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Applying the Wayfaring Model in Product Development: Case Study 'New Ski Concept for Norway'

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NTNU - NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

MASTER THESIS SPRING 2016
FOR
STUD.TECHN. EINAR S. WERGELAND

Applying the wayfaring model in product development: case study "new ski concept for Norway"

The task of this master's thesis is to continue development of a new ski concept for SGN Skis. The premaster project explored a concept of a smart ski. The master's thesis work will continue this mainly by exploring, testing and verifying several functions of a smart ski. From critical functions like sensors, actuators and microprocessor, to finally the system of them combined.

- run through entire engineering design process from early need finding to concrete product concept(s)
- in collaboration with SGN
- applying the concepts and tools of the wayfaring model in product development (Gerstenberg et al.2015)
- development of (final) product prototype(s)
- preparation of the foundation for a continuing a grant proposal submission to e.g. Innovation Norge
- also, it is encouraged to contribute to at least one scientific publications and or grant submission during the master

Formal requirements:
Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (https://www.ntnu.edu/web/ipm/master-thesis). This sheet should be updated one week before the master's thesis is submitted.
Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.
The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.
The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses. The contact person at SGN is Tore Frimanslund and Prof. Martin Steinert and Carlo Kriesi at NTNU.

Torgeir Welo
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Abstract

Throughout this thesis the wayfaring model has been applied in a product development case of a smart ski. Based on a vision of making a ski that changes properties based on input from the ski several critical functions have been identified and explored. Following the findings in this work and from general definitions of smart products, it is defined what a ’smart’ ski actually should be like. The different critical functions of a smart ski have been tested in terms of functional prototypes to confirm and exemplify the definition of a smart ski. A large number of sensors were evaluated to find the most applicable sensor to monitor ski performance. A test setup consisting of sensor(s), recording equipment and an analyzing tool has been developed from ground up in order to benchmark the different behaviors of a ski. Several ways of manipulating a ski have been explored. What was found most interesting was to manipulate the ski by having a dynamic mass distribution. Simple algorithms to control a system were tested briefly in order to confirm that the control system can work. Big opportunities were seen in artificial intelligence and machine learning, but remain unexplored within this thesis. A conceptual ski is suggested based on the findings and definition. In addition, a paper based on the findings of this thesis will be submitted to the journal of the International Sports Engineering Association (ISEA).

Samandrag

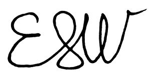
I denne masteroppgåva har Wayfaring-metodologien blitt anvendt i ei produktuviklingsoppgåve der ein har hatt ein visjon om ei smartski. Med utgangspunkt i ein visjon om å lage ei ski som endrer seg etter kva forhold eller køyrestil ho blir utsett for, så har ein funne og utforska fleire kritiske funksjonar ei slik ski må ha. Utifrå desse resultata saman med meir generelle definisjonar har ein definert kva ei ”smartski” er. Med hjelp av prototypar har ein kunne teste, verifisere og syne dei mest kritiske funksjonane til ei smartski. Eit stort spenn av sensorar for ei smartski har blitt testa. Dette for å finne dei sensorane som best egner seg til å måle korleis sjølve skia presterer. Ein har mellom anna utvikla eige testutstyr for å måle skikarakteristikkar under skikøyring beståande av sensorar, opptaksutstyr og analyseverktøy. Dette for å kunne samanlikne ulike ski opp mot kvarandre. I tillegg har fleire måtar for å manipulere eigenskapane til ei ski blitt utforska. Der fann ein ei ski med dynamisk massefordeling mest interessant. Det vart også laga nokre enkle kodar for ein mikrokontrollar for å verifisere at dei kan kontrollere eit styreelement. Det vart også funne eit stort potensiale i kunstig intelligens (artificial intelligence) og maskinlæring, men det vart bare sett på i liten grad i denne oppgåva. Basert på det ein lærte frå utforskinga av dei ulike kritiske funksjonane til ei smartski utvikla ein ei konseptski. I tillegg har det blitt utarbeida eit forslag til ein artikkel i journalen til The International Sports Engineering Association.

Preface

This Master's thesis was written the spring of 2016 as part of my Master's degree in mechanical engineering at Department of Engineering Design and Materials (IPM) at the Norwegian University of Technology and Science (NTNU). This work is a continuation of my pre-master's project “Next Generation Ski Manufactured in Norway” done in collaboration with SGN Skis. With a Wayfaring methodology this work has explored a smart ski concept generated in the pre-master.

I believe that part of this work would be interesting to the industry in terms of defining smart products, and smart skis in particular. It is also a case where the Wayfaring methodology has proven to be working when applied in a product development case. The findings from this work have also lead to a submission to the journal of the International Sport Engineering Association.

This work would never be the same without the interactions and help from other people. First of all, I would like to express my sincere gratitude to the supervisors, Martin Steinert and Carlo Kriesi at TrollLABS IPM, and industry contact Tore Frimanslund at SGN Skis. I would also like to thank my co-students Øystein Bjelland, Marcus Horn, Christopher Lange, Jørgen Blindheim and the trolls at TrollLABS for contributing both professionally and for making studying fun. And last, but not least, Ingvild Tømta, Anders S. Skarpeid, Jon Christian Halvorsen for helping out in the field.



Gløshaugen, NTNU, June 2016

Contens

Chapter 1
Background

The Setting

Skiing

In this thesis the term skiing will mostly cover downhill oriented skiing like freeride, backcountry touring and off-piste skiing. Freeride skiing is when the skiing involves off-piste or backcountry terrain where the skier use natural obstacles to challenge himself on the way down. Backcountry touring is more about the outdoor experience. It covers skiing where the skier hikes up a slope or mountain and then skis down. Off-piste skiing is when the skiing is done in or close to a ski resort but outside the groomed tracks.

SGN Skis

SGN was funded by local ski enthusiasts in Sogndal, Norway in 2012. Their ski model “Togga” was crowdfunded after a few years of development. During the last years their assortment of skis has expanded to cover several models of touring and freeride skis. All of the skis have a recognizable freeride characteristic. The size of the company is still small, but the amount of skis sold are increasing, and SGN is the top selling Norwegian freeride ski brand.

TrollLABS

The TrollLABS is more than a Lab. It is more about the people than machines and facilities. It is run by Professor Martin Steinert as a R&D Project for The Research Council of Norway. The lab houses several Ph.D.s and master students, and access is limited to these people. To do research on early-phase product development, the fuzzy front-end of new product development, is the main field of research at TrollLABS. Both development of new products and research on the development processes are done at the lab.

The physical lab is filled with machines and material enabling the users to make a large span of prototypes. Especially the rapid types of prototyping are common in this lab. Additive manufacturing, laser engraver, paper printer, and electronics are among the tools available. Normally one would guess additive manufacturing to be the tool of choice, but the laser engraver is actually among the most common tools for rapid prototyping at TrollLABS. Another common tool is the Arduino microcontroller. This cheap and easy programmable microcontroller is used for several projects because of its ease of use. For the early phase exploring prototypes a lot of paper, cardboard and glue is used.

Goal and Scope

The starting point for this thesis was the pre-master's project "SGN Skis: Next generation skis manufactured in Norway". The abstract from it describes what was discovered: "This premaster project have together with SGN Skis been exploring opportunities to design and manufacture skis in Norway. Through empathizing, need finding and early prototypes a wayfaring towards the next generation ski have started. The work have consisted of meetings, interviews, need finding workshops, patent and literature search and prototypes. From the empathizing, some good insights in user needs have been found. They have been the foundation for several solutions generated. Most of the work have been prototype driven, where the use of low-resolution and low-fidelity prototypes have made learning possible. Two main concepts have been explored in more detail, a smart ski concept and an additive manufactured ski. The smart ski concept is a ski that by means of sensors, actuators and a microcontroller sense the snow conditions or style of riding and respond on the input by manipulating the ski. The additive manufactured ski is a concept where an individual customized ski is produced by additive manufacturing techniques" (Wergeland, 2015). A lot of need finding were done in the pre-master's project, and made a good base for continuing the work of the master's thesis. With the idea of new technology and high-end niche products being a way of making ski production in Norway possible, we decided in agreement with SGN to continue with the smart ski concept. The reason for this was the possible impact the workload of a master's thesis could do, but also the technical aspect and the interesting new field a smart ski could be. As a side effect the sensor part of the smart ski concept could possibly be useful also in ski design.

To make a health, safety and environment-assessment for the work of the master's thesis is mandatory. The assessment can be found in Appendix A1.

The goal from start was to go from early need finding to concrete concepts for the smart ski concept presented in the pre-master's project. By means of the wayfaring approach (Gerstenberg et al, 2015; Steinert & Leifer, 2012) which will be covered in detail in the methodology chapter, the work started out with a vision of finding a way to what a smart ski could be.

The goal of this master's thesis was to contribute to SGN and their ongoing Innovation Norway project in a good as possible way by developing a smart ski concept as far as possible. In addition a contribution to a scientific journal or conference was seen as a good achievement. To make a foundation for a grant proposal to Innovation Norway was also seen as a possible goal for this work. The main contribution was assumed to be the product development methodology and insights from the TrollLABS and NTNU environment applied in this product development case. The potential product development results were seen as the most important goal in order to achieve the more advanced goals.

Chapter 2
Methodology

Introduction: Human-Centered Design

An introduction to the methodology and mindset is given in this chapter. This thesis is made in the TrollLABS environment, and is deeply inspired by the methods and mindset taught there. TrollLABS is inspired by human centered design, praticed in several product development envirnonment, e.g. at Stanford University's d.school and in the company IDEO. Terms and methodologies will be explained in the following sub-chapters.

IDEO and the d.school are examples on what human-centered design is. A describing sentence is given in the small book "The Field Guide to Human-Centered Design" by IDEO, where they say : "We believe that a solution is out there and that by keeping focused on the people we're designing for and asking the right questions, we'll get there together" (IDEO.org, 2015). The main idea is to always have the user in focus. Not to impress other engineers. The take away point is that human-/user-centered design focus on to make solutions made to cover true user needs. How this is done is not set by strict rules or methodolgy, and there are many ways to achieve this.

Needfinding

To empathize with your users is an important part of a human/user-centered design process. When needfinding one empathize to discover unmet needs or needs that are not fully covered by existing solutions. Through observation, engagement and immersing (d.school, 2010) the designer/engineer can experience the situation of the user. By diving deep into the user one can potentially discover pain points the user conscious or unconscious are facing. First of all it is important to discover who the most important user is. It might be the doctor who operates the medical equipment instead of the patient who is being treated (Leifer & Steinert, 2014). There are several ways of empathizing with the users. To have an anthropologist-like approach where interaction is observed seems to be effective (IDEO.org, 2015; Leifer & Steinert, 2014). To really experience your user's experiences in their environment the concept of experience prototyping gives the designer insights in how it is like for the user to operate the solution/idea in his/her environment (Buchenau & Suri, 2000). By doing a proper job in the empathizing phase one can potentially make a foundation for radically innovative solutions.

Wayfaring

To be a hunter or gather, how can it be related to product development? At TrollLABS many of the projects done are inspired by the idea of a wayfaring approach to product development. The paper "'Finding One's Way': Re-Discovering a Hunter-Gatherer Model based on Wayfaring" (Steinert & Leifer, 2012) presents the idea of how one can approach the search for the next big idea by modeling it as a cooperation by hunters and gatherers. Where the hunters are the ones that hunts for the next big idea, whereas the gatherers are the optimizers, the ones who do the more traditional and linear product development when the prey is hunted (Steinert & Leifer, 2012).

So, how is a hunter at TrollLABS like? To be a hunter is something dynamic. Instead of using fixed positions from previous hunts, and static rules, one have to adapt to the idea of a moving, and perhaps a change in, the target being hunted (Steinert & Leifer, 2012). When entering the hunting ground it can be helpful to have a vision for the hunt (Gerstenberg et al., 2015). The vision should be open-ended enough to allow many different approaches. This could allow for a large degree of freedom during the hunt. If the vision is replaced by a list of requirements the degrees of freedom might be reduced drastically. In the example case explained in the paper of Gerstenberg et al. (2015) they point out that by working with a vision they get a solution space that is open, ambiguous and uncertain. This uncertainty is part of the hunt, and is something that is impossible to totally eliminate. One of the main ideas in the wayfaring model is to go hunting as a team. The team should be small and agile with a big as possible diversity in skill.

With the vision set, one can aim for what is believed to be the target, see Figure 1. As an engineer this freedom and uncertainty might feel uncomfortable. If radical innovations are wanted it is hard to preplan and know the solution space. By having a physical, mental and organizational environment which makes it is possible for teams to experiment, prototype and learn this uncertainty can be easier to deal with (Leifer & Steinert, 2014). The environment should also allow for safe failing, which is of great importance according to Snowden and Boone (2007). Also, when being in an unknown solution space prior knowledge and experience do not play the same role as before. In this situation one might discover unknown unknowns (Gerstenberg et al., 2015; Snowden & Boone, 2007), discoveries unknowingly found and previous unknown. In addition to this one should never rule out the chance of serendipity findings. By being opportunistic and open-minded the chance of bumping into interesting findings is probably larger.

Now, with an established vision for the project, where do you go? Now the divergent wayfaring can begin (Steinert & Leifer, 2012). By repeating a cycle of prototyping, testing and learning, one can wayfare towards the dynamic target, moving the aim as knowledge is accumulated. According to Gerstenberg et al. (2015) you can call these cycles probing for new ideas. "One of the ideas of probing is therefore to build and test prototypes that create completely new knowledge – knowledge that is impossible to accurately anticipate regardless of what our expectations may be"(Gerstenberg et al., 2015). In more detail, each probing should hopefully give new knowledge benefitting the project. The probing should consist of divergent thinking (generative design questions) where solutions are generated followed by convergent thinking (deep reasoning questions) to narrow down and benchmark the solutions generated (Leifer & Steinert, 2014). After one or several iterations the insights learned, or the abductive learning, would hopefully give better ideas on where the target might be located (Steinert & Leifer, 2012). This new learning should lead to a shift in where the prey is believed to be. The target should then be moved towards this new location. New probing are done towards the new target, and what is believed to be the target might have changed drastically. This might be an unexpected major discovery, something by Steinert and Leifer (2012) called a dark horse prototype. This is a prototype or probing that discover something unexpected that is benefitting the project to a large degree.

Since time often is something a project is short of, to be effective in the early phase of a product development project is important. The choice of prototype is important when it comes to having an effective process. On the importance of having a conscious idea on how you prototype Gerstenberg et al. (2015) mention: "Progress is achieved by the emergence of new ideas as a result of previous probing cycles. Therefore, it is important to minimize the time spent and to maximize the learning outcome for each probing cycle. This accomplished by concentrating on just testing the critical functions by building a low resolution prototype that is reduced to the properties that are necessary to only test the critical function ".

It is important not to go home prematurely. Both the length and ambiguity can be tiring for the team. A good hunting team is able to leave paths and go the extra mile in order to bring home the next big idea. When the time has come, and the team feels that this is the target, position is locked and more traditional product development work can start. Now is the time to bring home the prey and prepare it. This is when other traditional methodologies and the gatherers take over.

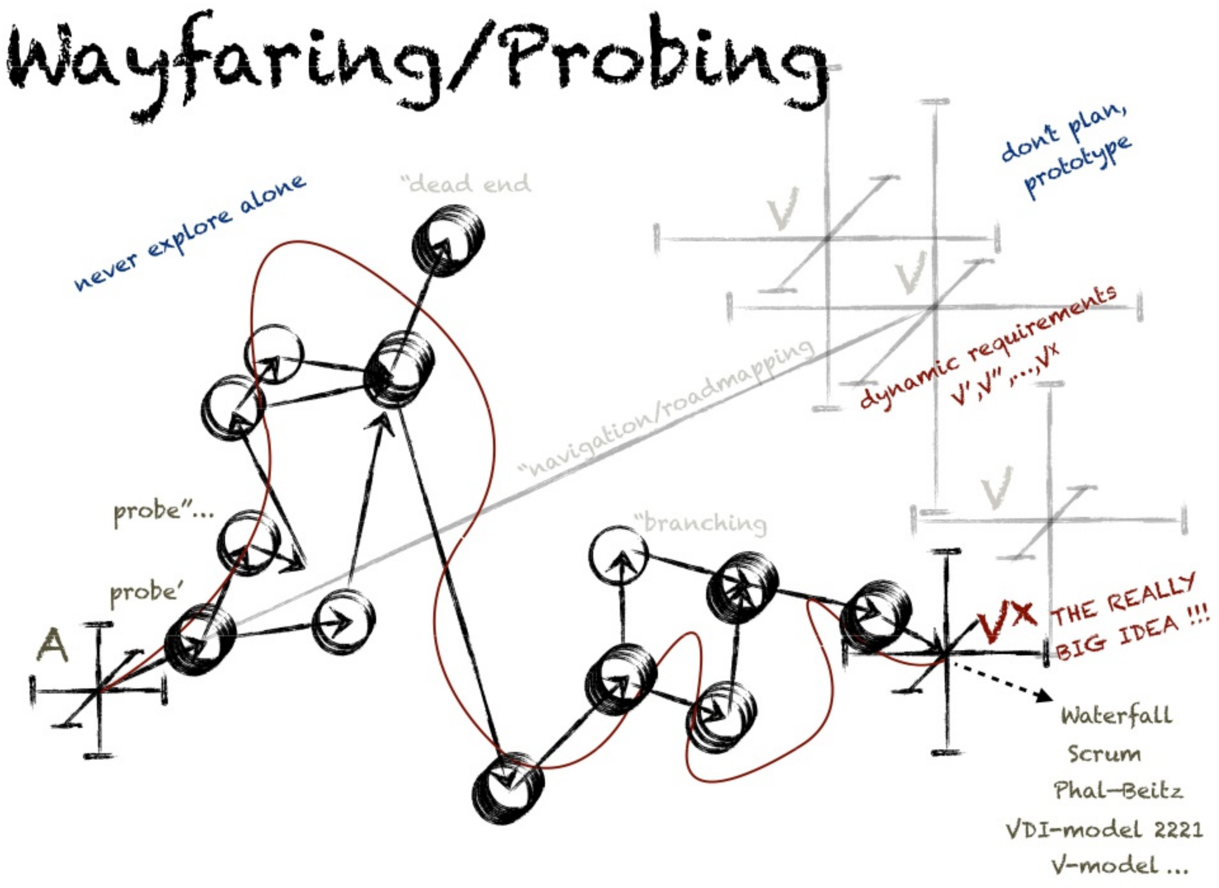


Figure 1: Wayfaring Model. From Gerstenberg et al. (2015).

What Is A Prototype?

The answer depends on who you ask. Some might think of a prototype as something close to a finished product. In typical human-centered design settings the definitions could be as follows: “We define prototype as any representation of a design idea, regardless of medium. This includes a pre-existing object when used to answer a design question” (Houde & Hill, 1997). “We define prototype as an approximation of the product along one or more dimensions of interest“ (Ulrich & Eppinger, 2012). “1) prototypes are for traversing a design space, leading to the creation of meaningful knowledge about the final design as envisioned in the process of design, and 2) prototypes are purposefully formed manifestations of design ideas” (Lim et al., 2008). What does this mean in practice? If you want to answer the question of the size of an object, take a pizza box like Houde and Hill (1997) did when prototyping an architect’s computer. If you want to show the top manager an interesting concept, a different approach might be more beneficial (Schrage, 1993). This brings in terms like resolution and fidelity which according to Houde and Hill (1997) means “amount of detail” and “closeness to the eventual design” respectively. If you want to show off and sell your ideas to people outside the product development sphere one might want to have higher resolution and fidelity prototypes. On the other hand a prototype made early in the process could benefit the project more by being a low-resolution and low-fidelity prototype. An example of a low-fidelity and low-resolution prototype of a conceptual ski construction is shown in Figure 2. In the Bootcamp Bootleg by d.school they encourage to keep the prototypes rough and rapid to make the learning outcome as big as possible.

