workshop uniquely suited for learning about the industrial internet.

An interesting next step would be to quantify how or what is prototyped at the workshop using multiple sensors that are wirelessly connected. Combined with other metrics or measurements, such as fidelity and novelty of prototypes by the ProtoBooth at TrollLabs, or various other performance measurements, one could gain more insight into prototyping behaviour. TrollLabs is suited in analysing prototyping behaviour since novice and experienced user utilize the lab, there is continues and varied work done, and the users are susceptible for partaking in experiments.

Another interesting venue of applying an industrial prototype of higher fidelity could be seminars held at ProtoMore. These seminars could work as a testbed for specific experiments, since many of the variables can be controlled. These seminars have an established framework, facilitators are familiar with II and willing to participate in experiments, the seminars lasts for one day, and participants and facilitators evaluate the sessions afterwards.

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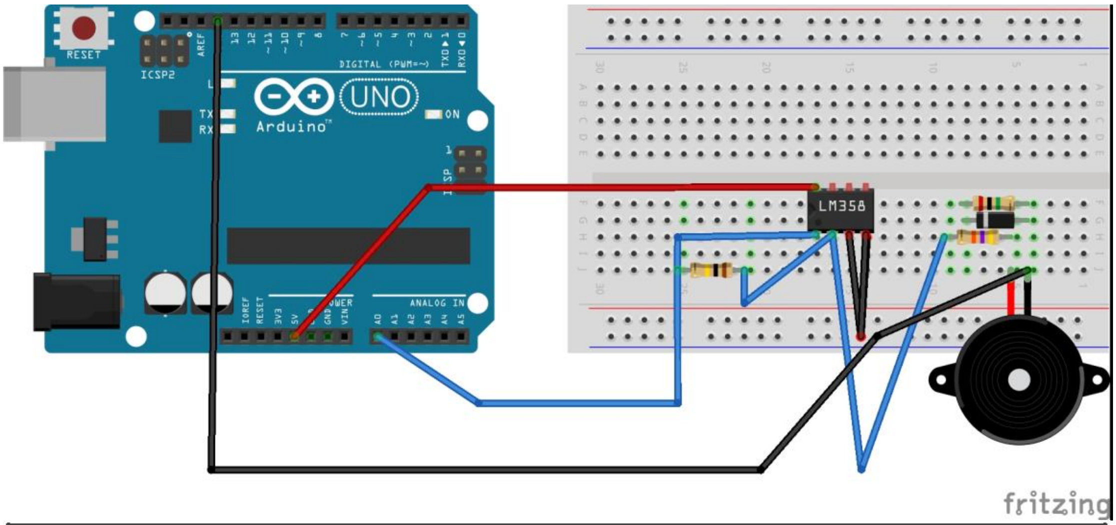
Appendix

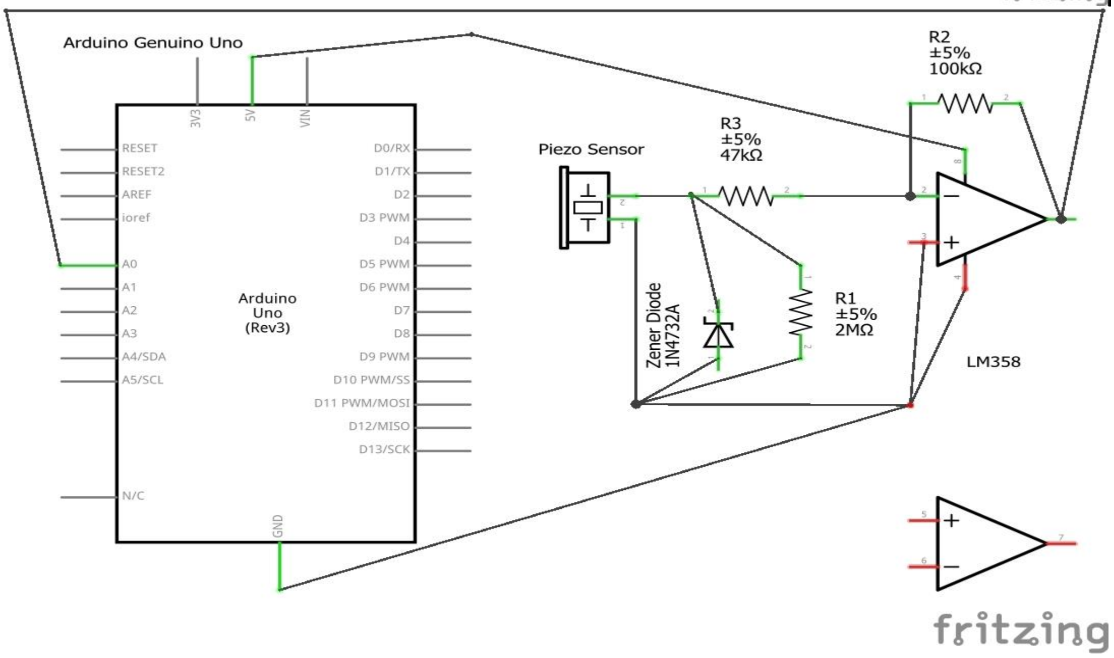
A1: Prototyping Audio

```
%% Matlab script - Import audio file
 [Mill,Fs] = audioread('C:\...\ Fres_ZOOM0007.MP3');
[Conv, Fs] = audioread('C:\ ...\Samtale_ZOOM0009.MP3');
[Work, Fs]=audioread('C: \...\P314_stille_ZOOM0011.MP3');
[LC, Fs]=audioread('C: \...\LC_ZOOM0004.MP3');

%Clean data set
r=40000; %Length of vector taken into pwelch
f_range=0:1:7999; % frequency range

%partition the sound
Data_Mill_1=vec2mat(Mill(:,1),r);
Data_Mill_2=vec2mat(Mill(:,2),r);

%Transpose to fit pwelch
Data_Mill=[Data_Mill_1' Data_Mill_2'];

%Data_PMill gives magnitude of frequency, f gives  frequncy in Hx
[Data_PMill,f]=pwelch(Data_Mill,[],[],f_range,Fs);

Data_Conv_1=vec2mat(Conv(:,1),r);
Data_Conv_2=vec2mat(Conv(:,2),r);
Data_Conv=[Data_Conv_1' Data_Conv_2'];
[Data_PConv,f]=pwelch(Data_Conv,[],[],f_range,Fs);

Data_Work_1=vec2mat(Work(:,1),r);
Data_Work_2=vec2mat(Work(:,2),r);
Data_Work=[Data_Work_1' Data_Work_2'];
[Data_PWork,f]=pwelch(Data_Work,[],[],f_range,Fs);

Data_LC_1=vec2mat(LC(:,1),r);
Data_LC_2=vec2mat(LC(:,2),r);
Data_LC=[Data_LC_1' Data_LC_2'];
[Data_PLC,f]=pwelch(Data_LC,[],[],f_range,Fs);

%% Graph of Mill Different time snippets
%Four Different FFT snippets of Mill

plot(f, Data_PMill(:,10),'--', f, Data_PMill(:,60), '-', f, Data_PMill(:,100),':', f,
Data_PMill(:,120), '.')

xlabel('Frequency (Hz)')
ylabel('Magnitude (dB)')
title('FFT of Four Mill Sound Snippets')

%Find peaks
```

```
[PKS,LOCS,W,P]=findpeaks(Data_PMill(:,10)','MinPeakWidth',6,
'MinPeakProminence',1*10^-6);

%% Graph of LC Different time snippets
%Four Different FFT snippets of Mill
plot(f, Data_PLC(:,10),'--', f, Data_PLC(:,60), '-', f, Data_PLC(:,100),':', f,
Data_PLC(:,120), '.')

xlabel('Frequency (Hz)')
ylabel('Magnitude (dB)')
title('FFT of Four Laser Cutter Sound Snippets')

Pxx1=(Conversation1,[],[], [], Fs);

%% Neural Network
% audioInputs is a 10 000 x 880 matrix of 10 000 frequencies and 880
% samples
audioInput=[Data_PMill Data_PLC Data_PConv Data_PWork];

%audioTarget is a 4x880
a=ones(1,140);
b=zeros(1,140);
T1=[a;b;b;b];

a=ones(1,284);
b=zeros(1,284);
T2=[b;a;b;b];

a=ones(1,216);
b=zeros(1,216);
T3=[b;b;a;b];

a=ones(1,240);
b=zeros(1,240);
T4=[b;b;b;a];
audioTarget=[T1 T2 T3 T4];
```

A2: Prototyping Vibrations





Script, based on the knocking example script

```
const int knockSensor = A0; // the piezo is connected to analog pin 0

// these variables will change:
int sensorReading = A0;      // variable to store the value read from the sensor pin
int ledState = LOW;         // variable used to store the last LED status, to toggle the light
//PrintWriter
void setup() {
  Serial.begin(9600);       // use the serial port
}
void loop() {
  // read the sensor and store it in the variable sensorReading:
  sensorReading = analogRead(A0);
    Serial.println(sensorReading);
  delay(1);  // delay to avoid overloading the serial port buffer
}
```

NTNU	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
HMS		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

Enhet: Institutt for produktutvikling og materialer **Dato: 2016.09.21**

Linjeleder: Torgeir Welo

Deltakere ved kartleggingen (m/ funksjon): Heikki Sjöman, stud.ass./ Martin Steinert, veileder/ Martin Gundersen, student.
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Prosjektoppgave student Martin Gundersen. Prototyping industrielt internett

Er oppgaven rent teoretisk? (JA/NEI): *«JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «JA»: Beskriv kort aktiviteteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.*

Signaturer: *Ansvarlig veileder: Martin Steinert* *Student: Martin Gundersen*

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs workshop.	MG	Romkort	Romkort		
1a	Bruk av roterende maskineri	MG	Maskinens brukermanual	Ukjent	Ukjent	
1b	Bruk av laserkutter	MG	Maskinens brukermanual	Ukjent	Ukjent	
1c	Bruk av 3D printer	MG	Maskinens brukermanual	Ukjent	Ukjent	
1d	Bruk av skjæreverktøy	MG	Ukjent			
1e	Bruk av samenføynigsmidler (lim og lignende.)	MG	Produktets brukermanual og datablad	Datablad	Ukjent	
2	Bruk av Protomore workshop i Molde	MG				Samme risikobilde som TrollLabs

3	Tilstedeværelse ved arbeid utført av andre.	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	
4	Eksperimentelt arbeid	MG	Egen risikovurdering-må gjøres for hvert enkelt eksperiment		Prosessavhengig	

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet (1-5)	Vurdering av konsekvens: Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)	Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
1	Bruk av TrollLabs workshop.								
1a-i	Bruk av roterende maskineri	Stor kuttskade	2	D	A	A	D	2D	Sørg for at roterende deler tilstrekkelig sikret/dekket. Vær nøye med opplæring i bruk av maskineri.
1a-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iii		Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iv		Flygende spon/gjenstander	3	C	A	A	B	3C	Bruk øyevern og tildekk hurtig roterende deler (Fres og lignende.)
1a-v		Feil bruk-> ødelagt utstyr	3	A	A	C	A	3C	Vær nøye med opplæring i bruk av maskineri
1b-i	Bruk av laserkutter	Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1b-ii		Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Bruk hansker ved håndtering av varme materialer.

1b-iii		Øyeskade-laser	2	D	A	A	C	2D	Bruk øyevern! Skru av laser når maskinen ved oppsett.
1b-iv		Brann	2	B	A	D	C	2B	Vær nøye med opplæring i bruk av maskin. Ha slukkeutstur tilgjengelig
1c-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskin.
1c-ii		Innhalering av plast/ printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern/ vernebriller
1c-iii		Feil bruk-> ødelagt maskineri	3	A	A	C	A	3A	Vær nøye med opplæring i bruk av maskin.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk skapre verktøy og riktig skjæreunderlag
1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk skapre verktøy og riktig skjæreunderlag
1e-i	Bruk av samenføynigsmidler (lim og lignende.)	Eksponering på øyet	2	D	A	A	B	2D	Bruk øyevern, ha datablad tilgjengelig
1e-ii		Eksponering hud	4	A	A	A	A	4A	Bruk hansker, ha datablad tilgjengelig
1e-iii		Eksponering åndedrett	4	A	A	A	A	4A	Bruk åndedretsvært/ god ventilasjon. Ha datablad tilgjengelig.

1e-iv		Søl	4	A	B	A	A	4A	Ha papir/ rengjøringsmateriell tilgjengelig. Ha datablad tilgjengelig.
2	Bruk av Protomore Workshop								
3	Tilstedeværelse ved arbeid utført av andre.	Se andres risikovurdering om sikkerhet betviles.	3	C	C	C	C	3C	Hold et øye med hva som foregår rundt deg.
4-i	Eksperimentelt arbeid	Vann-drukning	1E	A	A	A	D	1E	Bruk redingsvest i båt og lignende.
4-ii		Elektrisitet- strøm	3	B	A	A	A	3V	Typisk lite energi involvert. Bruk isolerte verkøty

Sannsynlighet vurderes etter følgende kriterier:

Svært liten 1	Liten 2	Middels 3	Stor 4	Svært stor 5
1 gang pr 50 år eller sjeldnere	1 gang pr 10 år eller sjeldnere	1 gang pr år eller sjeldnere	1 gang pr måned eller sjeldnere	Skjer ukentlig

Konsekvens vurderes etter følgende kriterier:

Gradering	Menneske	Ytre miljø Vann, jord og luft	Øk/materiell	Omdømme
E Svært Alvorlig	Død	Svært langvarig og ikke reversibel skade	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket
D Alvorlig	Alvorlig personskade. Mulig uførhet.	Langvarig skade. Lang restitusjonstid	Driftsstans > ½ år Aktivitetsstans i opp til 1 år	Troverdighet og respekt betydelig svekket
C Moderat	Alvorlig personskade.	Mindre skade og lang restitusjonstid	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket
B Liten	Skade som krever medisinsk behandling	Mindre skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
A Svært liten	Skade som krever førstehjelp	Ubetydelig skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

Risikoverdi = Sannsynlighet x Konsekvens
Beregn risikoverdi for Menneske. Enheten vurderer selv om de i tillegg vil beregne risikoverdi for Ytre miljø, Økonomi/materiell og Omdømme. I så fall beregnes disse hver for seg.