The reason for building prototypes is different depending on the setting. Some build prototypes to learn, solve disagreements, start conversation, fail quickly and cheaply and manage the solution-building process (d.school, 2010).

In the environment of TrollLABS the English or Norwegian language is sometimes a limiting factor when it comes to describing a phenomena or the activity. Sometimes new words need to be made to describe what is going on. We have made the activity of making prototypes a verb, and the phrase “To prototype” is often used in our setting. This confirms what Schrage (1993) writes about prototyping language, and is probably a sign of prototypes being important and included in our environment.

Bottom line is: Let the prototypes be a way of asking the right questions in order to learn as much as possible in a fast way. By knowing when to use the different levels of fidelity and resolution, prototypes can be effective in how it communicates ideas internally and externally of the development process.

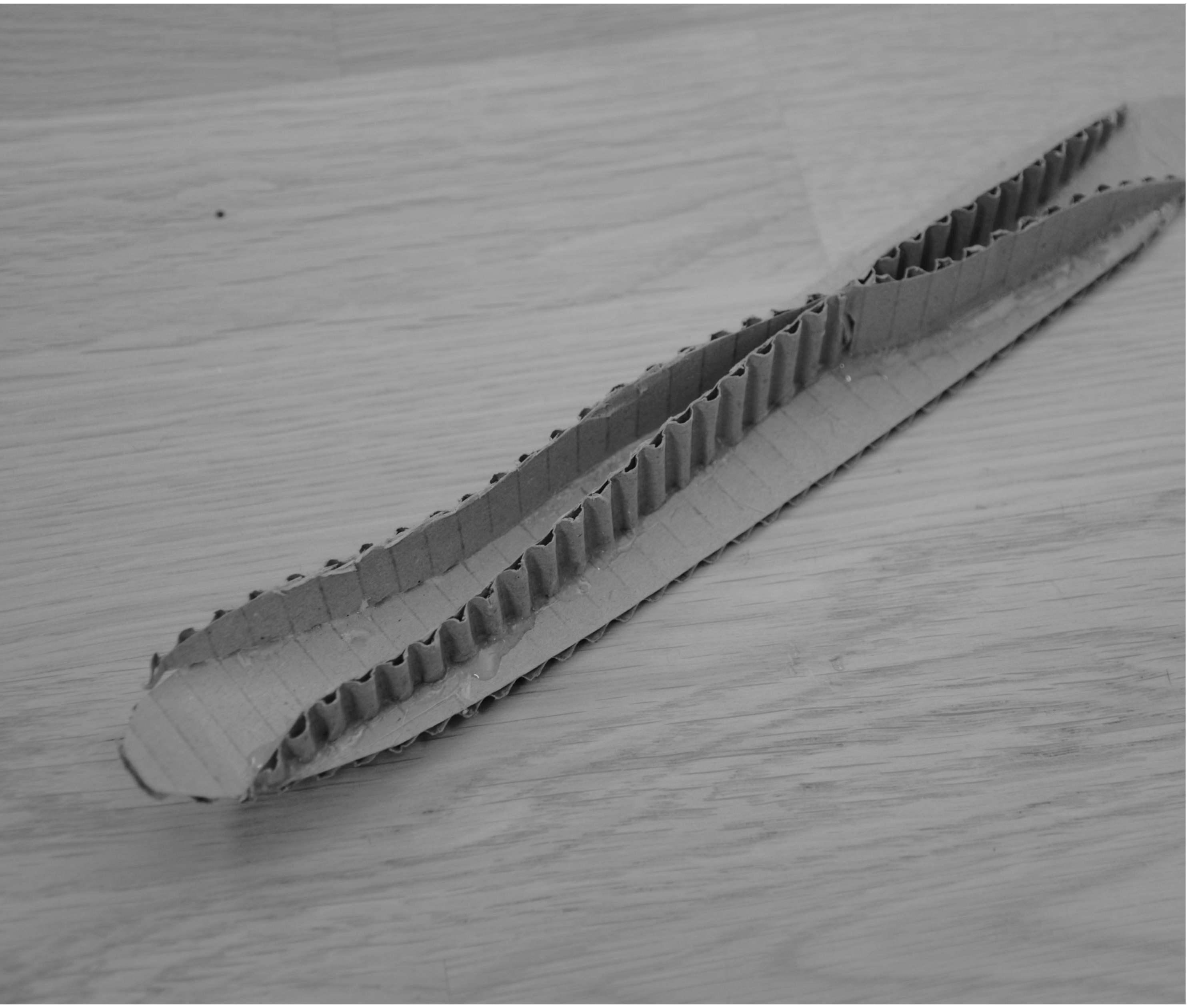


Figure 2: Example of low-fidelity and low-resolution prototype of a ski construction solution.

Chapter 3
Journey

Introduction: Why the Concept of a Smart Ski?

With the basis in the wayfaring model, this work has an opportunistic approach in terms of trying out ideas, making prototypes, and asking questions. If a prototype or technique can give feedback on a certain question, then it could be worth trying. By aiming for to test critical functions in low-fidelity and low-resolution prototypes, learning cycles can be fast and provide new learning. In this particular wayfaring towards our vision of making a smart ski, a lot of different ways "to prototype" ideas have been practiced. This chapter will cover the journey towards what the next generation ski could be. Reason for the choice of the smart ski concept is given in the pre-master's work and the goal and scope chapter, it will not be repeated here. First we need to know what a smart ski is, the following sub-chapter will give an introduction to what became a definition of a smart ski used in this work.

The other sub-chapters cover the different components of a smart ski and the way the different ideas was uncovered. They are organized by category, and not in the sequence they were done. This is to keep the reader on track when presenting the different ideas. The most important findings are given in the text in short form. More details are given in the different "probing" sections. The probing sections are explaining why, how and the new learning from the probing done during this thesis.

What Is a Smart Ski?

Smart Products

The word smart is used in many settings to describe products, and in many cases without being smart at all. For this work the definition of smart products will be "..smart products are defined as consumer products that are equipped with intelligence-generating technologies including (i) sensors and/or actuation, either to gather data from the environment or to use the data to change the environment, (ii) computing power for data analysis, and (iii) optional interfaces to exchange information with their environment" (Dawid et al., 2016). Another term used is intelligent products (Meyer et al., 2009). In the work of Meyer et al. (2009) a three-dimensional model of intelligent products is presented. The three axes are "Location of intelligence", "Level of intelligence" and "Aggregation level of intelligence". The pure example of an intelligent product is a product where the intelligence is at the object, the object are doing decision making and it can be aware of its role in a system. The perception of a smart product at TrollLABS is that the intelligence should be in the product or system itself, being able to process and react on input in an autonomous way. Examples of smart products and technology are Appel's smart watch "Apple Watch", Oral-B's bluetooth toothbrushes and systems to detect elderly people's wellness based on sensor data (Suryadevara et al., 2013). Given the example of Oral-B's bluetooth toothbrushes, they are offering a solution that gives instant feedback to the user on how to improve their toothbrushing. The intelligence is inside the product system, where the toothbrush provides sensor data to the smartphone that processes the data to give feedback to the user. This leaves the toothbrushes with a fairly high score on all of the axes in the intelligence model of Meyer et al.

Three Examples of Smart Products in the Sporting Goods Industry

The first example of smart technology in the sporting goods industry is the increasingly amount of activity monitors, and in particular we will look at Fitbit alta. This wristband wearable is a watch equipped with sensors to monitor activity. When the activity level is below certain threshold values, the Fitbit will remind the user with notifications. The goal of the activity monitor is to motivate the user to be more physically active.

A recent example of products previous being "dumb" now becoming smart is the Altra IQ Smart Shoe. It is a running shoe with embedded pressure and accelerometer sensors and bluetooth communication. The shoe can transmit the sensed data to an iFit wearable or an android/iOS smartphone application. With the help of the smartphone application the runner can get feedback on his or her performance in terms of running cadence, foot strike zone, ground contact time, balance between left and right foot, the specific pressure for each foot and so on. This kind of real-time feedback is helpful to improve the running form, and potentially reduce the risk of injury. The classification of intelligence according to the model of Meyer et al. is high. The location of intelligence is at object, at least if the system of the smart shoe and smartphone is counted as a unit. The level of intelligence can at least be classified as a problem notification if not a decision making intelligence. The argument for calling it a decision making system, is that based on the sensor input the system not only notifies the user about current state, it also provide advices on how to improve running form.

In the world of tennis, Babolat, a tennis racket manufacturer, have introduced smart technology in their "Babolat play" products. By embedding accelerometers, gyroscope and piezoelectric sensors into the tennis racket they are tracking tennis performance. The data is transmitted to a smartphone after the session and then providing statistics and analyzed data as feedback. Part of the solution is close to a "gameification" (Deterding et al., 2011) of the tennis session, where your improved performance is awarded by receiving higher scores, e.g. higher scores in technique, power and endurance. When classifying this product, it is more of an analytic tool. The feedback is not instant, and the learning loop is slow and to certain degree left to the user to fulfill. The system collects data, analyze it, and finally present it as human-friendly statistics giving the user the ability to track performance and improvement.

Skiing Smart; Examples of Not-So-Smart and Smart Products in the Skiing Industry

When looking back in time there have been examples of technology that potentially could be qualified as smart or partial-smart. The two ski brands K2 and HEAD implemented piezo fibers in order to damp a ski (Ashley, 1995; Cass et al., 2003; Rothemann & Schretter, 2010). The systems consisted of three parts, piezo fibers for sensing/power generation, a chip, and piezo fibers for actuation (Vandergrift et al., 2000). The question to be asked would then be; is it a truly smart ski? It has a sensing system, processing of the signals and an actuating part. Both the sensor and actuator qualifies to be part of a smart product, but the grade of intelligence is, at least when strict to the definitions, not qualifying this concept to be called a truly smart product.

To narrow the focus, some recent ski related examples will follow. First out is Madshus' "empower" cross country skis which claims to be a smart product. This is not the case if one look into the details and specifications of the product. In this case the skis are equipped with a RFID chip. Each ski is physically tested for flexural characteristics and given a unique profile, then connected to the specific ID of this ski. These characteristics are important to match with the physical measures and skills of the skier when selling and using a ski, especially when the level of the skier is above intermediate. Another way to use the flexural characteristics is when applying ski wax. Among the factors to consider when applying ski wax is flexural characteristics of the ski, the skier's weight and skills, and snow and weather conditions. The additional smartphone application can guide the skier on what type of wax and length of the wax zone. If a classification of this solution were to be made, it would probably be classified far below the given example of the Altra IQ smart shoe. Reason for this is the RFID only containing information about the product itself, and the location of the intelligence is outside the product. Main feature of this smart technology is an advisory service based on static data obtained during manufacturing. The product is lacking sensors and actuators to sense or act on input, and according to the smart product definition of Dawid et al. (2016) one could argue this would mean the Madshus empower ski not being a smart product.

RENOUN are not claiming to have a smart product, but they are an example of companies introducing new technology into skis. In their skis they have added what they call Hyper Damping Technology. The technology is basically a non-Newtonian polymer. When it is exposed to vibrations the polymer will turn stiffer. In this case channels inside the ski core is filled with this polymer. This makes the ski stiffer when skied at higher speeds or when the surface is icy etc., at least in theory. The technology is still at an early stage meaning not many skis have been sold yet. The take away point from looking at RENOUN and similar ski companies, is that new technology brought into the ski industry most often is small incremental innovations mainly in the domain of material. In other words, there are not many smart products in the skiing industry at the moment.

A visit to the ISPO Munich 2016 trade fair was made to get insights in the smart products present in the winter sport industry today. A detailed report from the visit is given in Appendix A2. At the trade fair a lot of products that was wearing the label "smart" was found. Many of them without being near what a smart product is, at least if based on the definitions given by Dawid et al. (2016) and Meyer et al. (2009). Two examples of smart products worth mentioning from the ISPO Munich 2016 follow.

First out is the startup company Pomocup. They showed a prototype of a ski wearable for the backcountry skier that collects uphill performance data and monitors key performance data on a small screen. The core of the product is a set of motion sensors that is recorded at a high sample rate. Further the data is analyzed, and important measurements like vertical speed, temperature and slope angle are displayed on a small monitor on the unit. When categorizing this product, it falls more into the instrument or monitor category. The product has sensors, it has smart algorithms to analyze the sensor data, but the output "only" is quantifiable numbers monitoring the performance, not an actuator that change the ski or environment to make the skiing experience better. Question is: does this type of smartness fully qualify to be a smart product?

MotionMetrics' product Carv, is a good example of how far the implementation of technology have come in the skiing business. This product prototype is a ski wearable which promise to give real-time feedback on skiing technique. With pressure sensors installed in two insoles together with motion sensors, the unit is able to sense important characteristics of skiing technique. With the help of a smartphone and an application, recorded data can be processed and live instructions given in the smartphone's earplugs. This product is not only sensing the physical phenomena and monitoring physical data, it is also processing the data and converting it into advisory response to the skier. In terms of the work of both Dawid et al. (2016) and Meyer et al. (2009), this should classify Carv as a smart product. Compared to the other ski related examples, Carv has a higher degree and location of intelligence.

A smart ski

All the previous examples and definitions of smart technology leads to what this thesis would state as a smart ski. No previous work has been found that states what a smart ski is. The background work done above made a good framework for the different components found necessary for a smart ski concept. A ski or an auxiliary system mounted on a ski which fulfill the smart product definitions given by Dawid et al. (2016) and Meyer et al. (2009) was found to be a smart ski or smart ski device/wearable. What did this mean in practice? There should somehow be a certain threshold to qualify for being a smart ski. In the paper submission we suggested the following as a definition of a smart ski:

(I) The ski should have sensors to gather data either from the ski itself or the environment that is related to the ski. What kind of sensors and data is dependent on the purpose of the smart ski.

(II) There should be an intelligent component analyzing the data. The analyzed data should control an actuator and/or be visualized to the user.

(III) The actuator should manipulate the skier/ski/environment directly or indirectly as a reaction to the analyzed data.

How Can Ski Performance Be Measured?

Test Setup

For tests done indoors at TrollLABS the most important tools were found in the electronics corner and the parts made in the laser cutter. As a basis for all the tasks where electronics or microcontrollers were needed the Arduino platform was weapon of choice. The microcontroller unit used during the whole thesis was an Arduino Uno. Different sensors and ordinary electronic parts were available at the lab, such as standard sensors, wires, breadboards etc.

When testing skis, the most frequent tested ski was a self-made ski, also know as Randorocker. The specifications of the ski is 185 cm long with a turning radius of 20 meters and a waist of 95 mm. It can be categorized as a semi-light backcountry touring ski. Other skis used were a mountaineering competition ski (Dynafit DYNA World Cup, 160 cm) and a light touring ski (Hagan Y-Flow 181 cm). When recording vibrations the way of testing was as follow. The ski was clamped to a table with two clamps in the binding area. The sensor was mounted at the start of the tip of the ski, where the side cut ends. A typical setup of the electronics for testing a sensor is sketched in Figure 3. The Arduino was collecting and sending the sensor data to a computer via serial communication. The sensor data was sent together with a timestamp, recorded by an application made by Roger Meier called CoolTerm, and visualized and analyzed in MathWorks' Matlab. An Arduino code similar to the one in Appendix AC1 was used to record the data. The Matlab code was an early iteration of the code given in Appendix MC1 (to be explained in greater detail when describing the analysis of the vibration data). More advanced code was developed during the work, and will be described in more detail later.

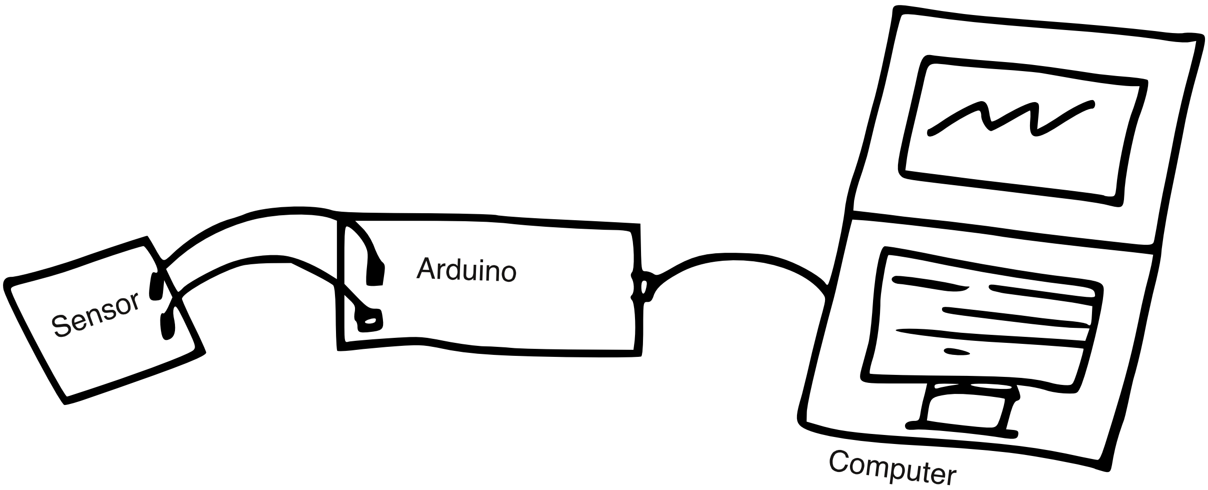


Figure 3: Sketch of standard test setup for testing sensors.

Sensors

Preliminary testing

Already at the end of the pre-master's project some thoughts on how to develop a smart ski system was tested. This made a good platform for further work during the master's thesis. The Arduino platform was chosen as a base for prototyping a system. Reason for this system was the flexibility, amount of available resources online, cost and availability of components. To not get fixed on existing solutions, and to have an open mind, a lot of the available sensors for the Arduino system were tested. Several probings were done, and for a detailed overview of the results see the sensor matrix in Appendix A3. During the process of working with these sub-challenges, the main idea was to do probings of critical functions. To not mix what was being tested, the experiments or prototypes was kept as low-fidelity and low-resolution as possible in order to do fast iterations and learning. The new learning from each cycle gave insight in how to develop new ideas, bringing the concept closer to the vision. Some of the probings indicated not to continue, but was definitely useful when they could guide the direction for the next probing. The most important probings are summarized in the following sub-chapters.

Vibration testing

Introduction

Vibrations were chosen as the most important characteristic to measure. Reason for choosing vibrations was the fact that a shattering ski is one of the things a skier points out being a "pain point".

Probing: Accelerometer

Why?

Accelerometers are among the sensors used in industry to measure vibrations. To find out if such sensor could be managed and useful for the project was seen as important. Additionally the preliminary testing with a smartphone's accelerometer gave good results. This gave reason to believe in the concept of using an accelerometer.

How?

By setting up a test system like described in "Test Setup".

New learning?

1) First iteration was with a digital accelerometer. There was a limiting sample rate of 500 Hz for this particular accelerometer. It was changed for an analog accelerometer for the next iteration.

2) From the code written for the purpose, where the improved code is seen in Appendix AC1, sample rates close to 1 kHz were obtained.

3) The need to make weather protection for the accelerometer was obvious when the accelerometer was meant for a skiing environment. The process was prototype-driven, and started by making physical cardboard models together with the accelerometer breakout board to get the right fit from the start. This was experienced as an efficient way of designing such component. To set the measurements of the casing was fast when doing it this way, and few cross-checking were needed when modeling the 3D-model in the Siemens NX software. To manufacture the casing an Ultimaker2 at the TrollLABS was selected. Figure 4 shows three steps of the development, where (A) shows the cardboard prototype, (B) the 3D model and (C) the finished casing.

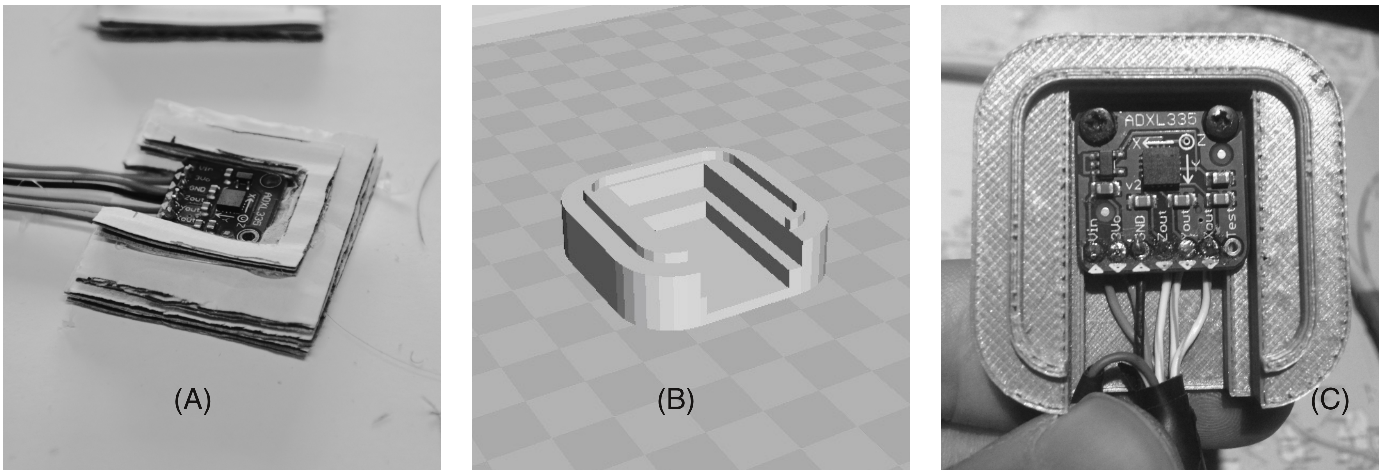


Figure 4: Prototype-driven process: (A) carboard model (B) 3D model (C) additive manufactured prototype

Probing: Piezo element
Why?
The piezo element is used for many different applications ranging from seismographic measurement to alarm buzzers, and also vibration measurements. There were several reasons why this type of sensor was interesting. The cost is much lower than an accelerometer and the electric consumption is non-existing. To check if this was a sensor applicable for sensing ski vibrations was seen as important to check out.
How?
By setting up a test system like the standard setup described earlier. This time the sensor was a piezo element in the form of an alarm buzzer. Figure 5 (A) shows the buzzer mounted on a ski.
New learning?
When compared to the accelerometer the piezo element gave close to the same results, but lacked the accuracy and possibility to see the oscillations of the ski. To do analysis of the data with the help of Matlab was possible. More details on how to analysis are given later. The best results were obtained when an alarm buzzer was used as a sensor. To further see if the buzzer was able to distinguish between directions of the vibration, the buzzer was mounted perpendicular to vibrations in the sideway direction of the ski. See Figure 5 (B) for the setup. This did not give better results other than weaker signals, when comparing it to a buzzer mounted flat on top of the ski.

Probing: Other ways of measuring vibrations?
Another way of collecting vibration data was found to be by installing a strain gauge on the ski. This have already been done earlier, and from the work of Rothemann and Schretter (2010) it seemed to be a good way to measure vibrations. To get this solution to work properly the strain gauge need to be glued to the ski. This makes it a more permanent sensor, and is not movable between different skis. A big bonus when using a strain gauge is that the deflection of the ski can be measured. This thesis did not make it to test the strain gauge, but the idea seem promising for later work covering ski performance. Another way to do strain measurements is to use optical fibers. It is used in fatigue laboratories for detailed strain measurements.

Summary
The most promising results in terms of recording vibration data from a ski were the accelerometer and a piezo element. With a three-axis accelerometer the acceleration in three dimensions was measured. This gave the opportunity to obtain vibration data like it is done in industry (Rogers et al., 1997; Östling, 2016), so not surprisingly this was a solution that worked. A perhaps more surprising finding was the piezo buzzer. It was able to get satisfying results for analyzing the data, but at a much lower cost. When the cost of the component is one tenth of the accelerometer, in addition to being simpler to install, it is definitely a component to consider in a future commercial system.

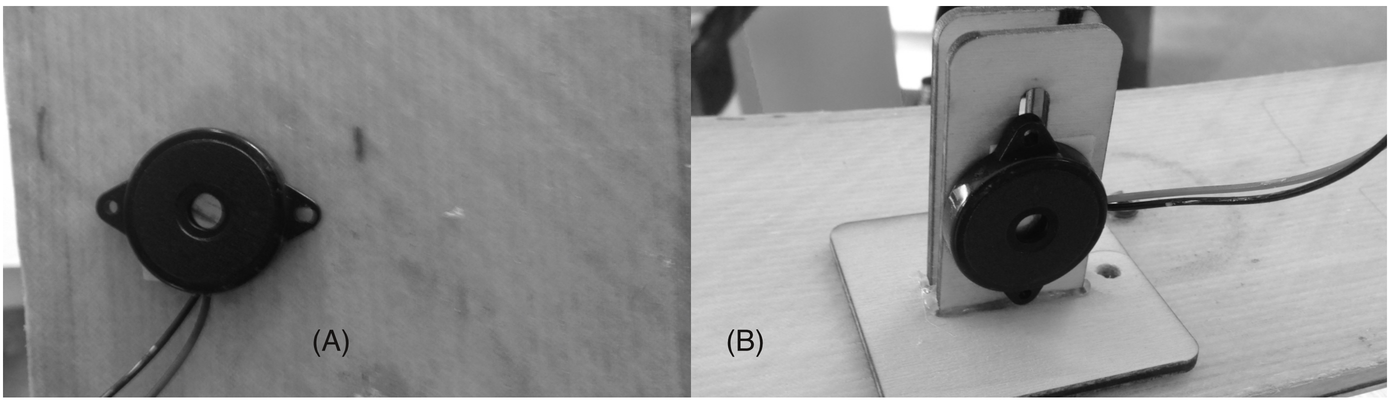


Figure 5: (A) Piezo buzzer (B) Side-hit setup

Visualization
Not everything analysed need to be quantified by numbers. The human senses are also valuable to sense or see what is going on. To better get an idea of what was going on when skiing, a point-of-view camera was installed on top of a ski to record video when skiing.

Probing: Visualization
Why?
In order to get more types of input, and to learn more about how a ski performs when skied, the idea of filming a ski with a point-of-view camera came up.
How?
Mount a camera on top of the ski, see Figure 6. In this case a GoPro Hero3 was chosen. It was able to record at 120 frames per second. To mount the camera was easy. The camera manufacturer offers mounts for many applications, and their flat mount was perfect to mount on a ski. When replaying the recorded video it was possible to see in a fairly detailed way how the ski vibrates and moves when skied.
New learning?
This was a solution which right out of the box was easy and useful. The only thing to take care of was the the mounting of the camera and recording of video. The video recorded was useful for visualizing what is happening when skiing.

Feedback from skier
Introduction
"How can we pinpoint the vibrations or behaviors of a ski that we do not like?" was a question who came up at one point. What if the skier could give feedback when skiing, giving a signal when "bad thing happens"?

Probing: Feedback from skier
Why?
Based on the idea of getting feedback from the skier to pinpoint bad ski behavior.
How?
Since a recording system already was made, the feedback button a.k.a. the "shitty button", was just a matter of implementing into the existing system. The button was simply a pushbutton connected to an analog reading port on the Arduino, making it possible to graphically pinpoint the sections of the graph where the "bad vibrations" happen.
New learning?
The button worked well to manually pinpoint the sections of bad ski behavior, but had a noisy signal due to the wiring. When the button was un-pushed the signal input was noisy.

Summary
This was the start of the "shitty button", a button the skier could press while doing recordings with the vibration sensor. Basically a push button located on the controlling remote for the recording equipment.

Figure 6: GoPro Hero3 camera mounted on a ski

Speed

To know how fast a ski is skied was another interesting quality found useful when measuring ski performance. The first thing that came to mind when measuring speed was GPS. Today most smartphones are equipped with a GPS to determine positional data. A lot of bike computers and sport watches are also now delivered with GPS. To utilize what is already brought when skiing could be a possible solution to obtain the speed. One problem with GPS is the power consumption and the need of reception of satellite signals. The last drawback mentioned is probably the main reason for not using a GPS for obtaining speed when in a mountain environment with high peaks and narrow valleys.

Normally a ski is skied on slopes with a certain inclination. The slopes skied during backcountry touring is ranging from 10 to 35 degrees of inclination. The fact that the skier's speed can be decomposed into two dimensions, vertical and horizontal, opens for new ways of measuring the speed.

Probing: Altimeter
Why?
Check if vertical speed can be useful when skiing characteristics should be obtained. Vertical speed could be a good way to characterize the speed of the ski.
How?
By using an existing sport watch, Suunto Ambit3 Peak, with an altimeter and logging function it was easy to obtain altimeter data. The results were calculated from the web-application at movescount.com.
New learning?
Instead of finding advanced solutions or make them from scratch this was a fast way of getting feedback on what kind of vertical speed one could expect from an altimeter used in a ski. The results were promising, and it was possible to distinguish between different speeds found during skiing. From several rounds of testing a feel for the average descending speed were obtained. The results can be seen in Table 1.

Probing: Arduino with Barometer
Why?
Make a system that can record barometric values while descending ski slopes.
How?
By connecting a barometer to an Arduino Uno with a SD-Card logger. An Arduino code was written to do the recording. It can bee seen in Appendix AC2. Matlab was used to plot the results. A plot of the recordings can be seen in Figure 7. The setup can be seen in Figure 8.
New learning?
From the plot in Figure 7 it was easily seen that different descending speeds down a stair at NTNU's facilities could be obtained from a barometric recording.

Summary
By the help of a barometer it is possible to measure air pressure. Vertical speed can be obtained if air pressure is recorded over time. This was tested both by the help of a sport watch equipped with an altimeter and by setting up an Arduino with a barometer/altimeter. The sport watch could submit data on vertical speed during ski descents. By means of an Arduino microcontroller it was possible to record barometric data over time. The sensor and data recorded could potentially be part of a smart ski system.

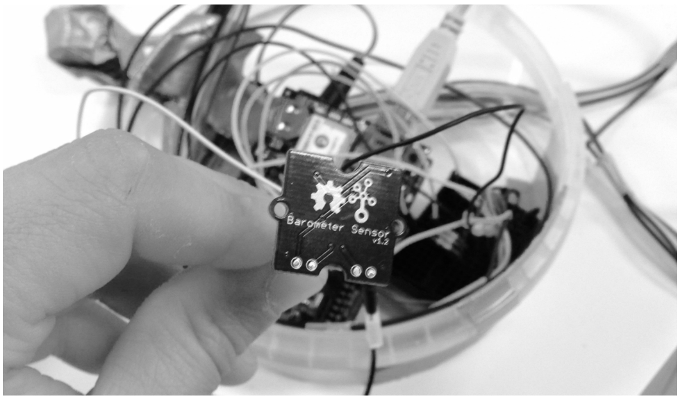


Figure 8: Barometer sensor and recording equipment in the background.

Table 1: Vertical Speed data from selected ski descents.

Where	Average descending vertical speed [m/min]	Min/Max vertical speed [m/min]	Comment
Stryn Rando	-181	-269	Above treeline slope
Stryn Rando	-162	-217	Above treeline slope
Stryn Rando	-191	-236	Above treeline slope
Sogndal	-95		Treeskiing
Gråkallen	-103	-205	Treeskiing
Todalen	-192	-224	Above treeline slope

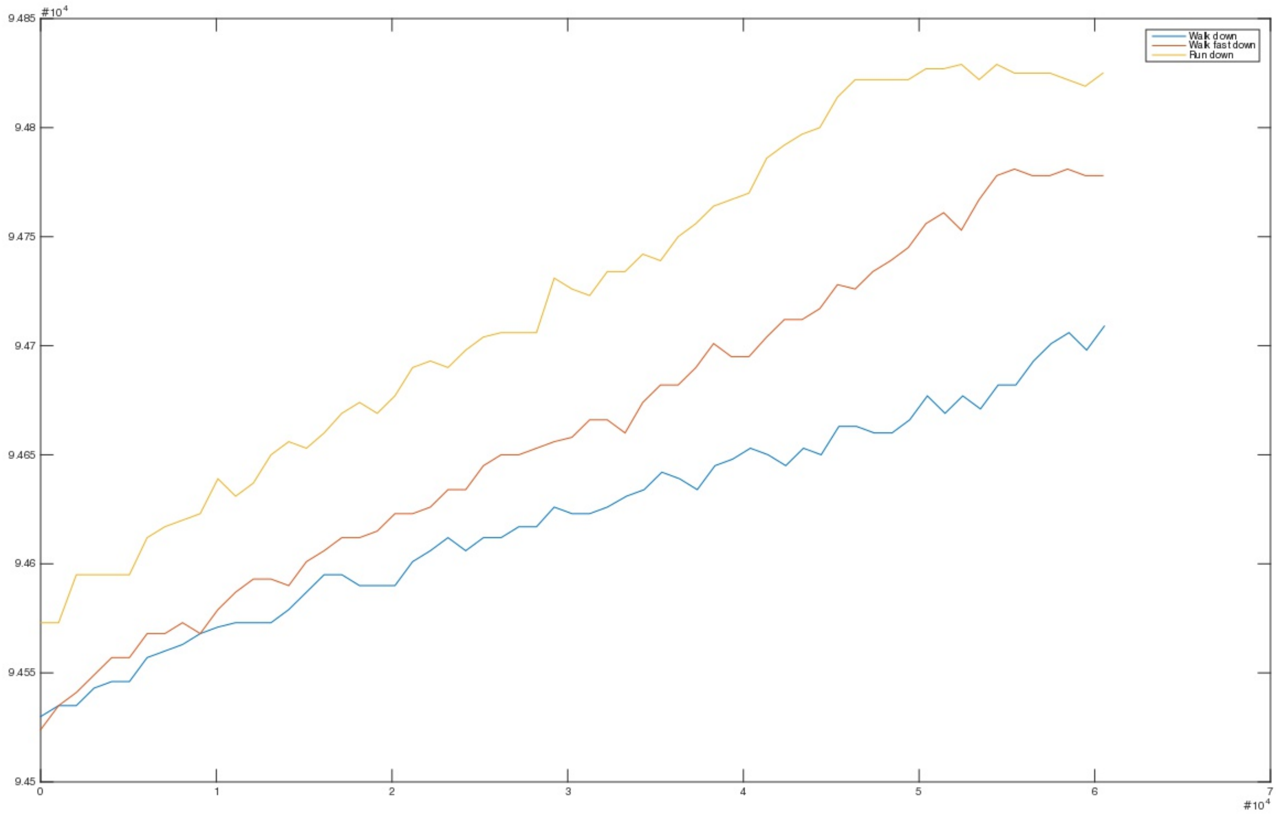


Figure 7: Plot of different descending speeds down a stair at NTNU.

Recording sensor data

The first way to record the sensor data was by the help of an Arduino. It was done during the preliminary testing. The goal for this probing was to see if sensor data could be recorded when skiing.

Probing: Record sensor data
Why?
Wanted to record ski characteristics in a good as possible way when skiing. The sensor data was seen as an important part of the smart ski system.
How?
Started out with an Arduino Uno recording data to a computer via serial communication over USB. The wiring of the Arduino were simple, sensor output was recorded from the analog inputs on the Arduino. The rest of the wiring was ground, power and a reference voltage. The sensor was an analog accelerometer with a range +/- 3 g. A Matlab code was written, where the goal was to make a code where sensor data was recorded steadily with a time-stamp. This took some trial and error, and several iterations of the code were made. The final code for recording to computer is given in Appendix AC1. By using CoolTerm to record the serial data sent from the Arduino it was possible to write to file on the computer. The data could then be visualized in Matlab plots, like the one found in Figure 9.

To be able to record sensor data while out in field some improvements were needed. First step was to acquire a SD-card logger for the Arduino. A GPS-Logger shield from Adafruit for the Arduino was used as logger. Still the wiring was straightforward with the same accelerometer connected to the analog inputs. The first iterations of the logger were based on the code written for writing to serial communication, similar to the code in Appendix AC1. However, after some recordings it came clear that the sample rate was unsteady because of the SD-card. “Hiccups” lasting 70-80 milliseconds during the recording was making the sampling unreliable. Help was found in the middle of the internet jungle. At an Arduino forum some expert gave the advice to use a code where the data recorded were stored in the internal memory, and then loaded to the SD-card. This way the sample rate could easily be 300-400 Hz with an Arduino Uno. This code was adapted and rewritten to work with the system already made. It worked fine from start. The code can be found in Appendix AC3.

How to control the recording process went through a few iterations, starting with a push button located inside the casing of the microcontroller evolving to a wired remote with a push button to start/stop the recordings and a buzzer to communicate the status of the sampling. Reason for choosing sound as feedback when controlling the microcontroller was the fact that bright sunlight and strong reflections in the snow makes screens and LEDs hard to see, especially while wearing ski goggles. The remote is shown in Figure 10, where the main components are the buzzer (A), start/stop recording (B) and the “shitty button” (C).
New learning?
Learnt a lot about coding the Arduino. To be able to get the timing right got much easier when the time-interrupt function was discovered. This made steady sampling possible. The Arduino Uno is a very simple microcontroller, making programming challenging in the way that the code has to be written in the right way to work properly. Solving the challenge of steady recording to SD-card was an important achievement for the thesis.

Summary
Starting from scratch, choosing the Arduino platform and ending up with a standalone sampler capable of recording 4 analog channels at a sample rate of at least 300-400 Hz. There are of course commercial solutions out there that match these specs, but at a cost of $50-60 there are not many alternatives that can be compared to this solution. To implement the remote controller worked well from first try. The insights learned from making the sampler was useful during the process, but also for later work it was probably useful. This solution made a good platform for the recording to come later in the project.