Til kolonnen "Kommentarer/status, forslag til forebyggende og korrigerende tiltak":
Tiltak kan påvirke både sannsynlighet og konsekvens. Prioriter tiltak som kan forhindre at hendelsen inntreffer, dvs. sannsynlighetsreduserende tiltak foran skjerpet beredskap, dvs. konsekvensreduserende tiltak.

MATRISE FOR RISIKOVURDERINGER ved NTNU

KONSEKVENS	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
		Svært liten	Liten	Middels	Stor	Svært stor
		SANNSYNLIGHET				

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge		Beskrivelse
Rød		Uakseptabel risiko. Tiltak skal gjennomføres for å redusere risikoen.
Gul		Vurderingsområde. Tiltak skal vurderes.
Grønn		Akseptabel risiko. Tiltak kan vurderes ut fra andre hensyn.

13 A2 – A Step-by-Step Description of Workflow

Physical interactions:

1. Turn a switch to power on external fan.
2. Turn a switch to power on laser cutter.
3. Open laser cutter lid.
4. Clean lens with cotton and acetone.
5. Select and place the chosen material in the laser cutter workspace.
6. Close the lid.

16. On the laser cutter button interface press the green button to initiate the print job.

Virtual interactions:

Assumes the machine has no programmes running, and that a user is importing a dxf-file.

7. Open the Gravostyle programme.

In the pop-up window “material definition”: Define the size and margins of the virtual workspace.

In the general window:

8. Import the dxf-file by pressing “ctrl + I” or doing so by using the toolbar File --> Import.

In the pop-up window “2D DXF import”:

9. Determine the thresholds for connecting vectors and scaling.

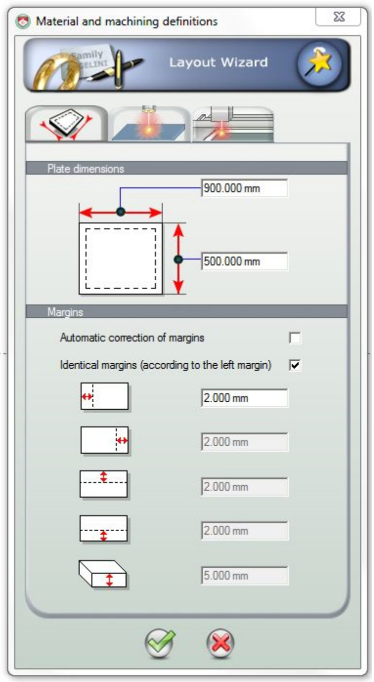


Figure 13.1: In this window, users determine the virtual workspace.

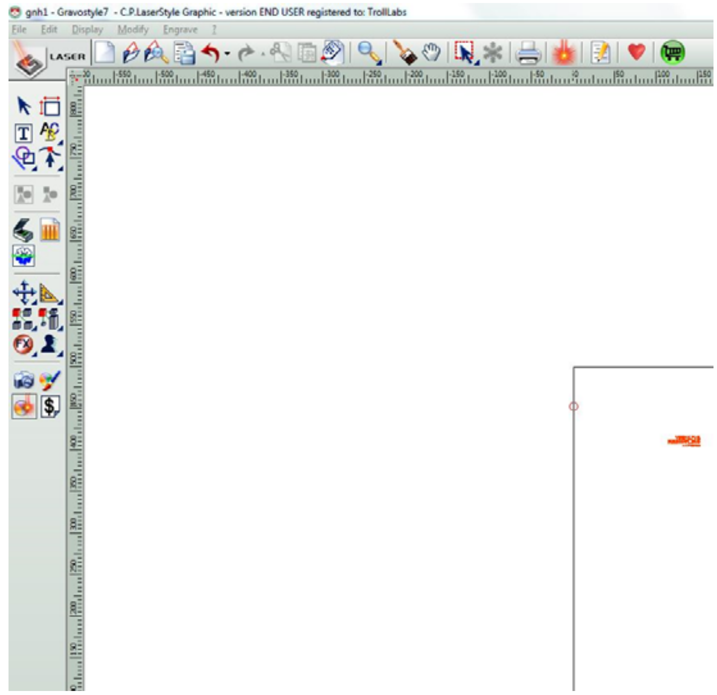


Figure 13.2: The general window has few "signs" (check in with Norman) to guide users along.

In "Laser Colours":

10. Assign colours to the vectors to differentiate them. Check of the right boxes to correctly assign lines or fill depending on

In Marking:

11. Select a material pre-set.
12. Assign laser parameters to colours.
13. Determine "piece origin".
14. Press **Preview…** to confirm the print job is correctly located and the right vectors are shown.
15. Press **Run** to send the print job to the laser cutter.

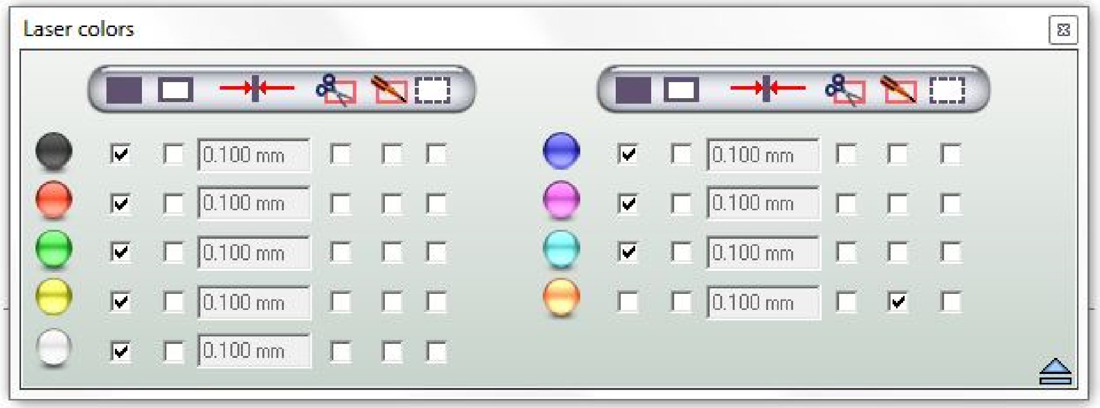


Figure 13.3: Users differentiate between vectors through colouring them. Black is the first colour to be run, and orange the last. The different checkboxes determine whether the encircled area is filled, or if only the vector is coloured.

14 A3 – Recurring Problems or Misuse and How to Troubleshoot Them

What: User forget to turn on the external fan, and may therefore not start the machine.
Consequence(s): The laser cutter will also emit a high frequency sound to remind users of something being wrong and display an error message on the built-in display aswell a red led is blinking.
Fix: Turn on the fan.

What: User do not clean the lens before use.
Consequence(s): The lens has reduced life expectancy and may produce lower intensity laser beam. Will not hinder the job itself.
Fix: Clean the lens and redo the print job.

What: Users forget to secure the workpiece properly before running a job.
Consequence(s): The worksheet traverses while the laser is running, misaligning the material or bending it so the laser is misfocused.
Fix: Put something heavy close by or tape the material to the support beams.