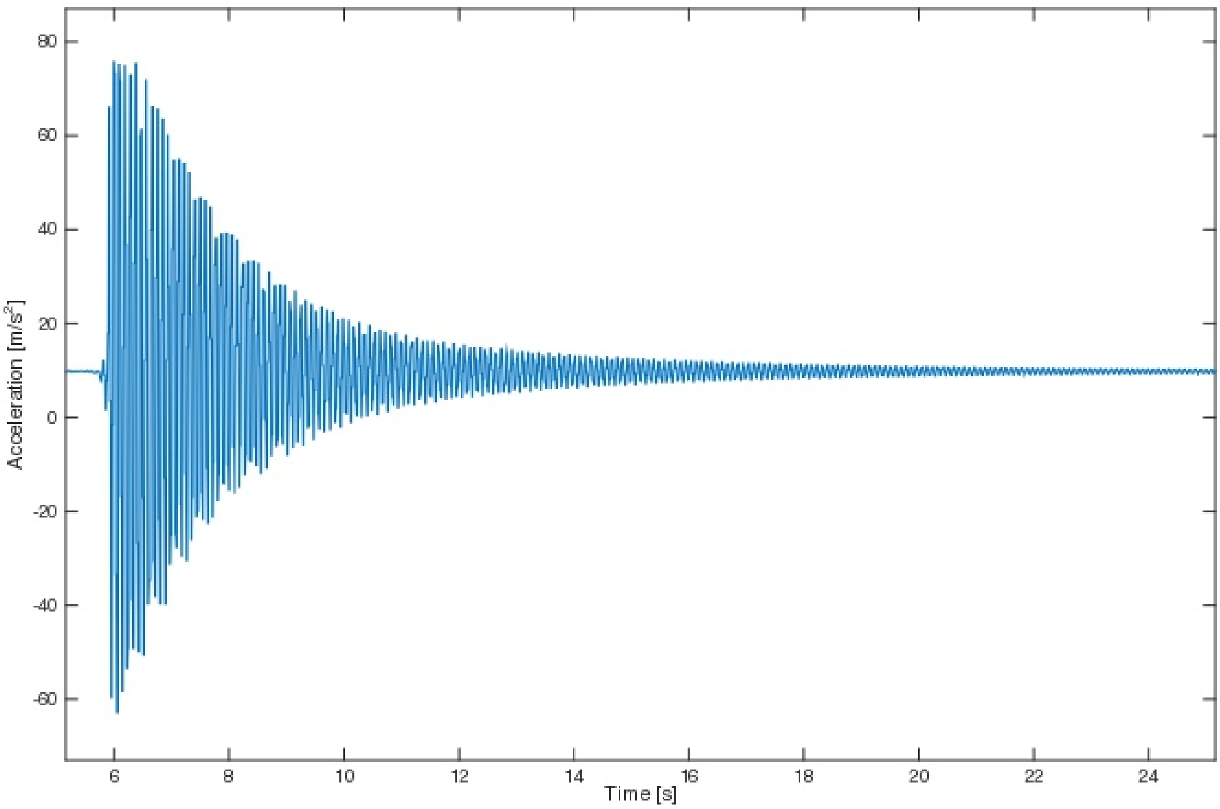


Figure 9: Matlab plot of oscillating ski.

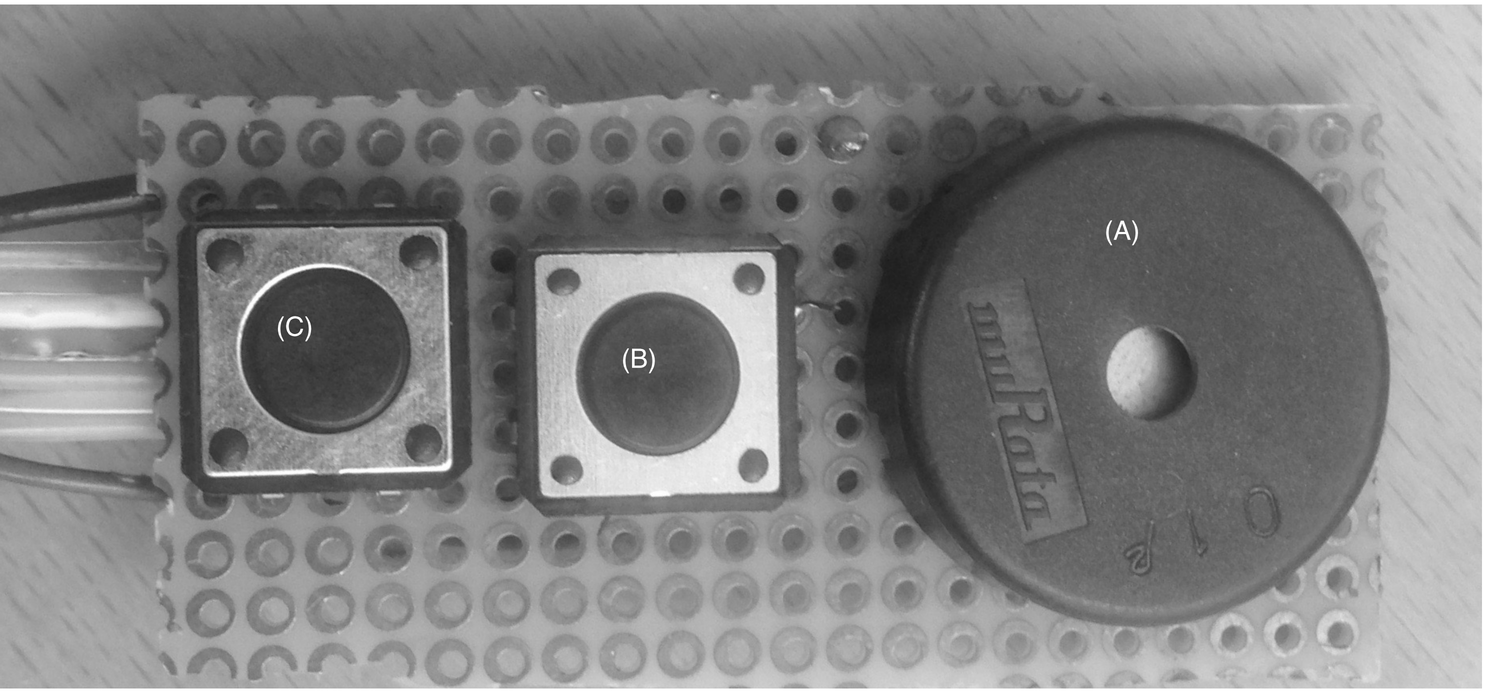


Figure 10: Remote for recording system. (A) Buzzer, (B) Start/Stop Recording and (C) "Shitty-button" (to distinguish bad ski performance).

Analysing sensor data

After being able to get the first sensor data, the hunt for a way to analyze them in a good way started. The first analyses of vibrations in this thesis was done by an iPhone. By using an application called Vibsensor the ski oscillations could be measured by the smartphone. After recording the vibrations from the ski, the application could analyze the data in a “magical" way that showed the different frequencies the ski was oscillating. This was something to investigate more.

Probing: Power Spectral Density
Why?
It was important to see if the data obtained from the recording system could be analyzed and useful with the help of a fast Fourier-transform.
How?
The “magic” happening in the Vibsensor application was learned to be Power Spectral Density (PSD). By doing some background research the method used was found to be a fast Fourier-transform, and is capable of presenting the frequencies of the oscillations recorded (Mercer, 2006; Peters, 2012). Matlab was found to be the tool for the job. The programming language and software of Matlab is powerful when it comes to scientific and engineering math. The built-in functions and examples make a lot of possibilities. By the help of the examples in Matlab and by looking at what others have done, a code was made. The input to the code was the recorded sensor data from recordings done by the Arduino. The code was improved during the work and fitted to meet the needs to analyze the sensor data during the work of the thesis. The Matlab code can be found in Appendix MC1. The output from the code was a plot of the vibration data together with the power spectral density, as can be seen in Figure 11.

During the thesis a visit to Sandvik Teeness AS was made. They are producing tool holders for milling, turning, drilling and boring that are highly damped. The core competence in Sandvik Teeness is to dampen unwanted vibrations. Luckily the people at Teeness also have a passion for skiing. A tour was given by D.Eng. Dan Östling. They are doing a lot of analyses on a variety of machining tools. The most important learning from this meeting was probably the fact that when measuring a ski with a sensor both the impulse and response is covered in the PSD analysis. The way they solve this in Teeness’ lab is by knowing the impulse (Östling, 2016). In a lab setting it is possible to know the impulses given, but in the field when skiing a ski, the impulses are hard to filter out or monitor. This is something to keep in mind when doing the different analysis of the skis.
New learning?
Most important was that the analysis worked well. The different analyses could benchmark the different series of recording. The input from Sandvik Teeness about the vibration recordings both consisted of the impulse and the response was important for the understanding of the recording of vibration data.

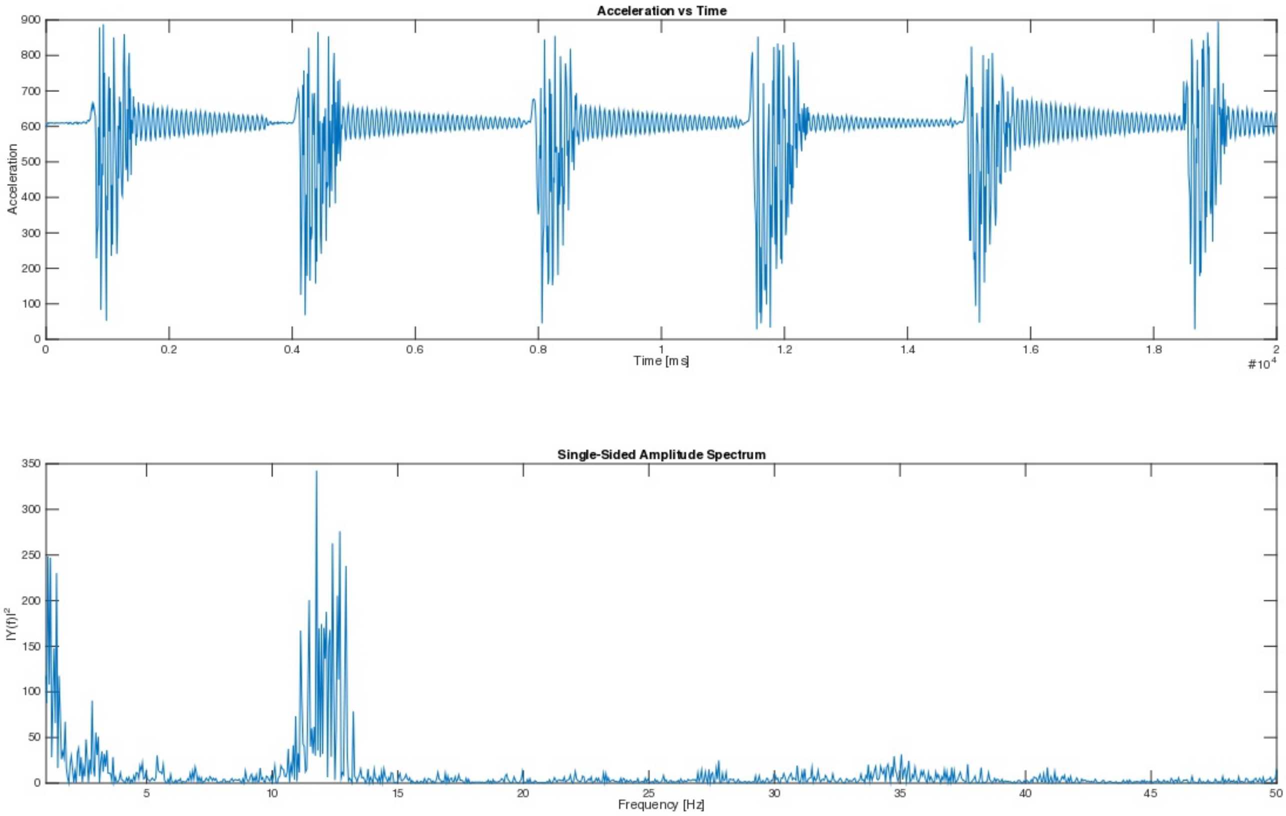


Figure 11: Plot of accelerometer data and PSD analysis.

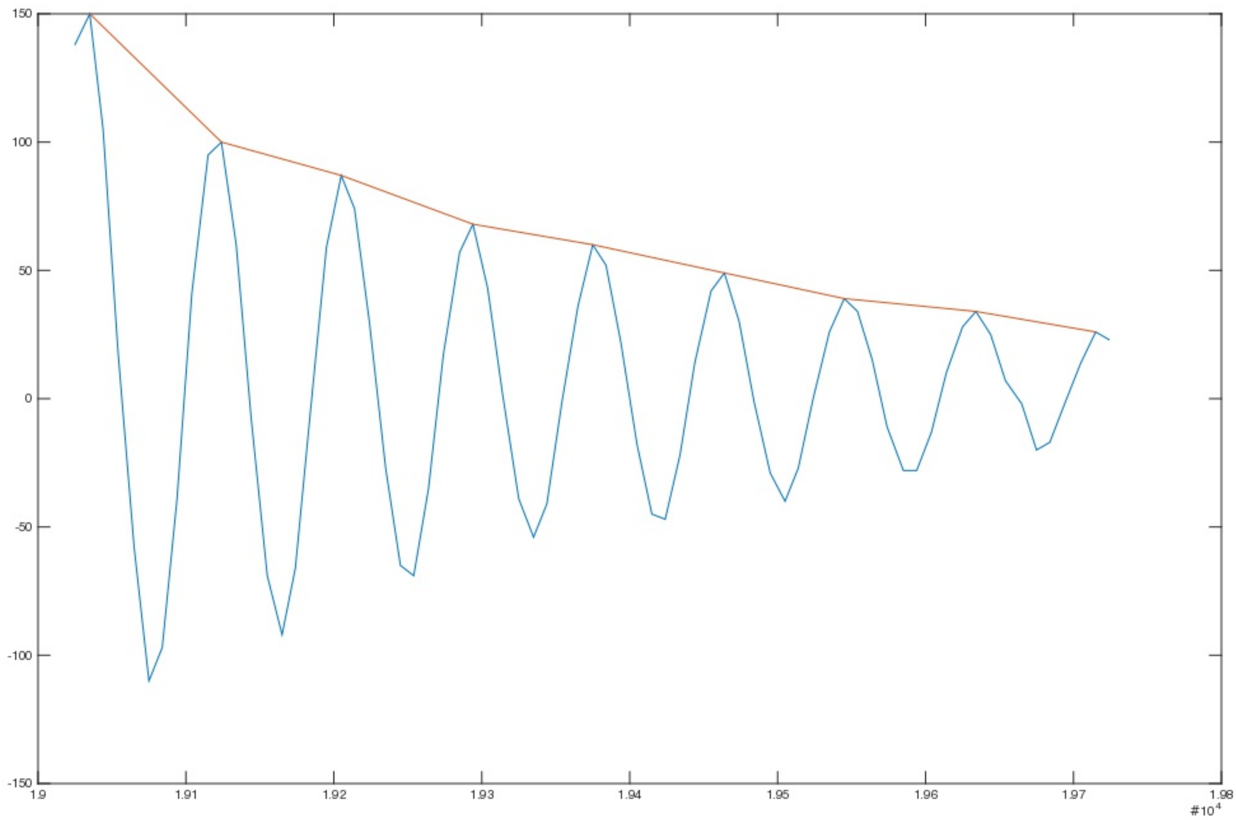


Figure 12: Plot of logarithmic decrement.

Probing: Logarithmic decrement

Why?

This was thought of as another way of benchmarking the vibration data. The idea was that it could be a good way of comparing different skis or different states of a ski.

How?

Another way of analyzing the vibration data was found during the probing for different analyzing tools. It was found possible to calculate the logarithmic decrement and the damping ratio (Irgens, 1999) from the accelerometer data. The numbers obtained, in the case of a ski, tells how fast the ski dampens, and can be used as a tool to benchmark different skis. The formula for logarithmic decrement and damping ratio is given in Formula 1 and Formula 2 respectively. Figure 12 shows an analysis of a vibrating ski. The code written for the purpose can be found in Appendix MC2. The input data was the data recorded from the accelerometer sensor. When the data was loaded into Matlab some work was needed to sort out the right data to be analyzed.

Formula 1:

$$\delta = \frac{1}{n} \ln \frac{x(t)}{x(t+nT)}$$

Formula 2:

$$\zeta = \frac{1}{\sqrt[2]{1+(\frac{2\pi}{\delta})^2}}$$

New learning?

The logarithmic decrement could be obtained for different skis by the help of the Matlab code written. This made it possible to benchmark different skis, and to rank the performance of different skis or actuators/devices put on a ski. To get the right raw data some work to isolate a proper damped oscillation was needed.

Summary

To handle the technique of analyzing vibrations was found very useful. To do PSD analyses of skis made it possible to benchmark skis and the effect of devices manipulating the ski. This tool was something brought through the rest of the thesis as a reference tool. The damping ratio was also found to be an interesting way of presenting ski characteristics.

A system for measuring ski vibrations

Introduction

The following sub-chapter will bring the pieces more together and sum up the previous sub-chapters. By putting together what was discovered from the sensor, recording and analyzing parts the result was a recording system. It was capable of sensing vibrations, record data and finally analyze it in software. Reason for making a system like this was not only to make a setup for benchmarking ski characteristics and performance, but also use the knowledge to make a smart ski. The components are in many cases shared.

During the process of making the recording system several small improvements were made. To make the accelerometer weather protected was done by designing a small 3D printed casing. The process of this was interesting in a perspective of prototyping. Instead of taking exact measurements of the accelerometer breakout board, cardboard were used to build the case, test the design, and then take measurements. Insights from making a physical prototype first revealed some design insights useful for the final design. It is hard to compare this process to a “traditional” approach, but the insights were gained fast in the cardboard domain instead of in CAD software or after printing the part. The steps are quickly covered in Figure 4, where the cardboard model (A), CAD model (B) and physical model (C) are shown. This is a good example of a prototype driven process in practice.

For the casing for the microcontroller the tolerances were much lower. Instead of spending too much time designing a casing in CAD software, a potato salad box was stolen from the author’s mother. In the search for a connector for the accelerometer nothing were found in the shelves of the mechatronic lab. The only cable and connector found was a CAT-5 cable used for computer networks. The number of wires was perfect for the accelerometer sensor.

When doing the first testing on snow some practical issues appeared. A need to control the recordings without opening the casing of the microcontroller was exposed. The solution to this was a wired remote that could be handheld during skiing, explained earlier and shown in Figure 10. The probing for a system capable of measuring ski characteristics is covered in the following.

Probing: Measuring vibrations while skiing

Why?

See if recording of vibration data is possible to obtain while skiing. Analyze the data to see if different characteristics can be found from different types of ski conditions and skis.

How?

A trip to the mountains of Sogndal, where SGN is located, was made in February. The recording system was mounted with the accelerometer taped to the ski and the microprocessor inside the jacket of the skier. To better get a picture of how the system work three different skis were tested in the same conditions for benchmarking. The skis tested was SGN Hurrungane 101 in two lengths (179 cm and 189 cm) and 4FRNT Raven (190 cm). During a day in the ski resort Sogndal Skisenter Hodlekve the different skis were tested for several runs in different types of snow. A picture of one of the skis equipped with a sensor can be seen in Figure 13. When analyzing the different runs it was possible to distinguish between different snow conditions from looking at the recorded data. When looking at Figure 14 an example of powder skiing can be seen plotted in the graph as a PSD analysis. Figure 15 shows skiing in the prepared piste. The different characteristic of how the ski vibrated during different conditions was found interesting.

New learning?

Different snow conditions could be separated from the data analysis. A very important finding for further development of a smart ski.

Figure 13: Test setup in Sogndal.

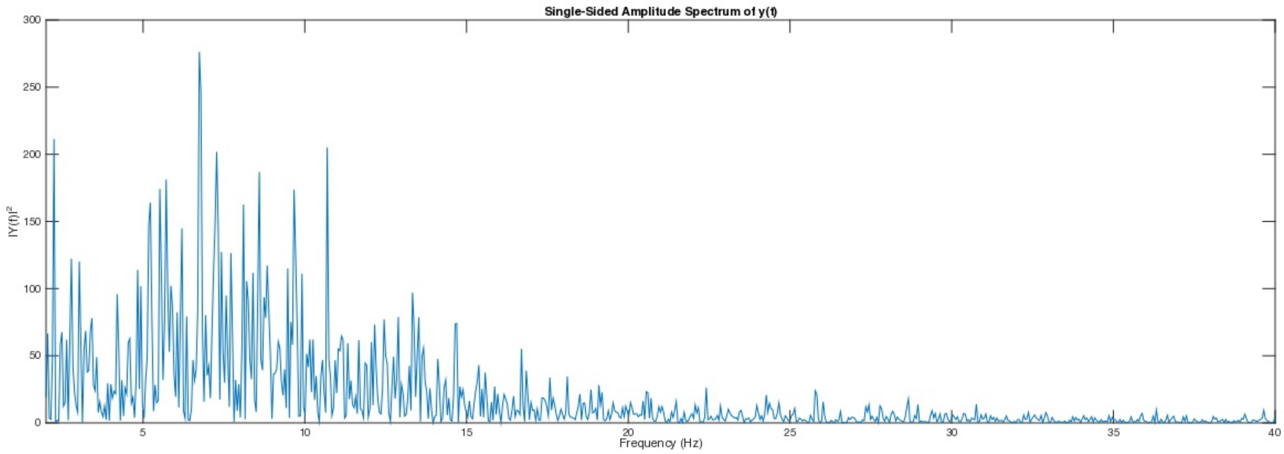


Figure 14: Plot of a PSD analysis done on vibration data from powder skiing.

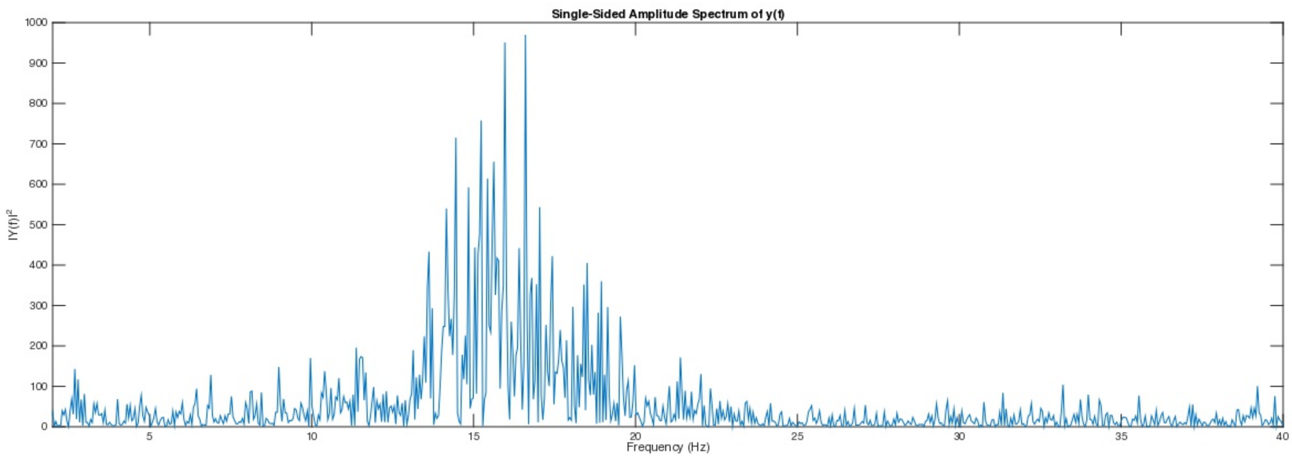


Figure 15: Plot of a PSD analysis done on vibration data from piste skiing.

Probing: Synchronized video and vibration data
Why?
When doing testing with both the microcontroller and the camera the idea of synchronizing the recorded data came up. Was it possible to visualize the vibration data together with the video recorded during skiing?
How?
By installing a GoPro Hero3 on top of the ski together with the accelerometer both video and vibration data could be recorded simultaneously. A trip to the local ski resort, Vassfjellet Skisenter, close to NTNU was made. With the help of the "shitty button" a timestamp in the vibration data and in the video could be made. The data was recorded at a sample rate 100 Hz and the video at 120 frames per second. This could probably have been done more accurate if done with the same sample rate. A code that did the wanted task was found in the internet jungle by searching for similar problems in Matlab forums and check scientific papers. The code was able to combine the video and graph even if the sample rate was different. Figure 16 shows a screenshot from a video with synchronized video and plotting of the vibration data.
New learning?
From the video analysis it was obvious that the ski was moving sideways during certain snow conditions. It was especially clear when skiing lightweight skis. "Side hits" became a term, and was seen as a "pain point" to investigate when making actuators. Just the fact that it was possible to synchronize the video and vibrations was a cool feature, and was seen as a nice evaluation tool for later work. Especially when deeper analysis of the ski performance is needed.

Summary
Roughly the system, after a few iterations, consisted of a sensor (A), a microcontroller (B) and a remote (C), which can be seen in Figure 17. In addition a point-of-view camera could be added to have a visual input as well.

The recording system was able to record vibration data well from first try. The different skis tested had their own characteristics from the analyzed data. It was also possible to distinguish between powder skiing and piste skiing.

To synchronize the video and vibration data was successfully done with the help from a Matlab code. This made it possible to analyze the vibration data with a better understanding of what kind of impact the ski was facing.

Another important finding during the iterations of testing and using the recording equipment was the discovery of what we started to call "side hits", and was found as a result of putting the point-of-view camera on the ski. Especially on very light skis the side hits were obvious when analyzing the videos.

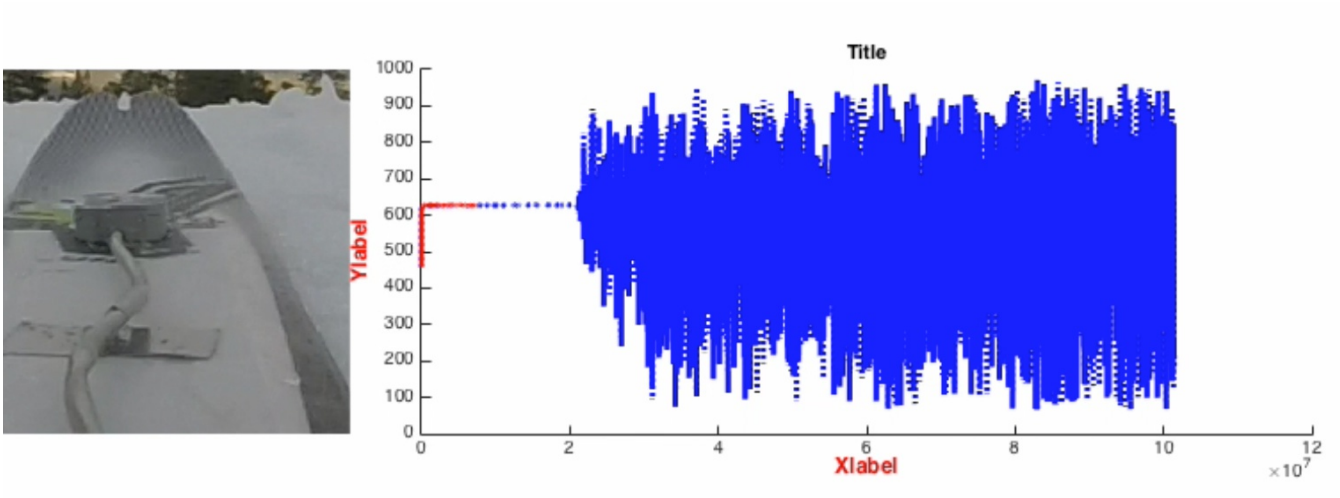


Figure 16: Screenshot from video with synchronized vibration plotting.

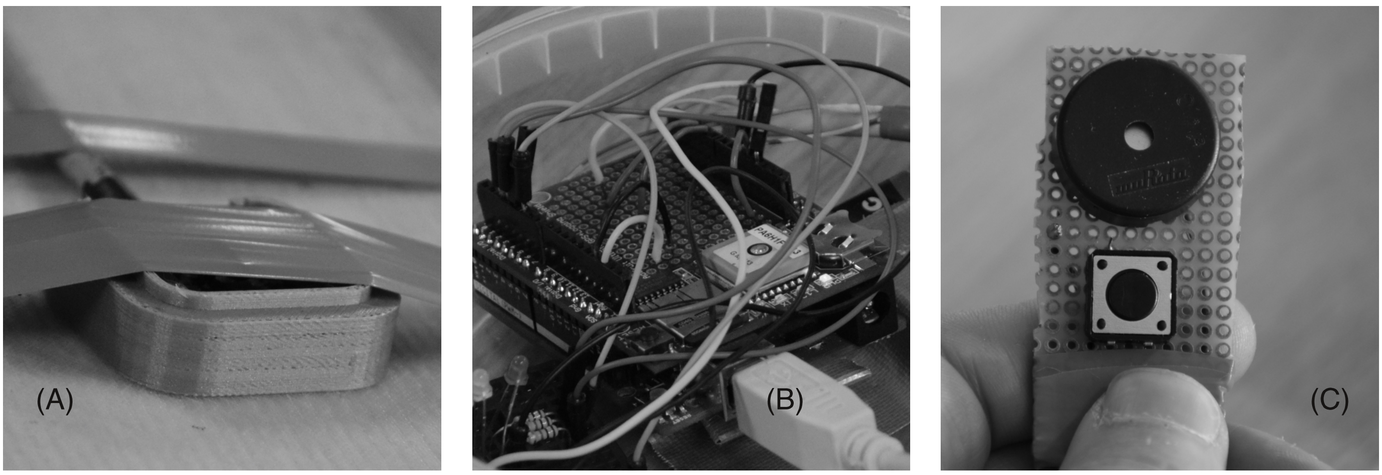


Figure 17: (A) Sensor, (B) microcontroller and (C) remote

How Can We Manipulate a Ski?

Introduction: Mass-spring-damper

A smart ski needs an actuator to manipulate a ski physically. To simplify the problem, a ski can be seen as an oscillating system. In the case of a ski, it is damped harmonic oscillation. The most obvious way to model an oscillating system is a mass-spring-damper system (Härkegård, 2004; Irgens, 1999; Tipler & Mosca, 2007), shown in Figure 18. The mathematical representation is given in Formula 3, where x is displacement, m is mass, c is a damping constant and k is the spring constant. This model was adapted to make a framework for what parameters of the ski to be manipulated. The goal for the wayfaring was to find the most important properties of a ski to change in order to make an actuation system.

Test Setup

The following was the common setup when doing benchmarking and recordings of how to manipulate a ski. The system to measure the vibrations was the one described in "A system for measuring ski vibrations" (an accelerometer, a microcontroller recording to SD-card and a remote). The accelerometer was mounted at the tip of the ski. This is where the amplitude of the vibrations was believed to be at the largest. The analyses were done by help of a Matlab code written. It can be seen in Appendix MC1. The skis tested were mainly the previous mentioned Randorocker and Hagan Y-flow. The ski was clamped by two clamps in the binding area if tests were done in the lab. Reason for this way of fixing the ski was that this was a "worst case scenario" when vibrating a ski. Normally the snow will support and damp the ski.

Formula 3:

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = 0$$

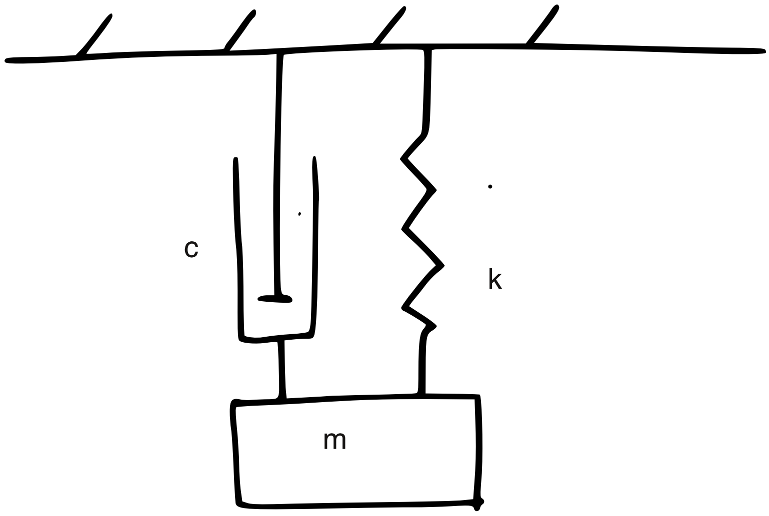


Figure 18: Sketch of a mass-spring-damper-system.

Damper

Introduction

The first parameter to look at from the mathematical model was damping. The aim was to see what possibilities there were to make a damper or utilizing some system to control damping of the ski.

Probing: Spring+mass as damper

Why?

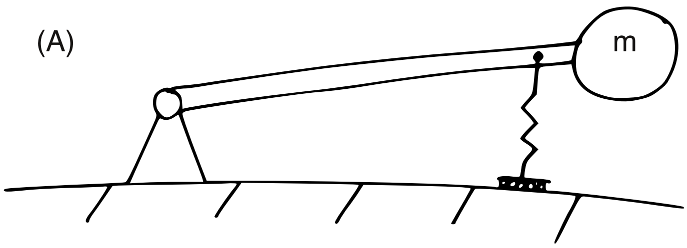
Can we make a damper of a mass connected to the ski?

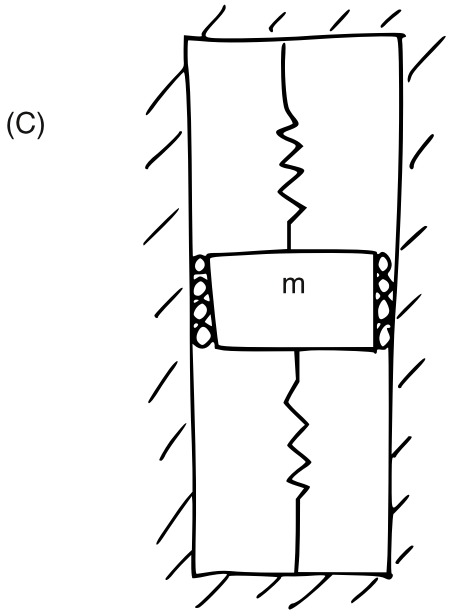
How?

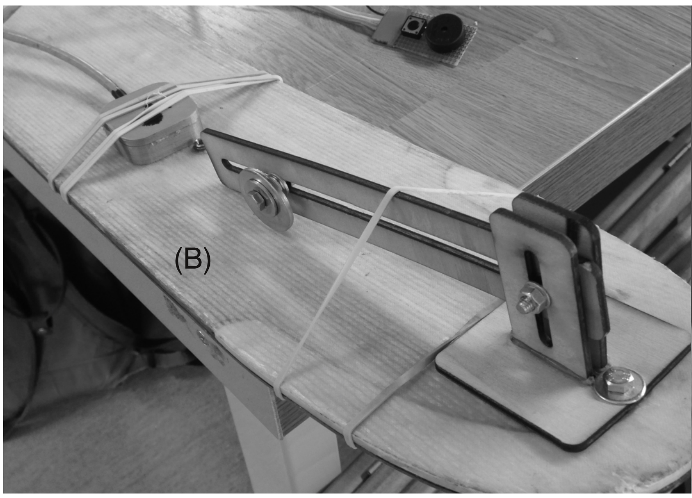
By simply making a cardboard model of a mass connected to an arm pivoting around a point, the first iteration of a damper was made. Visually, when the ski was vibrating, it was possible to see the damping effect of the prototype. The schematic drawing, (A) in Figure 19, shows the principle, and (B) shows a plywood prototype. Next iteration of a damper was to install a long bolt, add some mass that could slide on the bolt, and then add some springs to make the mass oscillating. Figure 19 (C) shows a schematic sketch and (D) a picture of the prototype. The bolt damper was brought out skiing to test the principle in real life.

New learning?

A Simple mass-spring-system connected to a ski with a small spring constant damps a free-oscillating ski well. If the spring constant is bigger, the damping is decreased. There was unfortunately not time to dive into a solution ready for implementation in a real ski. The bolt damper was skied to see how it felt. A small difference was sensed, but not enough to make it to further. The spatial aspect of a mass-spring system was found challenging. A small spring constant would require a certain range of travel to have an effect on the damping of a ski. There might be principles or solutions able to utilize this principle, but this exploring was not prioritized.







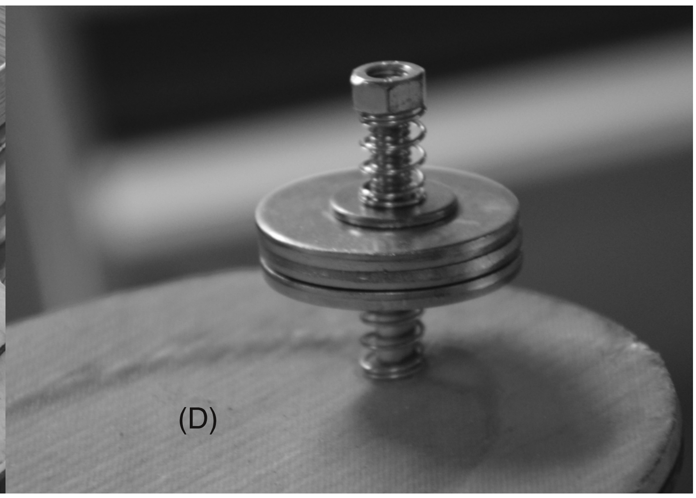


Figure 19: (A) Sketch of a pivoting mass. (B) Prototype of pivoting mass. (C) Sketch of spring-mass-system moving vertically. (D) Prototype of the principle in (C).

Probing: Non-Newtonian fluid as a damper?
Why?
Is it possible to utilize a non-Newtonian fluid as a damper for a ski?
How?
The idea started from playing around with corn starch mixed with water, also called oobleck. From this a small workshop was held. Some of the ideas wanted to be tested was a damper where plates was in contact with a non-Newtonian fluid. If one could change the area in contact with the fluid, would the force needed to move the plates be different? Reason for thinking this was that a shear thickening non-Newtonian fluid most likely would require a larger force to be moved when the contact area is bigger. A sketch of the idea is drawn in (A) in Figure 20. To test the hypothesis of the area relation two plywood prototypes were cut in the laser cutter. The difference between them was the area in contact with the non-Newtonian fluid. They are sketched in (B) in Figure 20. The two prototypes were tested in a cup filled with oobleck.
New learning?
From the testing of the prototypes it was definitely a greater resistance when trying to move them in the non-Newtonian fluid compared to water. When comparing the two versions, the one with a greater area was collecting more fluid (where some of the fluid was trapped between the plates). It was hard to conclude a big difference between the two. There was no doubt that the non-Newtonian fluid made resistance when the prototypes were pulled or pushed through the fluid. This gave certain believe in this being a concept to investigate to larger extend. Unfortunately the time to dive into the details was not there.

Probing: Piezo fibers to dampen or stiffen a ski
Why?
Can we utilize smart materials to manipulate the ski? From other previous work the use of piezo fiber technology has been exemplified (Ashley, 1995; Cass et al., 2003; Rothemann & Schretter, 2010).
How?
When diving into the data sheets from Smart Material Corp. and by looking at (Rothemann & Schretter, 2010), it became obvious that this type of actuators would require a fair bit of electric power to be driven. This made the idea stop here.
New learning?
When reading the paper of (Rothemann & Schretter, 2010) it came clear that they needed a voltage around 48V to power the system, and several batteries were needed. This made it less actual as an actuator. K2 and HEAD used a system consisting of two sets of piezo fibers and a chip. The first set of fibers were to generate power and sense vibration. The signals were then sent to a chip that inverted the signals. As a final step a new set of piezo fibers was working as an actuator. The subjective effect of the system is unknown to the author, but could be interesting to investigate more.