What: The height adjustment is done outside of the work sheet
Consequence(s): If not stopped early enough the mirror piece will be lower than the work sheet and the mirror may be damaged when it moves to the top-left corner to tune the coordinate system before starting the planned job. This could damage the motors, movement system, and mirror piece. Especially the height adjustment mechanism on the mirror piece is prone breakage when confronted with horizontal forces.
Fix: If stopped when the mirror piece is above the material sheet, the job could just be stopped and run again with the correct input. If not, the height adjustment sensor needs to be manually activated when the machine is reset to lower the machine bed.

What: User miscalculate mirror piece origin
Consequence(s): The job is misplaced on the workspace and may damage the mirror piece when height adjusting and cut outside of the material. Severe.
Fix: Change mirror piece origin in Gravostyle 7.

What: User sets a virtual workspace incompatible with the physical one. Often a result of the piece origin not set to the default origin and the virtual workspace surpassing the coordinates allowed in the physical workspace.

Consequence(s): The users will not be told directly if the virtual workspace is smaller than the physical one, but out of bound of the physical workspace. The piece origin will then be changed without explicitly telling the user by a warning. Results then the same as "user miscalculate mirror piece origin".

Fix: Reduce the virtual workspace to fully fit inside the physical one or change the piece origin so the virtual workspace fully fits inside the physical one.

15 A4 – List of Best Practices for Laser Cutter Usage:

1. Clean the lens before use.
2. Be close to the machine when running a job.
3. Laser cut from inner details to outer so that you don't move the work piece.
4. Engrave, then cut.
5. Cut smaller sections such as holes first before cutting out the outer area. This will reduce the risk that the material traverses.
6. When unsure that you have cut through. Don't remove the piece, just poke gently. Run the limited job again cutting the relevant parts.
7. Wait before opening the lid when cutting MDF and other materials that produce unhealthy gasses when cut.
8. Press "preview" before running the job to confirm that all wanted vectors are registered.
9. Look at the mirror piece when height adjusting and hold your finger on the orange button to pause the job if the height adjuster is malfunctioning.
10. Clean up the Gravostyle programme when finished.
11. Clean the bottom of the laser cutter regularly. There is a vacuum cleaner at TrollLabs perfect for smaller pieces.

16 A5 – Questionnaire for FFE Students

Questionnaire on laser cutter usage

This questionnaire is part of Martin Gundersen's master thesis on the industrial internet. In the final report all answers will be anonymized, but they may be linked to other parts of data collection related to the Protobooth and laser cutter.

Some questions are not required to be filled out and could be skipped altogether if they do not apply to you.

If you have any questions, worries, or feedback: Please write in the feedback section at the end or contact me at martin.a.gundersen@gmail.com.

* Required

Email address *

Your email

What is your first and last name? (Optional)

Your answer

What is your field of study? *

- ◯ Mechanical Engineering
- ◯ Industrial Design Engineering
- ◯ Electronics Systems Design and Innovation
- ◯ Computer Science
- ◯ Communication Technology
- ◯ Other: ______

Before starting the course Fuzzy Front End, how would you rate your familiarity with these topics? *

	Not	A little	Somewhat	Very
Laser cutting in general	○	○	○	○
The laser cutter at TrollLabs	○	○	○	○
3D-printing	○	○	○	○
Mechatronics	○	○	○	○
Design thinking	○	○	○	○
CAD software	○	○	○	○
Milling or turning	○	○	○	○

Today, how would you rate your familiarity with these topics? *

	Not	A little	Somewhat	Very
Laser cutting in general	○	○	○	○
The laser cutter at TrollLabs	○	○	○	○
3D-printing	○	○	○	○
Mechatronics	○	○	○	○
Design thinking	○	○	○	○
CAD software	○	○	○	○
Milling or turning	○	○	○	○

If you have used the laser cutter without someone helping you, how would you describe your first time using it "alone"?

	Not	A little	Somewhat	Highly
A success	○	○	○	○
Feeling comfortable	○	○	○	○
Feeling nervous	○	○	○	○
Feeling excited	○	○	○	○
Feeling afraid	○	○	○	○

Would you have used the laser cutter more if there was... (Check of all that apply)

- ☐ Better instructions online or close to the machine
- ☐ Someone present to help with machinery such as the laser cutter
- ☐ "Easier" software
- ☐ "Easier" hardware
- ☐ Other: ____________

What have you used the laser cutter at TrollLabs for? *

- [ ] Course work
- [ ] Personal projects
- [ ] I have not used the laser cutter
- [ ] Other: ____________

On how many occasions have you used the laser cutter this semester? *

- ○ 0
- ○ 1-2
- ○ 3-5
- ○ 5-10
- ○ 10+

If you have never used the laser cutter, why?

Your answer

Have you used the laser cutter at TrollLabs without someone helping you ?

- ○ Yes
- ○ No
- ○ Not sure

Did you at anytime experience one of these reasons for not using the laser cutter or delaying to using it? (Check of all that apply)

- ☐ No written step-by-step guide to help things along
- ☐ Afraid of damaging the laser cutter
- ☐ Intiminated by the complexity of the laser cutter
- ☐ Afraid to ask for help from more experienced workshop members
- ☐ Afraid to be caught as a novice around the laser cutter
- ☐ No experienced members of the workshop around to ask for help if necessary
- ☐ Forgot procedural actions on the laser cutter and therefore gave it up
- ☐ Problems or lack of proficiency with a CAD/drawing software
- ☐ Problems or lack of proficiency with the drawing programme on the affiliated computer
- ☐ Problems or lack of proficiency with the hardware components of the laser cutter such as turning on the fan, cleaning the lens.
- ☐ The laser cutter was out of order
- ☐ None of the above apply to me
- ☐ Other: ____________

Do you feel you recieved enough training and supervision for using the laser cutter?

- ◯ Yes
- ◯ No
- ◯ Maybe

If you took the introduction course to the laser cutter, how content were you with it?

	1	2	3	4	5	
Not content	○	○	○	○	○	Content

How do you feel about there being a system tracking your behavoir and usage of the laser cutter at TrollLabs?

	1	2	3	4	5	
Not content	○	○	○	○	○	Content

Would you mind there being such a system in your future workplace on all machines such as the laser cutter?

	1	2	3	4	5	
Not content	○	○	○	○	○	Content

Do you have a story you want to tell about using the laser cutter, or something else affiliated to it?

Your answer

Thank you so much for participating!

Feedback may also be sent to martin.a.gundersen@gmail.com or speak to me in-person at TrollLabs.

17 A6 – Questionnaire for Master's and PhD Candidates

Questionnaire on laser cutter usage

This questionnaire is part of Martin Gundersen's master thesis on the industrial internet. In the final report all answers will be anonymized, but they may be linked to other parts of data collection related to the Protobooth and laser cutter.

Some questions are not required to be filled out and could be skipped altogether if they do not apply to you.

If you have any questions, worries, or feedback: Please write in the feedback section at the end or contact me at martin.a.gundersen@gmail.com.