Probing: Gyro
Why?
Can a ski be stabilized by a gyro?
How?
A cardboard model consisting of a electric motor and a rotating disc. Standard test setup to record vibration data. Figure 20 (C) Shows the setup.
New learning?
Small effect from this micro gyro. A bigger one could probably make greater difference. The added mass from a bigger unit is probably too big to be practical on a ski.

Summary
Several iterations were done in order to explore possibilities on how to damp a ski. The experience from the testing was that a mass connected to spring with a small spring constant gave the best results. This was confirmed when talking to vibration experts like Dr.Eng. Dan Östling. The small spring constant made a challenge when it came to the spatial aspect of the solution.

Another interesting idea briefly explored was to utilize the properties of a non-Newtonian fluid. The idea of this came after playing around with corn starch mixed with water, by some also called oobleck. This mixture is acting as a non-Newtonian fluid if it is mixed the right way. A small workshop was held where possibilities to utilize the properties of a non-Newtonian fluid was explored. The concept was only touched briefly, but could potentially be tested in future work.

Something already done by other ski brands was to use piezo fibers to dampen oscillations (Ashley, 1995; Cass et al., 2003; Rothemann & Schretter, 2010). When looking at the possibilities for implementing that kind of fibers it was evaluated as a too power consuming and expensive. The general impression from the probing is that it should be possible to affect the damping properties of a ski, it is just a matter of tuning the solutions.

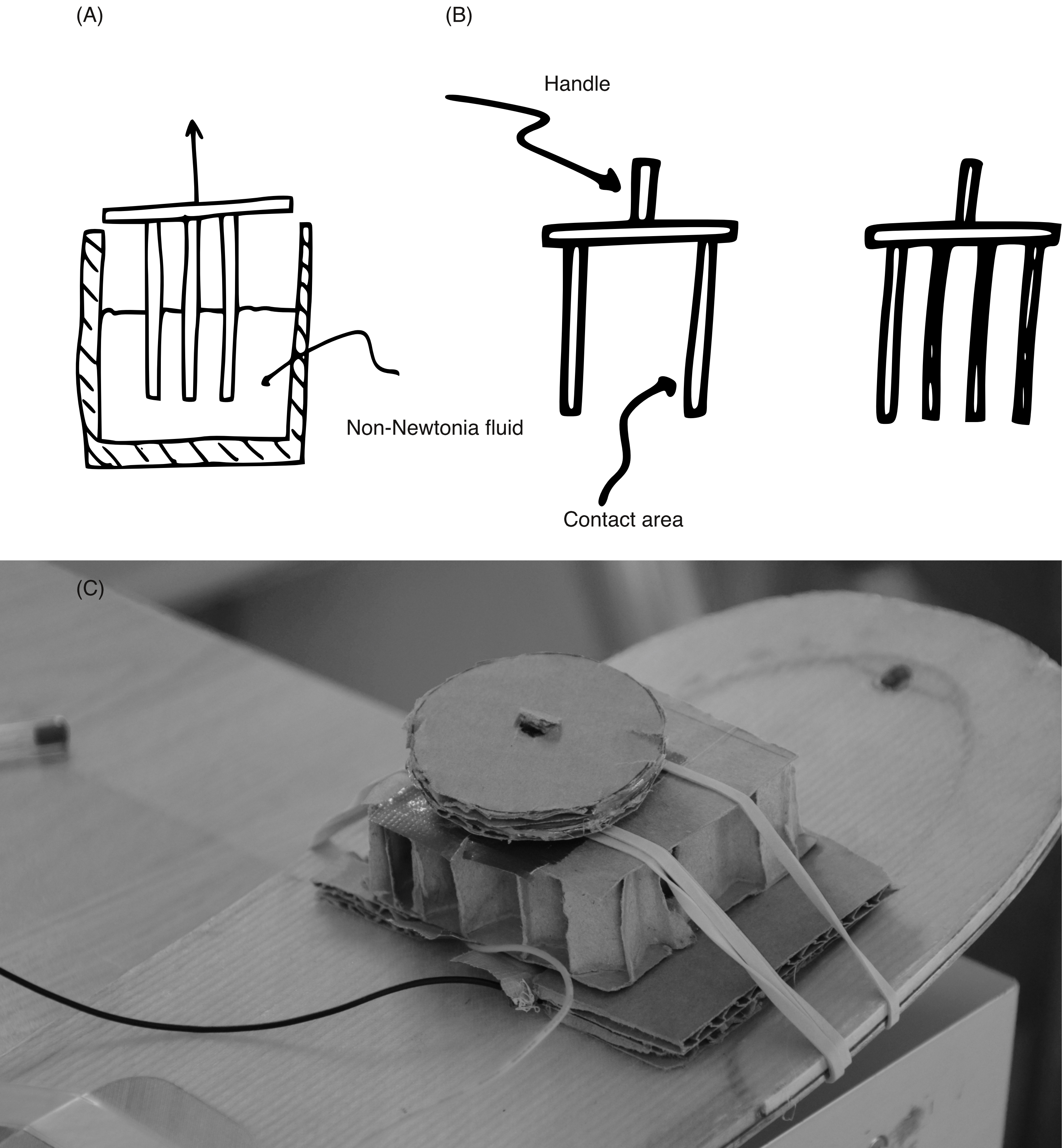


Figure 20: (A): Sketch of a idea on how to make a damper by utilizing non-Newtonian fluid. (B): Sketch of two different prototypes made. The area in contact with the non-Newtonian fluid is bigger in the rightmost model. (C): Gyro test setup.

Stiffness

Introduction

The wayfaring continued by looking at the stiffness of the ski. Again, the starting point was to broadly attack the solution space by having an open and opportunistic approach. One of the key points identified when the goal was to change stiffness was by manipulating moment of inertia (Hibbeler, 2016). The general formula for moment of inertia about the x-axis is given in Formula 4. A denotes the area. X and Y refer to the x and y coordinates and which axis the moment is about. In the specific case of a rectangular cross-section the moment of inertia is given in Formula 5. The parameters b and h denotes width and height of the cross-section respectively. In practice this mean small changes in height of the cross-section will have a large impact on the moment of inertia.

Probing: Adding stiffness to the ski by adding moment of inertia

Why?

As one of the important parameters of an oscillating system, the stiffness or spring constant is interesting to investigate. Could a solution be made to manipulate the stiffness of the ski?

How?

To get a fast input on the effect of added moment of inertia simply some small boards of plywood were added to a ski. The solution is shown in (A) in Figure 21. The idea was to have a spring leaf inspired solution replicating the increased cross section a ski normally have. Simply by making some inserts for bolts along the front section of the ski the plywood boards were attached. The test setup is shown in (B) in Figure 21.

New learning?

The plywood added made the ski slightly stiffer. Flexing the ski by hand made an impression of a stiffer ski. This was confirmed when doing some quick measurements in the lab. What also was interesting was the fact that the plywood boards had a dampening effect on the ski. This was most likely due to the fact that wood is a fairly damped material compared to the composites in skis. What also might have caused the dampening is the friction between the plywood layers or the friction between the plywood and the ski.

Conclusion

A simple prototype was made to confirm the effect when adding moment of inertia. It did not include an active and dynamic part, but the added structure to the ski was having an effect on the behavior of the ski. This probing made it interesting to investigate this parameter more in depth. Interestingly, the prototype that were made of plywood, was also giving the ski a higher damping rate.

Formula 4:

$$I_x = \int_A y^2 \, dA$$

Formula 5:

$$I_x = \frac{bh^3}{12}$$

Figure 21: (A): Prototype of adding stiffness by incrasing moment of inertia. (B): Testing the setup in (A).

Mass

Introduction

Mass was the last of the parameters investigated in the mass-spring-damper-system. Several ideas were tested. First thing to check out was to see what effect adding a stationary mass could have. This was something already done by other ski manufacturers in different ways. EVI skis have several skis where “nockers” are delivered with the skis. The additional mass makes the ski more stable according to EVI skis. This makes sense from a physical perspective too. Greater forces are required to vibrate and shatter a heavier ski. Several materials and placements of mass were tested in order to see if the added mass was having an effect. From the different test data obtained, the added mass was seen to have an effect. In the case of making an active system to add a static mass was not bringing the actuation function further. To look at more dynamic solutions were considered to be the direction to move in. The probings are described in detail below.

Probing: Stationary mass

Why?

To verify that mass is having an effect on an oscillating skis. Easier to test the adding of a static mass compared to a dynamic mass system.

How?

The ski was set up the standard way, as descibed earlier. With the ski clamped to the table, a mass was fixed to the ski tip, and the accelerometer sensor was attached to the tip area as well. Different masses were attached to the ski in order to benchmark the effect of changing the additional mass. Figure 22 shows an example of different masses added. A plain ski is shown in blue, an added mass of approximately 100 g in yellow, and an added mass of approximately 150 g in red. As can be seen from the figure, the added mass makes the ski oscillate at a lower frequency and with smaller amplitude.

New learning?

Adding mass makes the ski oscillate at a lower frequency. Can this be utilized in a dynamic system?

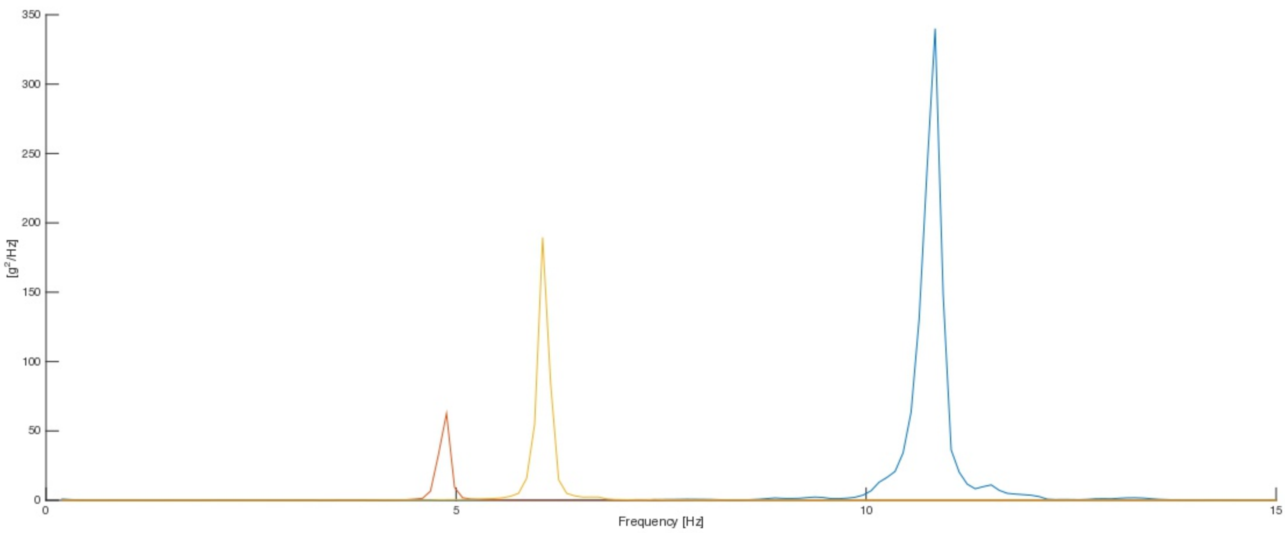


Figure 22: Plot of a PSD analysis where three different cases of added mass was measured. Blue is without any extra added mass. Yellow is approximately 100 g added to the tip of the ski. Red shows approximately 150 g added to the tip.

Figure 23: Prototype of moving mass.

Probing: Moving mass
Why?
From seeing the effect of adding mass to the ski, the idea of moving a mass was interesting to check out. When comparing two similar skis where the mass was the main difference the heaviest felt more stable. Could this be a parameter to change while skiing?
How?
The first test of a moving mass was done with a bolt slid through a flexible PVC tube. The setup can be seen in Figure 23. This was just a preliminary probing, so the resolution and fidelity was low. The main thing to find out was to see if there was an effect of moving mass while the ski was oscillating. To see if there was a difference between the ski with and without a moving mass, the ski was tested both with the added weight stationary and when the weight was moved from the middle of the ski to the tip. Figure 24 shows the vibrations recorded when the mass was stationary. The case of a moving mass is shown in Figure 25. When comparing the two it is possible from acceleration vs. time plot to visually notice a faster damping of the ski. When looking at the PSD plot it is possible to see the accumulation of the oscillating frequencies is lower in the case of a moving mass. This was a confirmation of the idea of a moving mass, and a reason to continue the probing in this direction.

After having a small workshop together with a co-student an idea of having a fluid as mass came up. Simply because the weight of a fluid is fairly high, and it is interesting in terms of how it can be moved from one position to the other. A setup was made from two 60 mL syringes connected to each other by a PVC tube. This made it possible to move water from one syringe to the other, hence moving mass from one point to the other. The first test setup is shown in Figure 26. It was working better compared to the first iteration where the bolt was sliding in a tube.

Since this was a system meant for skiing, to make a prototype for a ski was considered necessary. First test went bad before it was run. A trip to Rasletind, Jotunheimen, Norway was made to get some test data. There was no ski lift there, so the ascending was by skinning up human-powered. Unfortunately the syringes got a leak during the ascent, and were empty when arriving at the top of the mountain.

Next iteration of the syringe system was then made. This time holders made out of medium density fiberboard (MDF) was made to keep the syringes fixed to the ski. The holders were

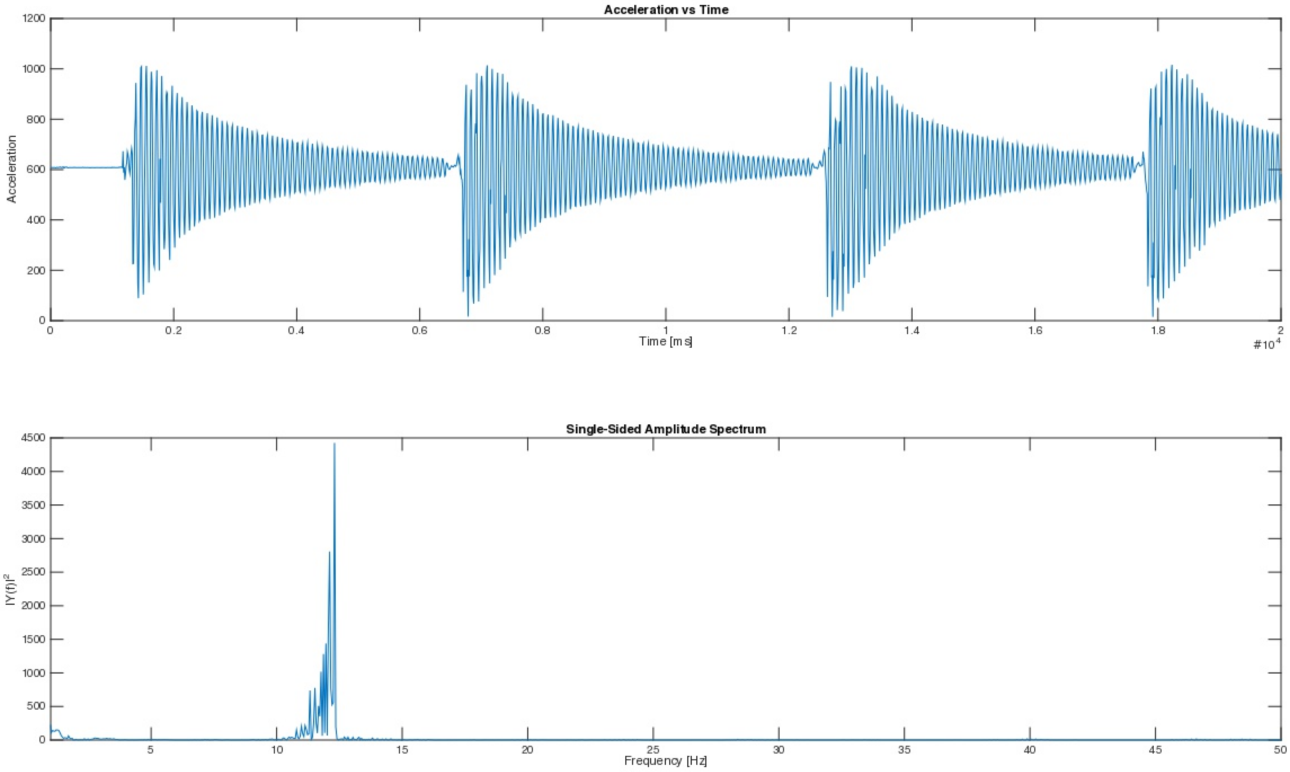


Figure 24: Plot of a PSD analysis where the mass was stationary.

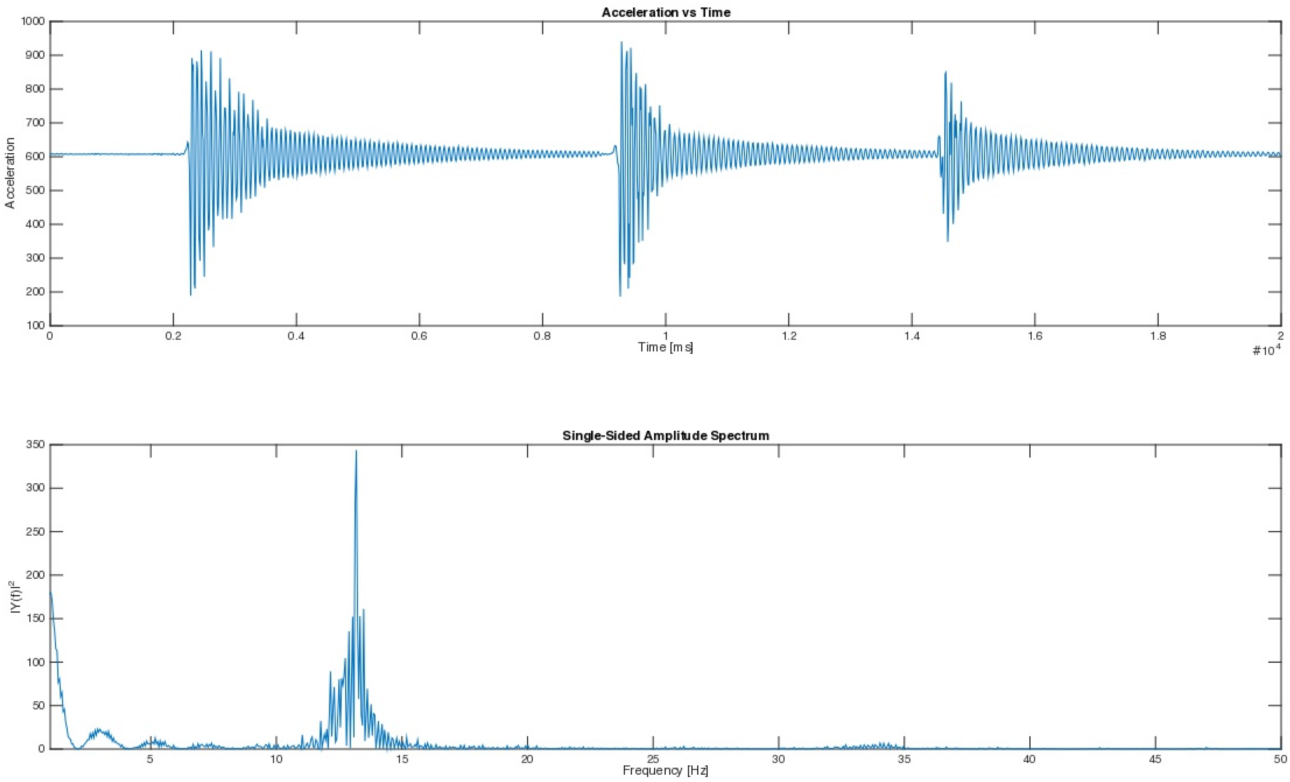


Figure 25: Plot of a PSD analysis where a mass was moved from the middle of the ski to the tip.

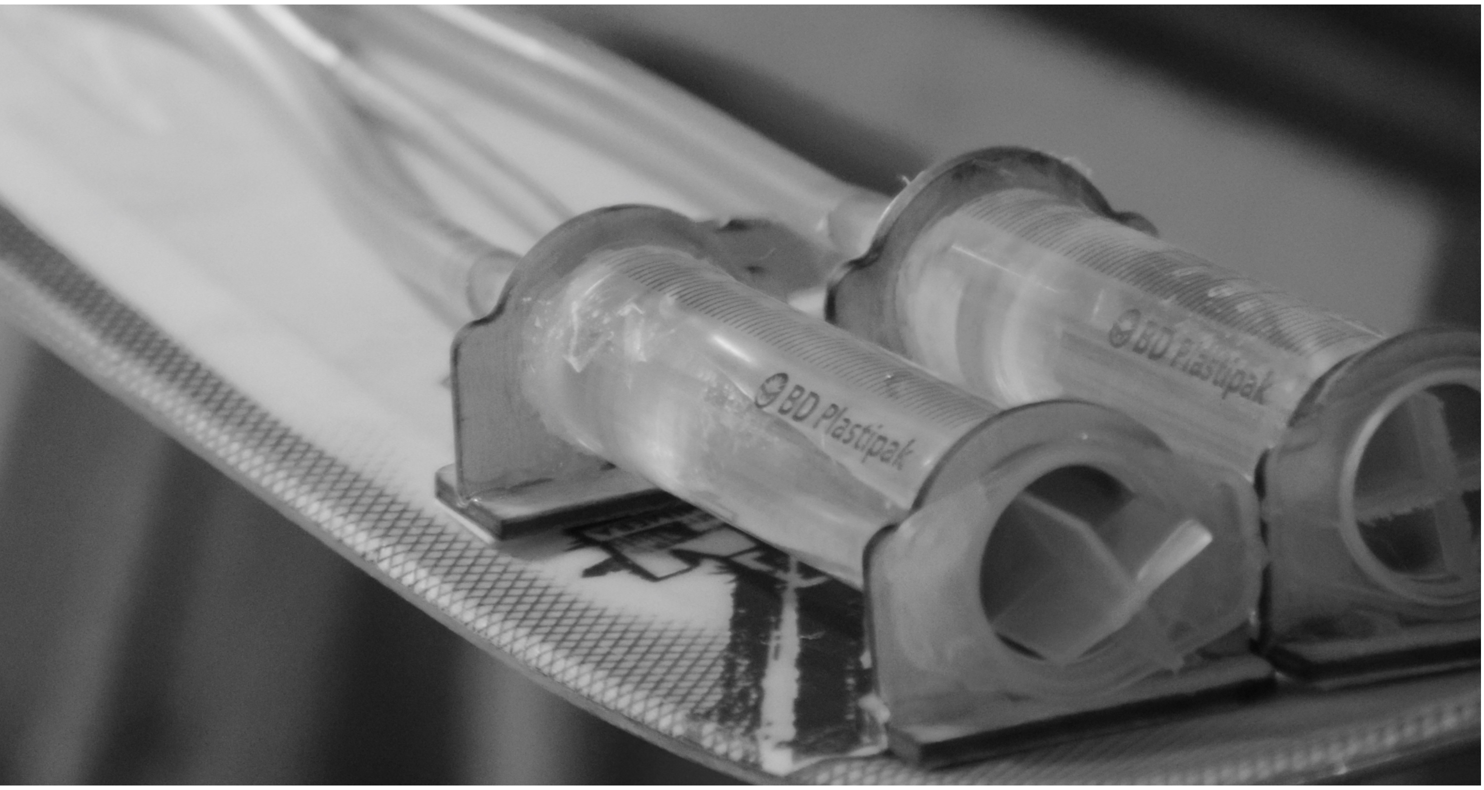


Figure 26: Prototype of moving mass by help of syringes.

designed by help of cardboard in the sketching phase, drawn in CAD software and cut in a laser cutter out of 3 mm MDF. This time a trip to Blånebba, Romsdalen, Norway was made to get feedback on the idea. The best feedback would be to have other skiers outside the project to test the prototypes. The author and an external tester were equipped with skis where syringes were fixed to the ski. The syringes made it possible to manually move mass from a position near the toe of the boot to the tip of the ski. Figure 27 shows how the system looked like. Unfortunately the MDF was performing bad when wet from the snow. Most of the syringes fell off either when skinning up or skiing down. Luckily the external tester got to do some descending with the mass at the tip of the ski. His feedback was that the ski had more grip and was more stable when the mass was added to the tip of the ski. This was confirming the idea of added mass, and made it interesting to continue with the idea of a dynamic mass distribution.

The next iteration was about to improve how the syringes were fixed to the ski, and to actually get data where the mass was positioned in different positions. Some quick benchmarking was done on how well different materials were sticking to the ski when fixed by double sided tape. The MDF performed poor, whereas plywood and acrylic glass was fixed to the ski in a good way. Plywood was chosen because it was cheaper and performing the same way as acrylic. The same shape as the MDF holders were used when cutting the plywood holders in the laser cutter. The holders were glued to the syringes and fixed to the skis by double-sided tape. The setup is shown in Figure 28. This time the syringes were kept in position during skiing, and were not prone to falling off when in a wet and snowy environment. Three test trips were made to test the new setup. First one was in Oppdal, second Ruten and last one Hurrungane. All of them located in Norway. The test setup was a Hagan Y-flow ski in length 181 cm with an ATK RT binding and Dynafit TLT5 boots, the syringe system described above was installed and an accelerometer sensor mounted on one of the skis. See Figure 29 for a detailed picture of the setup. An external tester was testing a similar setup during the testing in Oppdal. The test setup can be seen during the testing in Hurrungane in Figure 30.

What could be told from the analyses? The plot in Figure 31 shows a recording of the ski when skied with the mass at the tip. Figure 32 shows a recording when the mass is placed close to the toe

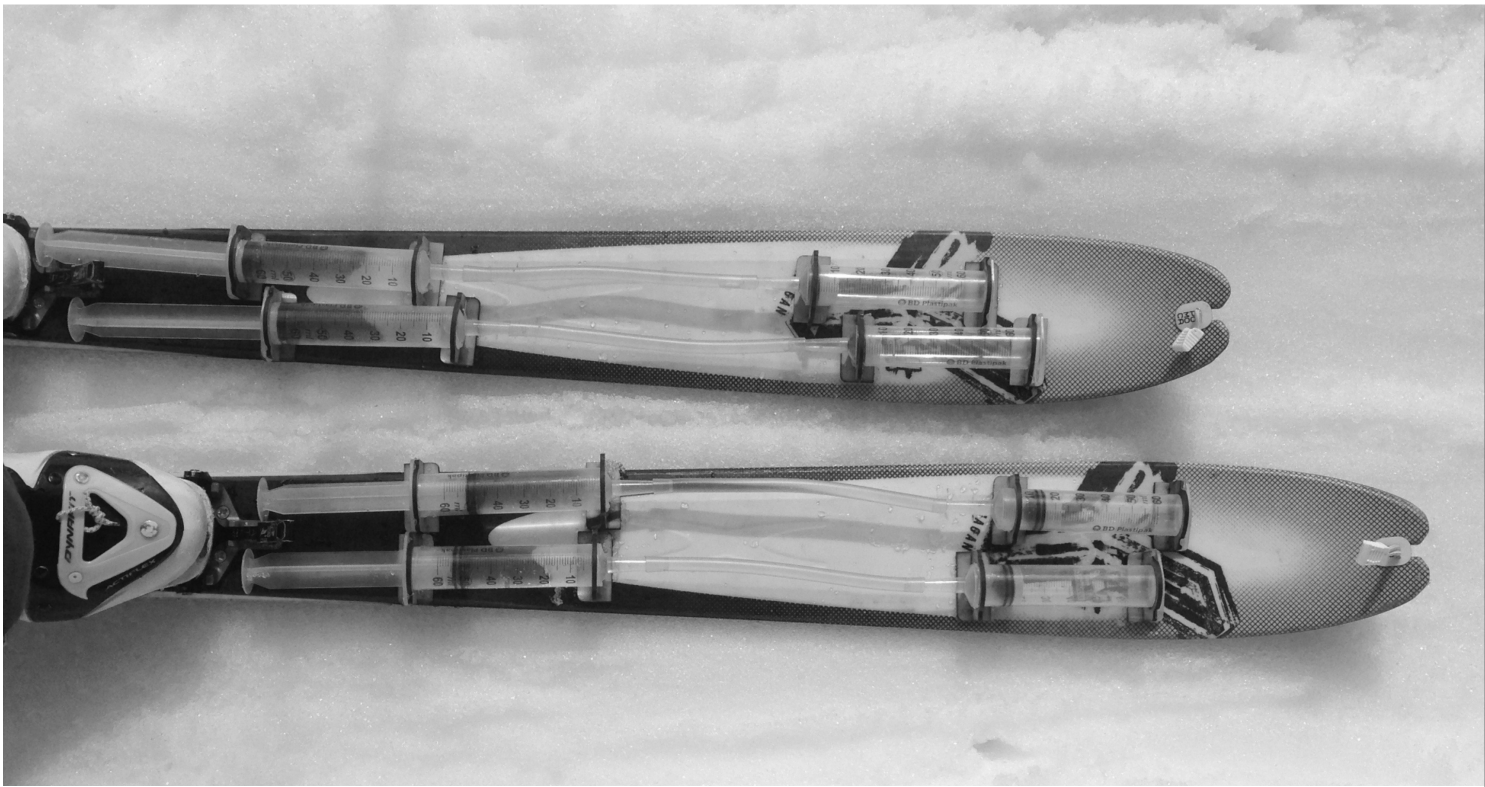


Figure 27: Prototype of moving mass by help of syringes while testing in Romsdalen.

of the boot. When looking at both plots there are not a significant difference in the data. What was subjectively felt during testing was that the ski was more stable and more force was needed to rotate and move the ski. The measured data could not confirm this with big conviction. Is it the added mass or the fluid that is playing the biggest role? When comparing the ski with and without the system, there was definitely a subjective difference between the two, this was confirmed by the external tester too. The plot in Figure 33 is from skiing the Hagan Y-flow ski without the system mounted. When comparing the plots in Figure 31 and Figure 32 with Figure 33, one could argue that the only difference is some less activity in the 5-10 Hz range. This is only a marginal difference, but could be reason to explain why the subjective feeling is different. For the next iteration of testing it could be useful to benchmark a fluid vs. a solid as mass, because the fluid itself could have a damping effect.

New learning?

Quick, low-fidelity and low-resolution prototypes result in fast learning. Instead of doing too much detailing before testing, the result from doing fast prototypes and several iterations is a fast way of doing product development.

There is a difference in ski performance when a mass is dynamically moved from the front of the boot to the tip of the ski. From the PSD analysis the magnitude of the oscillating frequencies seem to be lower in the case where the mass is moved during the vibrations.

At some point the water froze in the syringes, making it hard to move the mass. This was not seen as a big problem, but some investigation was needed.

The most important feedback from this probing was the dynamic mass distribution being something that made a subjective felt difference when skiing. To investigate the effects of a fluid vs. solid further could be interesting. Further investigation on the concept is needed in order to conclude if the concept is applicable in a smart ski concept.

Figure 28: Plywood syringe holders.

Figure 29: The setup while testing in Oppdal

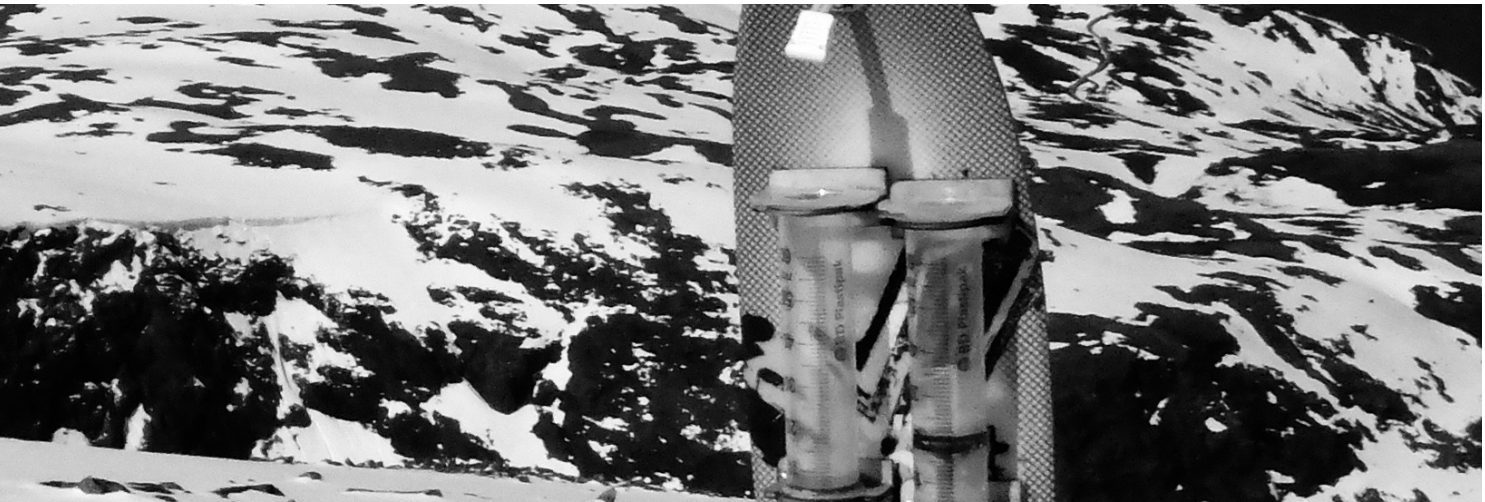


Figure 30: Test setup in Jotunheimen.

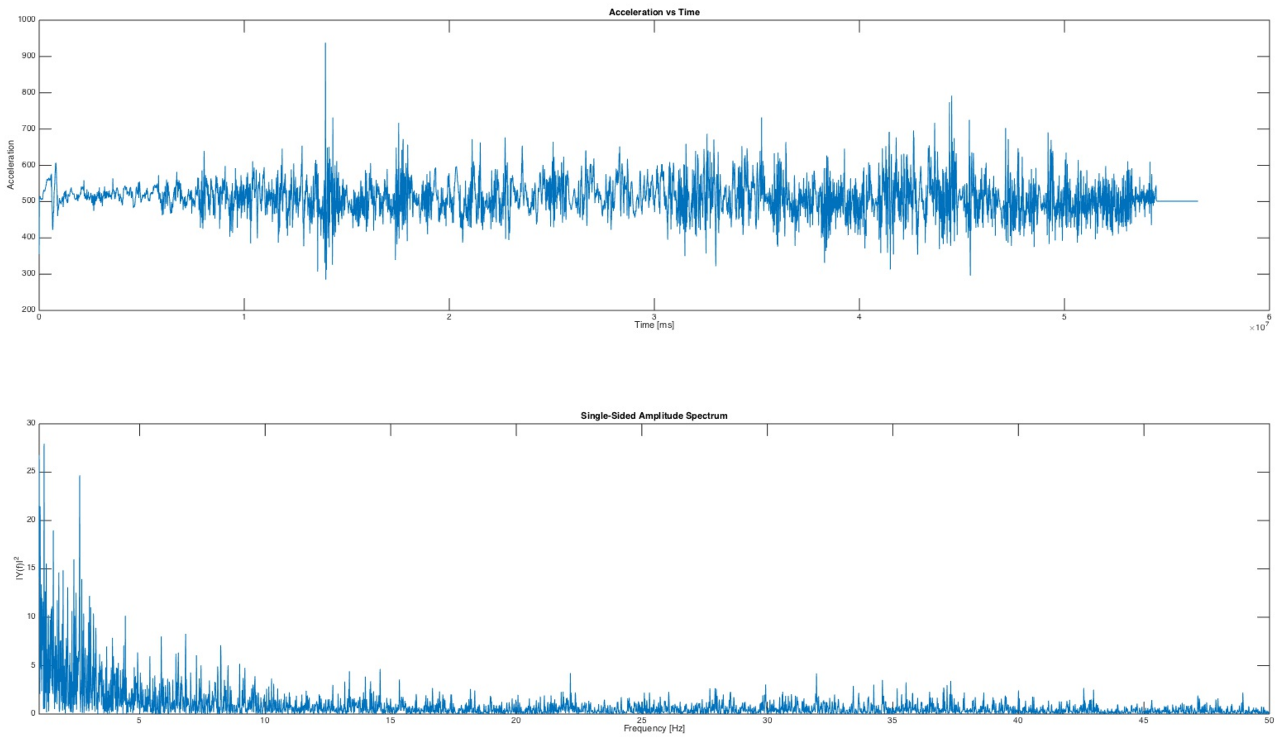


Figure 31: Plot of vibration data and a PSD analysis where the mass was stationary at the tip of the ski.

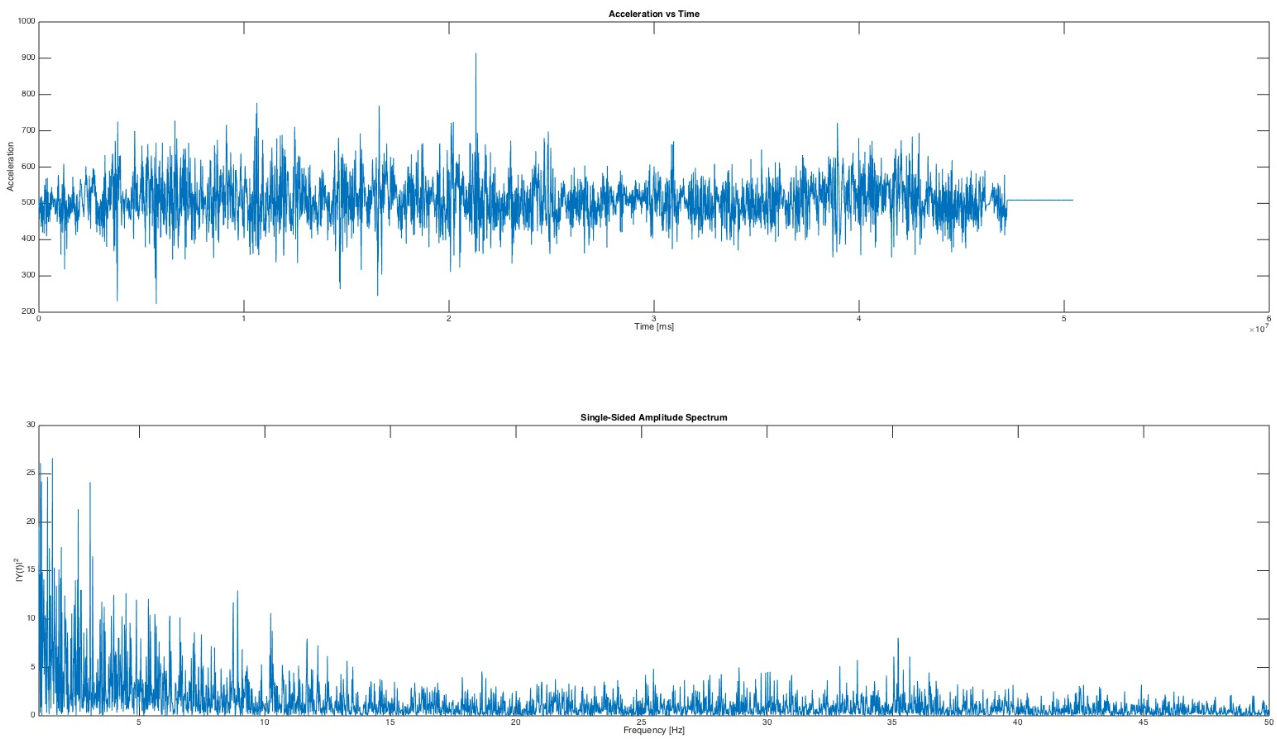


Figure 32: Plot of vibration data and a PSD analysis where the mass was stationary at the front of the boot.