* Required

Email address *

Your email

What is your first and last name? (Optional)

Your answer

How would you rate your familiarity with these topics? *

	Not	A little	Somewhat	Very
Laser cutting in general	○	○	○	○
The laser cutter at TrollLabs	○	○	○	○
3D-printing	○	○	○	○
Mechatronics	○	○	○	○
Design thinking	○	○	○	○
CAD software	○	○	○	○
Milling or turning	○	○	○	○

On how many occasions have you used the laser cutter this semester? *

- ○ 0
- ○ 1-2
- ○ 3-5
- ○ 5-10
- ○ 10+

Would you have used the laser cutter more if there was... (Check of all that apply)

- ☐ Better instructions online or close to the machine
- ☐ Someone present to help with machinery such as the laser cutter
- ☐ "Easier" software
- ☐ "Easier" hardware
- ☐ None of the above apply for me
- ☐ Other: ____________

Did you at anytime experience one of these reasons for not using the laser cutter or delaying to using it? (Check of all that apply)

- [ ] No written step-by-step guide to help things along
- [ ] Afraid of damaging the laser cutter
- [ ] Intiminated by the complexity of the laser cutter
- [ ] Afraid to ask for help from more experienced workshop members
- [ ] Afraid to be caught as a novice around the laser cutter
- [ ] No experienced members of the workshop around to ask for help if necessary
- [ ] Forgot procedural actions on the laser cutter and therefore gave it up
- [ ] Problems or lack of proficiency with a CAD/drawing software
- [ ] Problems or lack of proficiency with the drawing programme on the affiliated computer
- [ ] Problems or lack of proficiency with the hardware components of the laser cutter such as turning on the fan, cleaning the lens.
- [ ] The laser cutter was out of order
- [ ] None of the above apply to me
- [ ] Other: ____________

How do you feel about there being a system tracking your behavoir and usage of the laser cutter at TrollLabs?

	1	2	3	4	5	
Not content	○	○	○	○	○	Content

Thank you so much for participating!

Feedback may also be sent to martin.a.gundersen@gmail.com or speak to me in-person at TrollLabs.

18 A7 – Arduino Code for Module on Laser Cutter Lid

```
/* Eventlogger that timestamps when:
1: Power on
2: Lid open/closed
3: Changes to y-position
SD card attached to SPI bus:

** MOSI - pin 11
** MISO - pin 12
** CLK - pin 13
** CS - pin 8

RTC - DS1307:
** SCL - pin A5
** SDA - pin A4

ToF sensor VL530X:
** Vin - 5V
** GND - GND
** SCL - pin A5
** SDA - pin A4
*/
#include <RTClib.h>              // Real time clock
#include <SPI.h>                 // Communication to SD card
#include <SD.h>                  // SD card
#include <Wire.h>                // I2C communication
#include <VL53L0X.h>             // Pololu lib for ToF sensor

const int tilt1 = 6;             // digital input pin for most
sensitive tilt
const int tilt2 = 7;             // digital input pin for least
sensitive tilt
String dataString = "";
String dateTime = "";
unsigned long currentMillis;     // main counter
unsigned long previousMillis;    // updates when event is written to
SD-card
int currentToF;
int previousToF;
int interval1 = 20;              // timeout for lid opens or closes
int interval2 = 1000;            // timeout for laser mirror changes
boolean previous_tilt1 = HIGH;
boolean previous_tilt2 = HIGH;
int flag = 0;
int ToF_max1 = 8090;
int ToF_max2 = 8091;
#define enablePin 8         // connects to the SD card CS
#define HIGH_ACCURACY            // ToF sensor
//#define LONG_RANGE        // ToF sensor. Increases sensitivity

File dataFile;              // Declares datafile
RTC_DS1307 rtc;             // Declares rtc module
VL53L0X tof;                // Declares tof sensor
```

```
void setup() {

// Open serial communications and wait for port to open:
Serial.begin(115200);
Wire.begin();
while (!Serial) {
; // wait for serial port to connect. Needed for native USB port
only
}

Serial.println("Initializing SD card...");


pinMode(8, OUTPUT);              // chip select pin for SD-card

// see if the card is present and can be initialized:
if (!SD.begin(8)) {
Serial.println("Card failed, or not present");
// don't do anything more:
return;
}

if (! rtc.begin()) {
Serial.println("Couldn't find RTC");
while (1);
}

if (! rtc.isrunning()) {
Serial.println("RTC is NOT running!");
}

tof.init(); //ToF initiates
tof.setTimeout(500); //ToF
tof.setMeasurementTimingBudget(200000); //ToF

pinMode(tilt1, INPUT);
pinMode(tilt2, INPUT);

dataFile = SD.open("datalog.txt", FILE_WRITE); //file events are
written to

// following line sets the RTC to the date & time this sketch was
compiled
// this is used for reseting the RTC module
// rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));

// Writes to SD for each boot
DateTime now = rtc.now();
dateTime = ",";
dateTime += now.unixtime(), DEC;
dateTime += ",";
dateTime += now.year() , DEC;
dateTime += ",";
```

```
dateTime += now.month(), DEC;
dateTime += ",";
dateTime += now.day(), DEC;
dateTime += ",";
dateTime += now.hour(), DEC;
dateTime += ",";
dateTime += now.minute(), DEC;
dateTime += ",";
dateTime += now.second(), DEC;
dataString = "Boot";
dataString += ",,,";
// if the file is available
if (dataFile) {
Serial.print(dataString);
Serial.println(dateTime);
dataFile.print(dataString);
dataFile.println(dateTime);
}

// if the file isn't open, pop up an error:
else {
Serial.println("error opening datalog.txt");
}
Serial.println("Setup phase finished");
}

void loop() {
//monitor loop
while (1) {
currentMillis = millis();
currentToF = tof.readRangeSingleMillimeters();

// lid opens
if (digitalRead(tilt1) == LOW && previous_tilt1 == HIGH) {
flag = 1;
previous_tilt1 = LOW;
break;
}

// lid closes
else if (digitalRead(tilt1) == HIGH && previous_tilt1 == LOW) {
previous_tilt1 = HIGH;
flag = 2;
break;
}

else if (abs(currentToF - previousToF) > 10 && (currentMillis -
previousMillis > interval2) && previous_tilt1==HIGH && (currentToF
< 1400) ) {
flag = 3;
previousToF = currentToF;
break;
}
}
```

```
// writes changes
dataString = "";                           // declares strings
dateTime = "";                       // declares strings
DateTime now = rtc.now();            // record when time is stored
dateTime = ",";
dateTime += now.unixtime(), DEC;
dateTime += ",";
dateTime += now.year() , DEC;
dateTime += ",";
dateTime += now.month(), DEC;
dateTime += ",";
dateTime += now.day(), DEC;
dateTime += ",";
dateTime += now.hour(), DEC;
dateTime += ",";
dateTime += now.minute(), DEC;
dateTime += ",";
dateTime += now.second(), DEC;

if (flag == 1) {
flag = 0;
dataString = ",Lid opens,,";
}

else if (flag == 2) {
flag = 0;
dataString = ",,Lid closes,";
}

else if (flag == 3) {
flag = 0;
dataString = ",,,Laser mirror moving: ";
dataString += currentToF;
}

// if the file is available
if (dataFile) {
Serial.print(dataString);
Serial.println(dateTime);
dataFile.print(dataString);            // writes
measurements to SD-card
dataFile.println(dateTime);            // writes time to
SD-card
}
// if the file isn't open, pop up an error:
else {
Serial.println("error opening datalog.txt");
}
previousMillis = currentMillis;  // updates counter
dataFile.flush();                // flushes system
to not corrupt SD-card
delay(1000);
}
```

19 A8 – Part List for Module on Laser Cutter lid

Quantity	Type	Description	Vendor	Product ID
1	Microcontroller	Arduino Uno R3	Adafruit	50
1	Shield	Arduino Wireless SD Shield	Arduino	A000065
1	Breadboard	Half-sized	Adafruit	64
1	LCD display	Ywrobot. LCM1602 IIC V1		
2	Pushbuttons	generic		
1	Micro SD Card	16 Gb, generic		
1	Real time clock	RTC 1307	Adafruit	264
1	Time of flight sensor	VL53L0X	Adafruit	3317
2	Resistor	10k ohm, generic		

20 A9 – Arduino Code for RFID Reader

```
/*
    SD card datalogger

    The circuit:
    analog sensors on analog int 0, 1, and 2
    SD card attached to SPI bus as follows:
 ** MOSI - pin 11
 ** MISO - pin 12
 ** CLK - pin 13
 ** CS - pin 4

    Communication protocols
    SPI - SD shield (chipselect = 4), Display
    I2C - ToF, RTC
    Serial TTL - RFID
*/


// Add liberaries

#include <SPI.h>
#include <SD.h>
#include <Wire.h>
#include <RTClib.h>           // DS1307RTC
#include <Arduino.h>
#include <rfid_lib.h>         // Created by Sjoman and Erichsen
#include <SoftwareSerial.h>
#include <LiquidCrystal_I2C.h> //Running 1.2.1
#include <VL53L0X.h> //Pololu lib for ToF sensor



// Declares modules
Sd2Card card;
VL53L0X tof;
SdVolume volume;
SdFile root;
RTC_DS1307 rtc;

// YWRobot LCM1602 IIC V1
LiquidCrystal_I2C lcd(0x27, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);

#define HIGH_ACCURACY     // ToF sensor
#define enablePin      8  // connects to the RFID's ENABLE pin
#define rxPin         10  // serial input (connects to the RFID's SOUT pin)
#define txPin         11  // serial output (unused)
#define readyPin      6   // define pin number for yellow LED
#define readingPin     7  // define pin number for green LED
#define BUFSIZE       11  // size of receive buffer (in bytes) (10-
byte unique ID + null character)

#define RFID_START  0x0A  // RFID Reader Start byte
#define RFID_STOP   0x0D  // RFID Reader Stop bytes
```

```
unsigned long previousMillis = 0; // used for keeping time
unsigned long interval = 2000;
// define interval length (in milliseconds) for RFID
unsigned long interval2 = 1200000;
// define interval length for action (20 minutes)
unsigned long interval3 = 4000;
unsigned long interval4 = 30000;
// define interval length (in milliseconds) for wanting input
unsigned long interval5 = 60000;
unsigned long State3Millis = 0;
unsigned long stateWaiting = 0;
String previousDataString = "";
String currentDataString = "";
String dateTime;
int counter = 0;
const int chipSelect = 4;
//chipSelect for SD card
int flag = 0;

// opens SD-card datafile
File dataFile;                                              //
Declares datafile

// set up a new serial port
SoftwareSerial rfidSerial =  SoftwareSerial(rxPin, txPin);  //
define what I/O pins to read as RFID serial input.

void setup() {

  Serial.begin(115200);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port
only
  }

  Serial.println(F("Initializing SD card..."));
  pinMode(10, OUTPUT);            // chip select pin for SD-card


  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println(F("Card failed, or not present"));
    return;
  }

  if (! rtc.begin()) {
    Serial.println(F("Couldn't find RTC"));
    while (1);
  }

  if (! rtc.isrunning()) {
    Serial.println(F("RTC is NOT running"));
```

```
  }
  else {
    Serial.println(F("RTC is running"));
//rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
// following line sets the RTC to the date & time this sketch was
compiled
  }

  tof.init();            //ToF
  tof.setTimeout(500);   //ToF
  tof.setMeasurementTimingBudget(200000); //ToF

  pinMode(enablePin, OUTPUT);
  pinMode(rxPin, INPUT);
  pinMode(readyPin, OUTPUT);
  pinMode(readingPin, OUTPUT);
  digitalWrite(enablePin, HIGH);

// disable RFID Reader by default.
  digitalWrite(readyPin, HIGH);
// enable readyPin by default.
  digitalWrite(readingPin, LOW);
// disable readingPin by default.
  while (!Serial);
// wait until ready
  rfidSerial.begin(2400);
// set the baud rate for the SoftwareSerial port
  Serial.flush();
// wait for all bytes to be transmitted to the Serial Monitor

  lcd.begin(16, 4);
// sixteen characters across - 4 lines
  lcd.backlight();

  lcd.setCursor(0, 0);
  lcd.print("Hello!");

  dataFile = SD.open("datalog.txt", FILE_WRITE);

  attachInterrupt(digitalPinToInterrupt(2), smile, RISING);
// Button interrupt for smile. Pin 2
  attachInterrupt(digitalPinToInterrupt(3), sad, RISING);
// Button interrupt for sad. Pin 3

  Serial.println(F("Setup phase finished"));
}
```

```
void loop() {
   /*
      Loop checking for rfid readings is created by Jørgen Erichsen
      and Heikki Sjoman.
     When the RFID Reader is active and a valid RFID tag is placed
     with range of the reader,
     the tag's unique ID will be transmitted as a 12-byte printable
     ASCII string to the host
     (start byte + ID + stop byte)

For example, for a tag with a valid ID of 0F0184F07A, the following
bytes would be sent:
0x0A, 0x30, 0x46, 0x30, 0x31, 0x38, 0x34, 0x46, 0x30, 0x37, 0x41,
0x0D

We'll receive the ID and convert it to a null-terminated string with
no start or stop byte.
  */

  unsigned long currentMillis = millis();
// keeping time in the currentMillis variable.
  digitalWrite(enablePin, LOW);
// enable the RFID Reader
  char rfidData[BUFSIZE];
// buffer for incoming data
  char offset = 0;
// offset into buffer
  rfidData[0] = 0;
// clear the buffer
  digitalWrite(readingPin, LOW); // Reading LED off

  while (1) {
    currentMillis = millis();
// needs to be updated for every cycle

    if (rfidSerial.available() > 0) {

// if there are any bytes available to read, then the RFID Reader
has probably seen a valid tag
      digitalWrite(readyPin, LOW);
      rfidData[offset] = rfidSerial.read();
// get the byte and store it in our buffer

      if (rfidData[offset] == RFID_START) {

// if we receive the start byte from the RFID Reader, then get ready
to receive the tag's unique ID
        offset = -1;
// clear offset (will be incremented back to 0 at the end of the
loop)
      }
      else if (rfidData[offset] == RFID_STOP) {
// if we receive the stop byte from the RFID Reader, then the tag's
entire unique ID has been sent
```

```
        rfidData[offset] = 0;
// null terminate the string of bytes we just received
        break;
// break out of the loop
      }
      offset++;
// increment offset into array
      if (offset >= BUFSIZE) {
        offset = 0;
// if the incoming data string is longer than our buffer, wrap
around to avoid going out-of-bounds
      }
    }


    else if (flag == 1 || flag == 2) {
// check if interrupt smile or sad has been triggered. If so -
break.
      break;
    }

    else if ((currentMillis - previousMillis > interval2) &&
(tof.readRangeSingleMillimeters() < 600) && (currentMillis -
State3Millis > interval3)) {
      flag = 3;
//Triggered by person working on the computer and the RFID-tag has
not been read in a while
      break;
    }
    else if ((currentMillis - previousMillis > interval2) &&
(tof.readRangeSingleMillimeters() < 600)) {
      flag = 4;
// triggered by person working on the computer and the RFID-tag has
not been read in a while
      break;
    }

    else if ((currentMillis - previousMillis > interval4) &&
(currentMillis - stateWaiting > interval5)) {
      flag = 5;
      break;
    }
  }

  // Is not broken from RFID loop. Will now write to SD-card and
display depending on flag.
  if (currentMillis - previousMillis > interval) {
// if current time has surpassed the interval time - do this.

     currentDataString = rectify(rfidData);
// the rfidData string should now be able to be read to SD-card

    DateTime now = rtc.now();
// record when time is stored
```

```
    dateTime = ",";                          // writes the time
    dateTime += now.unixtime(), DEC;
    dateTime += ",";
    dateTime += now.year() , DEC;
    dateTime += ",";
    dateTime += now.month(), DEC;
    dateTime += ",";
    dateTime += now.day(), DEC;
    dateTime += ",";
    dateTime += now.hour(), DEC;
    dateTime += ",";
    dateTime += now.minute(), DEC;
    dateTime += ",";
    dateTime += now.second(), DEC;

    if (flag == 1) {        // writes the event of pushbutton smile
      flag = 0;
      digitalWrite(readingPin, HIGH);
     // stop showing that the RFID reader has read the card.

      Serial.print(F("Event: Smile"));     // write to serial
      Serial.println(dateTime);
      dataFile.print(counter);
      dataFile.print(F("Event: Smile"));   // write to SD-card
      dataFile.println(dateTime);

      lcd.clear();                         // updates lcd display
      lcd.setCursor(0, 0);
      lcd.print(F("Remember to also do"));
      lcd.setCursor(0, 1);
      lcd.print(F("it next time :)"));
      delay(3000);

      lcd.clear();                         // updates lcd display
      lcd.setCursor(0, 0);
      lcd.print(F("Thank you for your"));
      lcd.setCursor(0, 1);
      lcd.print("feedback!");
      delay(1000);
      previousMillis = currentMillis;
    }
    else if (flag == 2) {          // writes the event of pushbutton
sad
      flag = 0;
      digitalWrite(readingPin, HIGH);

      // stop showing that the RFID reader has read the card.
      Serial.print(F("Event: Sad"));       // write to serial
      Serial.println(dateTime);
      dataFile.print(counter);
      dataFile.print("Event: Sad");        // write to SD-card
      dataFile.println(dateTime);
```

```
      lcd.clear();                       // updates lcd display
      lcd.setCursor(0, 0);
      lcd.print(F("Remember to also do"));
      lcd.setCursor(0, 1);
      lcd.print(F("it next time :)"));
      delay(3000);

      lcd.clear();                       // updates lcd display
      lcd.setCursor(0, 0);
      lcd.print(F("Thank you for your"));
      lcd.setCursor(0, 1);
      lcd.print("feedback!");
      delay(1000);
      previousMillis = currentMillis;
    }

// trigger by someone close and over interval time
    else if (flag == 3) {
      flag = 0;
      lcd.clear();         // lcd display changes to get attention
      lcd.setCursor(0, 0);
      lcd.print("Hi!");
      lcd.setCursor(0, 1);
      lcd.print("Hey You!");

// Resets the timer for person close states
State3Millis = currentMillis;
                         }
// trigger by someone close and over interval time
  else if (flag == 4) {
      flag = 0;
      lcd.clear();           // lcd display changes to get attention
      lcd.setCursor(0, 0);
      lcd.print("Please register your");
      lcd.setCursor(0, 1);
      lcd.print("RFID card");
    }

// does not ping users, but signify that it can be used.
    else if (flag == 5) {        flag = 0;
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Waiting for input");
      stateWaiting = currentMillis;
    }

// if the file is available and the RFID tags are different, write.
    else if ((dataFile && (currentDataString != previousDataString))
|| (dataFile && (currentMillis - previousMillis > interval2))) {
      digitalWrite(readingPin, HIGH);

// Stop showing that the RFID reader has read the card.
      Serial.print(currentDataString);
      Serial.println(dateTime);
```

```
      dataFile.print(counter);
      dataFile.print(currentDataString);
      dataFile.println(dateTime);

      lcd.clear();                          // updates lcd display
      lcd.setCursor(0, 0);
      lcd.print("RFID-ID:");
      lcd.setCursor(10, 0);
      lcd.print(currentDataString);
      lcd.setCursor(4, 4);
      lcd.print("Thank you!");
      previousMillis = currentMillis;

    }

    else if (dataFile) {
      digitalWrite(readingPin, HIGH);

 // Stop showing that the RFID reader has read the card.
      Serial.println("same RFI read");
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print(F("same RFID read"));
    }
    // if the file isn't open, pop up an error:
    else {
      Serial.println("error opening datalog.txt");
      previousMillis = currentMillis;
    }

    delay(500);

// updates millis counter
    previousDataString = currentDataString;
  }

// Wait for all bytes to be transmitted to the Serial Monitor
   Serial.flush();
   rfidSerial.flush();
   dataFile.flush();
}

// interrupt function. Will stop existing loop to report pushbutton
smile
void smile() {
flag = 1;
}

// interrupt function. Will stop existing loop to report pushbutton
sad
void sad() {
  flag = 2;
}
```

21 A10 – Part List for RFID Reader

Quantity	Type	Description	Vendor	Product ID
1	Microcontroller	Arduino Uno R3	Adafruit	50
1	Time of flight sensor	VL53L0X	Adafruit	3317
1	Breadboard	Half-sized	Adafruit	64
1	Real time clock	RTC 1307	Adafruit	264
1	Micro SD Breakout board	MicroSD Card Adapter v1.1		
1	Micro SD Card	16 Gb, generic		
2	Resistor	10k ohm, generic		
2	Tilt sensor	BL-XT660	Arduino	

22 A11 – Python Overview Camera Code

```
# The code saves a timestamped picture every ten seconds if movement
# surpasses a certain threshold.
# Need a basic web camera (not compatible with the RPi noIR)
# Thanks to Truls Nygaard for setting up the code.

from picamera.array import PiRGBArray
from picamera import PiCamera
import numpy as np
import cv2,time,argparse,datetime

#radius for blur
r = 45

#argument parser
ap = argparse.ArgumentParser()
ap.add_argument("-v", "--video", help="path to the video file")
ap.add_argument("-a", "--min-area", type=int, default=500,
help="minimum area size")
args = vars(ap.parse_args())


#Camera initialization
cap = cv2.VideoCapture(0)
resx = int(cap.get(3))
resy = int(cap.get(4))
fps = int(cap.get(5))

# allow the camera to warmup
time.sleep(0.1)

#first frame is empty
firstFrame = None
number = 1

while True:
    #Get one image frame
    ret, frame = cap.read()
    frame = cv2.flip(frame, 1)

    #Convert to gray and blur
    gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
    blur = cv2.GaussianBlur(gray, (r, r), 0)

    if firstFrame is None:
        firstFrame = gray
        continue

    #create a frame with difference between this and last frame
    frameDelta = cv2.absdiff(firstFrame,gray)
    thresh = cv2.threshold(frameDelta, 50, 255,
cv2.THRESH_BINARY)[1]
```

```
    cv2.putText(frame, datetime.datetime.now().strftime("%A %d %B %Y
%I:%M:%S%p"),
           (10, frame.shape[0] - 10), cv2.FONT_HERSHEY_SIMPLEX,
0.35, (0, 0, 255), 1)

    cv2.imshow("Security Feed", frame)
    cv2.imshow("Thresh", thresh)

    movement = cv2.countNonZero(thresh)

    if movement > 1000:
        #waits 2 seconds before taking a picture
        time.sleep(2)
        img = "/home/pi/images/image%d.jpg" %number
        cv2.imwrite(img, frame)
        number = number + 1
        #waits 10 seconds after
        time.sleep(8)


    firstFrame = gray

    if cv2.waitKey(33) & 0xFF == ord('q'):
        break
```

NTNU HMS	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

Enhet: Institutt for maskinteknikk og produksjon

Dato: 2017.01.21

Linjeleder: Torgeir Welo

Deltakere ved kartleggingen (m/ funksjon): Heikki Sjöman, stud.ass./ Martin Steinert, veileder/ Martin Gundersen, student.
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Masteroppgave student Martin Gundersen. Prototyping industrielt internett

Er oppgaven rent teoretisk? (JA/NEI): **NEI** *«JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «JA»: Beskriv kort aktiviteteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.*

Signaturer: *Ansvarlig veileder: Martin Steinert* *Student: Martin Gundersen*

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs workshop	MG	Romkort	Romkort		
1a	Bruk av roterende maskineri	MG	Maskinens brukermanual	Ukjent	Ukjent	
1b	Bruk av laserkutter	MG	Maskinens brukermanual	Ukjent	Ukjent	
1c	Bruk av 3D printer	MG	Maskinens brukermanual	Ukjent	Ukjent	
1d	Bruk av skjæreverktøy	MG	Ukjent			
1e	Bruk av samenføynigsmidler (lim og lignende.)	MG	Produktets brukermanual og datablad	Datablad	Ukjent	
2	Bruk av Protomore workshop	MG				
3	Tilstedeværelse ved arbeid utført av andre.	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	
4	Eksperimentelt arbeid	MG	Egen risikovurdering- må gjøres for hvert enkelt eksperiment		Prosessavhengig	

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet	Vurdering av konsekvens:				Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
			(1-5)	Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)		
1	Bruk av TrollLabs workshop.								
1a-i	Bruk av roterende maskineri	Stor kuttskade	2	D	A	A	D	2D	Sørg for at roterende deler tilstrekkelig sikret/dekket. Vær nøye med opplæring i bruk av maskineri.
1a-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iii		Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iv		Flygende spon/gjenstander	3	C	A	A	B	3C	Bruk øyevern og tildekk hurtig roterende deler (Fres og lignende.)
1a-v		Feil bruk-> ødelagt utstyr	3	A	A	C	A	3C	Vær nøye med opplæring i bruk av maskineri
1b-i	Bruk av laserkutter	Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1b-ii		Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Bruk hansker ved håndtering av varme materialer.
1b-iii		Øyeskade-laser	2	D	A	A	C	2D	Bruk øyevern! Skru av laser når maskinen ved oppsett.

1b-iv		Brann	2	B	A	D	C	2B	Vær nøye med opplæring i bruk av maskin. Ha slukkeutstur tilgjengelig
1c-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskin.
1c-ii		Innhalering av plast/ printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern/ vernebriller
1c-iii		Feil bruk-> ødelagt maskineri	3	A	A	C	A	3A	Vær nøye med opplæring i bruk av maskin.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk skapre verktøy og riktig skjæreunderlag
1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk skapre verktøy og riktig skjæreunderlag
1e-i	Bruk av samenføynigsmidler (lim og lignende.)	Eksponering på øyet	2	D	A	A	B	2D	Bruk øyevern, ha datablad tilgjengelig
1e-ii		Eksponering hud	4	A	A	A	A	4A	Bruk hansker, ha datablad tilgjengelig
1e-iii		Eksponering åndedrett	4	A	A	A	A	4A	Bruk åndedretsvært/ god ventilasjon. Ha datablad tilgjengelig.
1e-iv		Søl	4	A	B	A	A	4A	Ha papir/ rengjøringsmateriell tilgjengelig. Ha datablad tilgjengelig.
2	Bruk av Protomore Workshop								Samme risikobilde som TrollLabs
3	Tilstedeværelse ved arbeid utført av andre.	Se andres risikovurdering om sikkerhet betviles.	3	C	C	C	C	3C	Hold et øye med hva som foregår rundt deg.
4-i	Eksperimentelt arbeid	Vann-drukning	1E	A	A	A	D	1E	Bruk redingsvest i båt og lignende.
4-ii		Elektrisitet- strøm	3	B	A	A	A	3V	Typisk lite energi involvert. Bruk isolerte verkøty

Sannsynlighet vurderes etter følgende kriterier:

Svært liten 1	Liten 2	Middels 3	Stor 4	Svært stor 5
1 gang pr 50 år eller sjeldnere	1 gang pr 10 år eller sjeldnere	1 gang pr år eller sjeldnere	1 gang pr måned eller sjeldnere	Skjer ukentlig

Konsekvens vurderes etter følgende kriterier:

Gradering	Menneske	Ytre miljø Vann, jord og luft	Øk/materiell	Omdømme
E **Svært Alvorlig**	Død	Svært langvarig og ikke reversibel skade	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket
D **Alvorlig**	Alvorlig personskade. Mulig uførhet.	Langvarig skade. Lang restitusjonstid	Driftsstans > ½ år Aktivitetsstans i opp til 1 år	Troverdighet og respekt betydelig svekket
C **Moderat**	Alvorlig personskade.	Mindre skade og lang restitusjonstid	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket
B **Liten**	Skade som krever medisinsk behandling	Mindre skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
A **Svært liten**	Skade som krever førstehjelp	Ubetydelig skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

Risikoverdi = Sannsynlighet x Konsekvens
Beregn risikoverdi for Menneske. Enheten vurderer selv om de i tillegg vil beregne risikoverdi for Ytre miljø, Økonomi/materiell og Omdømme. I så fall beregnes disse hver for seg.

Til kolonnen "Kommentarer/status, forslag til forebyggende og korrigerende tiltak":
Tiltak kan påvirke både sannsynlighet og konsekvens. Prioriter tiltak som kan forhindre at hendelsen inntreffer, dvs. sannsynlighetsreduserende tiltak foran skjerpet beredskap, dvs. konsekvensreduserende tiltak.

MATRISE FOR RISIKOVURDERINGER ved NTNU

KONSEKVENS	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
		Svært liten	Liten	Middels	Stor	Svært stor
		SANNSYNLIGHET				

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge		Beskrivelse
Rød		Uakseptabel risiko. Tiltak skal gjennomføres for å redusere risikoen.
Gul		Vurderingsområde. Tiltak skal vurderes.
Grønn		Akseptabel risiko. Tiltak kan vurderes ut fra andre hensyn.