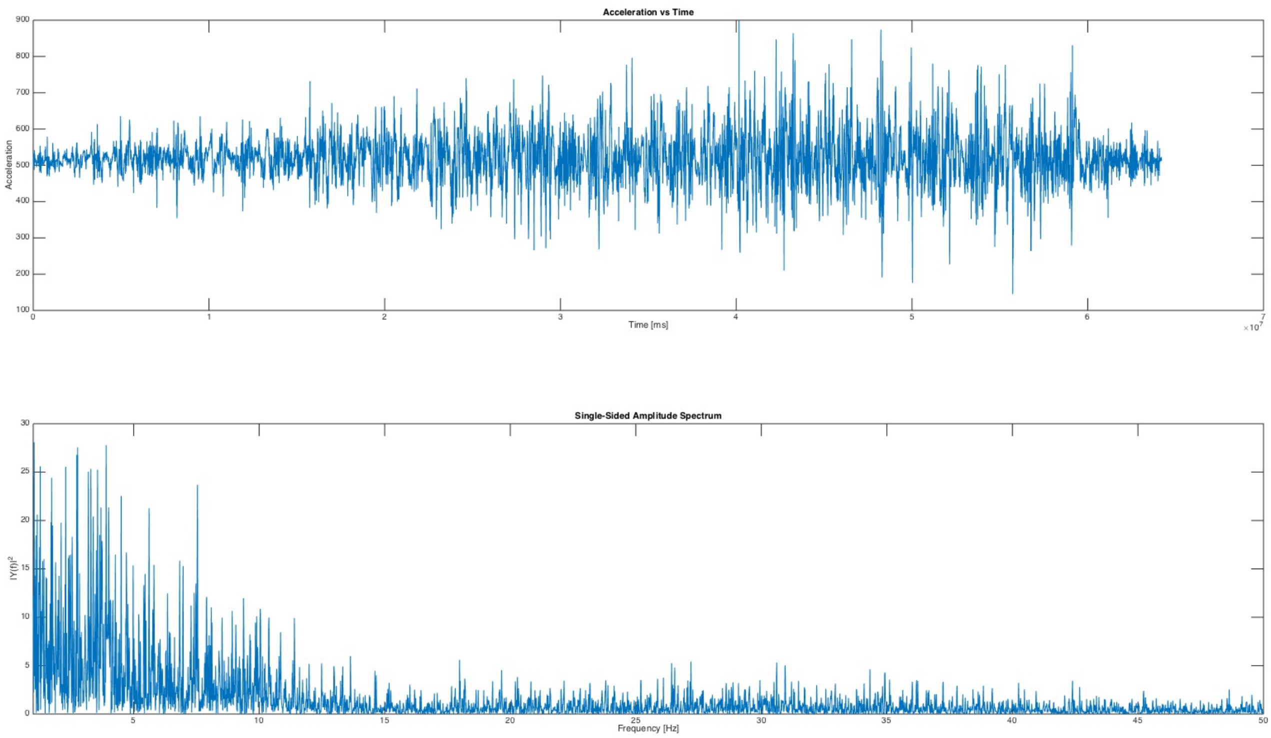


Figure 33: Plot of vibration data and a PSD analysis without the syringe mass system.

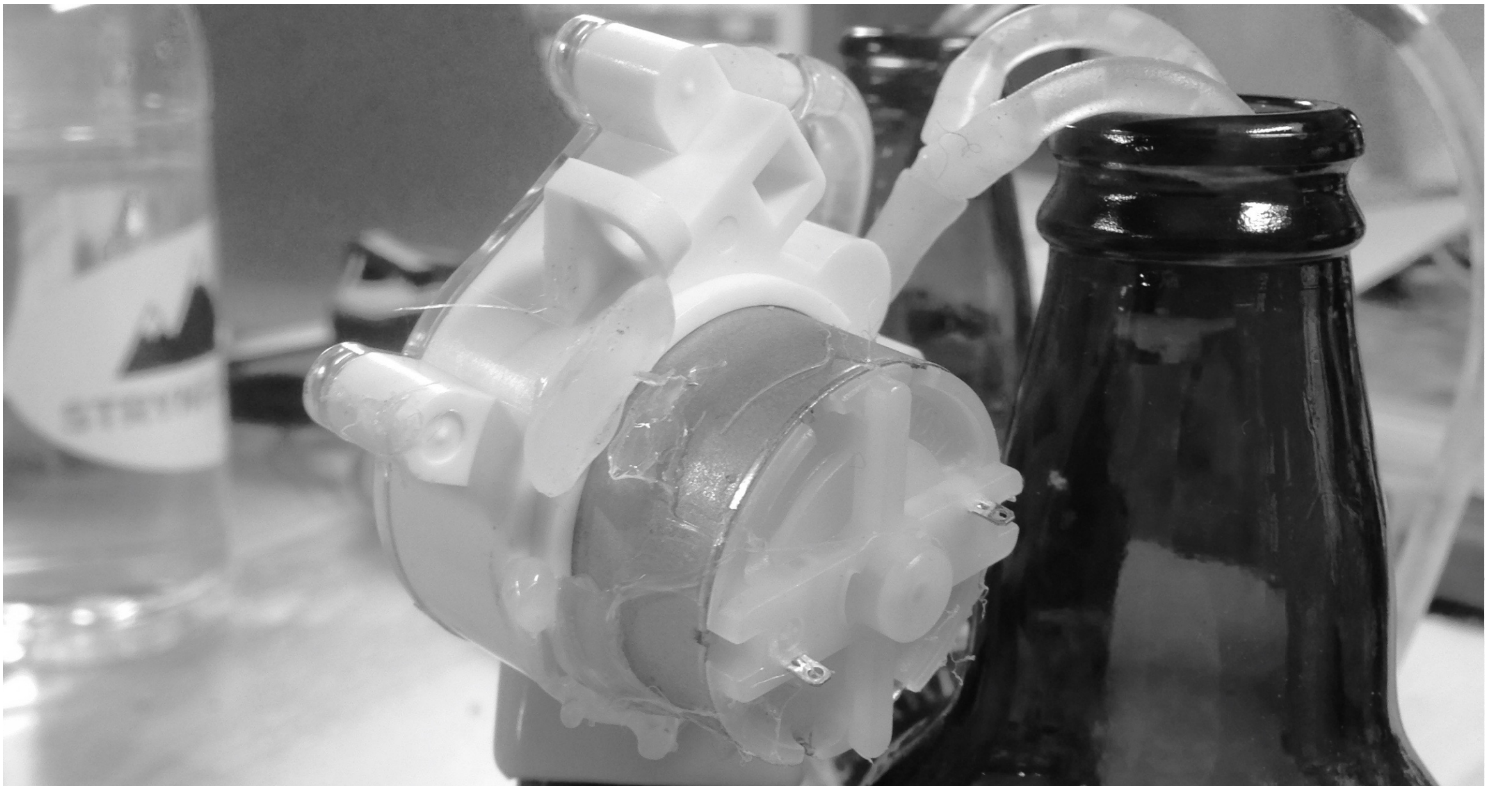


Figure 34: Testing peristaltic pump.

Probing: What kind of fluid?
Why?
Water freezes in temperatures below zero degree celsius. Are there fluids heavier than water out there?
How?
First thing tested was to make a salt solution. This would solve the freezing problems to a certain degree, but also add mass to the fluid. By putting salt solution into the syringe system weight was increased by 30%. The freezing temperature was not tested, but should at least be some degrees lower than zero degree celsius. If increased density was the main goal then mercury should be considered. Unfortunately the use of mercury is not advices due to the high toxicity.

By looking at other fluids used in cold environments, alcohols is obvious as candidate. Two alternatives were found from searching around the world wide web of internet. Glycerol and ethylene glycol. The minimum freezing point potential is -37 degree celsius and approximate -45 degree celsius. Glycerol is used in food application, most likely making it an environmental and nature friendly alternative. The density is also higher than the one of water, with a density of 1,261 g/cm^3.
New learning?
The use of a salt solution could increase the weight of the fluid by 30%. If water is replaced by glycerol the weight of the fluid is increased by 25% and freezing temperature decreased to -37,8 degree celsius.

Probing: How to move a fluid?
Why?
In order to make an actuator based on a fluid system, a way to move fluid was needed.
How?
First iteration was to test a peristaltic pump. The setup was just a peristaltic pump connected to an Arduino, where it was tested to move some fluid as shown in Figure 34. For the use in a ski this solution seemed too bulky and slow.

The search for a good solution to move fluid continued with a basis in the syringe system already made and described earlier. The first thing that came to mind was to use a pump for moving the fluid from one cylinder to the other. How can this be tested in a quick way? One solution could be to make a simple pump mechanism in a CAD-software and then 3D-print it. That would probably take at least one or two days to design, and then one day to print and install. There would also be a big chance to fail on the design, ending up with a

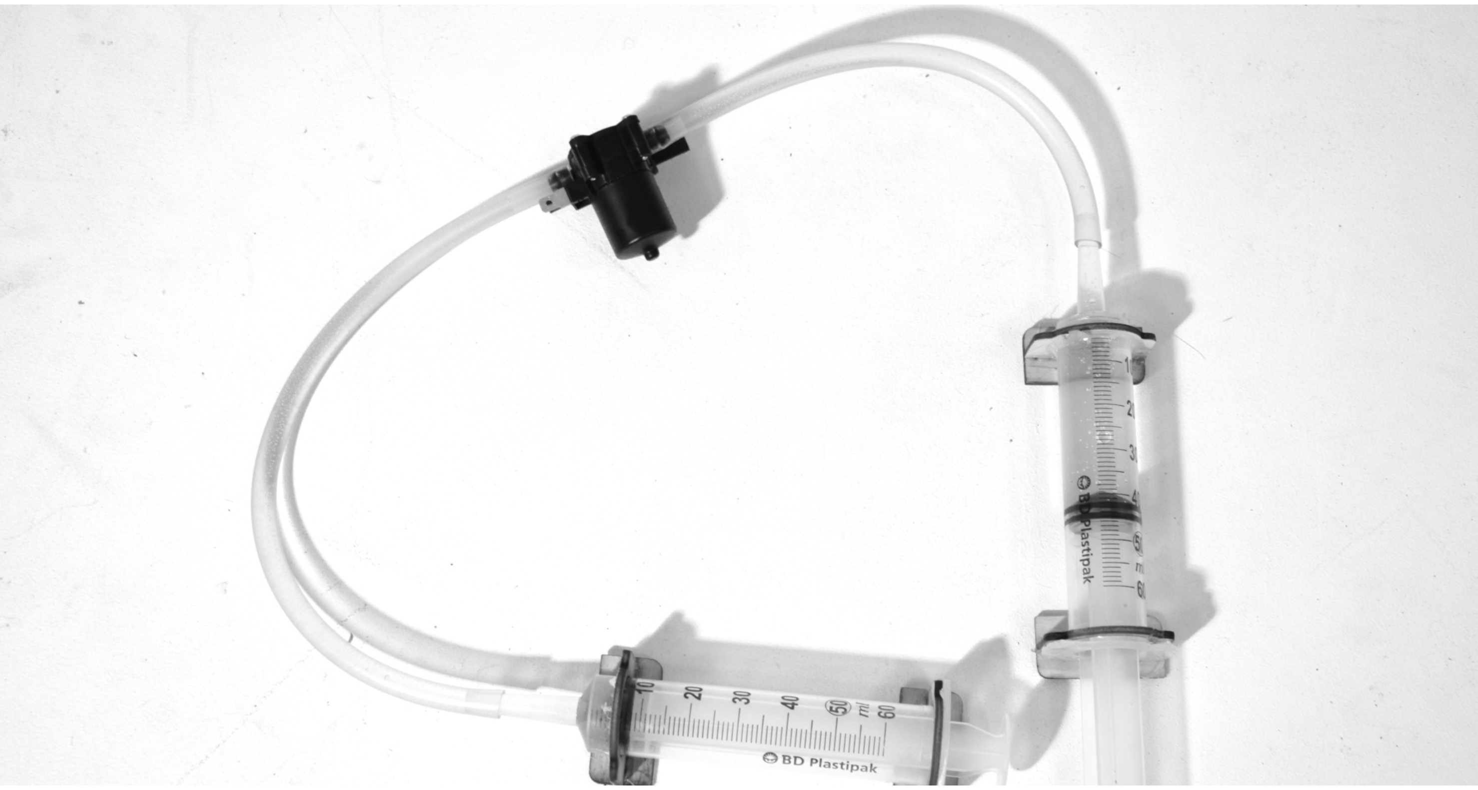


Figure 35: Windshield washer pump.

useless pump. Focus shifted quickly from trying to make an own design to check if existing pumps at the right scale were available. This could be a simple way to get a confirmation on the idea of using a pump. Where do you find pumps fitting a custom test setup? The search for a pump started, ranging from aquarium pumps in pet shops, to radio controlled boat water jets, to garden hose pumps driven by a drill, to windshield washer pumps. Luckily, this takes just a short while when searching the internet. The best off-the-shelf solution found was a windshield washer pump from Biltema. The pump fitted the syringe setup with minor modifications, see Figure 35 for details. The pump was rated to work in the range from 0-12V. It worked fine when pumping water from a cup. When connecting the pump to the two syringes the pump was only spinning without moving water. Some more attempts were made, but none could make the pump move the water from one syringe to the other. The reason why it did not work was probably that the pump was unable to work when the pressure on the outlet was too high. It could be because of the design of the pump, and a different type would work fine. Unfortunately the time to discover more of the pump mystery was not there.

Initially the idea of having a linear actuator was thought of as too bulky and bigger than a small pump. It was thought of as possible to make a linear actuator move a piston in order to move fluid. This was left to discover in future projects.

New learning?

To use a windshield washer pump or similar design of a pump was not sufficient. To make a linear actuator or a small servo or motor could possibly be a solution to move the pistons.

Summary

To add a static mass was tested. Positive results were obtained. Added mass decreased the oscillation frequency and amplitude of a freely oscillating ski. A prototype of a system where mass distribution manually could be changed was made. Three skiers tested the system. The main feedback was that the skis felt more stable when the mass was in the position at the tip. To make an actuator out of the idea was also tested. To move the fluid by a pump failed. By help of a small linear actuator it should be possible to move the pistons in a cylinder, making a change in the ski's mass distribution possible. This was not tested, but is believed to be a possible solution.

How Can We Make a Control System?

Microcontrollers

Several microcontrollers could possibly be utilized in order to make a control system for a smart ski. During this work an Arduino Uno was the base of all the microcontroller tasks needed. If the algorithms are based on easy coding there should be enough computer power in a simple microcontroller of the Arduino type. If things are scaled up and the processing power and memory required is of a more demanding character, other microcontrollers should be considered. A prime example of compact computing power is all the smartphones available. The computing power would most likely be good enough to run advanced algorithms and more heavy calculations. During this work only some simple control algorithms were written and tested in the Arduino language. Two challenges when dealing with electronics in a cold and wet environment is weather protection and battery life during those conditions. An example of electronics operating in these conditions is point-of-view cameras. This gives reason to believe a microcontroller embedded in a ski could work. What also could be a potential solution to make charging of the system easier, is to utilize inductive charging. This is already done in smartphones and toothbrushes.

Programmed algorithms

The easiest way to make a control system is probably to have a threshold value to activate or deactivate an actuation function. To make it more advanced is a matter of increasing the number of inputs and outputs and make the algorithms more advanced. This might be smart “enough” for a smart ski. If the sensor and actuation part is chosen with care, there might not be a need for an advanced algorithm as the system in total is having a great impact on the user or system, giving the impression of being smart.

Probing: Self-made altimeter with threshold values
Why?
See if is it possible to make a small system to distinguish between different vertical speeds. This could possibly be part of a smart ski control system.
How?
First round was a fast iteration just to check if the barometer could measure the rise in air pressure when descending, and is described when probing for a way of measuring vertical speed.

Next round was to analyze the data obtained in the first iteration to find suitable threshold values. In this case the system was tested while walking in the stairs at the university. This gave other threshold values compared to the ones when skiing. The analysis resulted in an Arduino code, shown in Appendix AC4. The code could by means of LEDs communicate if the person was slowly descending, descending medium speed or running down the stairs. Basically the code had threshold values for the different descending speeds, and by continuously measuring the barometric pressure and checking against the threshold values, the system was able to tell the descending speed sorted in three different states. Each state had its own colored LED. The sensor and system can be seen in Figure 8. The system worked fine when testing it in the stairs of NTNU.
New learning?
To use a barometer to distinguish between different descending speeds was found useful. It should be possible to implement in a smart ski system without big difficulties. The threshold algorithm worked out fine. There is nothing in the way of implementing more sensor data and make the algorithms more advanced.

Summary
During this work only simple algorithms were made in order to confirm the possibilities a microcontroller could have. Based on barometric readings and a small microcontroller an algorithm capable to distinguish between three different descending speeds was made. This example was with descending speed when walking in stairs, but the code could easily be adapted to other cases where an object is descending, e.g. skiing. There is nothing in the way of implementing more advanced code in a smart ski system. What was thought of during this work was to have an algorithm that by help of input from a barometric sensor and a vibration sensor could distinguish between high speed skiing above the treeline and playful skiing in the trees. This would most likely not require too much from the microcontroller. More probing is

Artificial intelligence and machine learning

There is no reason to restrict the possibilities for the processing part in a smart ski concept. Computing power is getting cheaper and smaller in spatial dimensions. For simple calculations, e.g. the vertical speed code made, the processing power needed is minimal. To bring the smart ski concept to the next level implementing artificial intelligence (AI) and machine learning could be a solution. One vision thought of is to utilize machine learning algorithms where sensed ski characteristics and actuators are taught by live feedback from the skier. The skier could filter what is felt during skiing into two categories, for example good and bad ski behavior. The machine learning algorithm could then actuate through an actuator, and by time learn what kind of response the skier prefers.

Recently there have been done work at TrollLABS where machine learning has been implemented in a chair (CH.AI.R). The chair is able to distinguish between different sitting positions by the help of sensors, a processing unit, and a screen to display the positions. Further development would possibly involve actuators to adjust the chair's position to optimize the seating experience for the user. This exemplifies what could be done in a smart ski. To explore the possibilities would depend on the rest of the system to be working. An artificial intelligence solution would depend on a proper actuation component for the ski and a computer hardware and software platform to be made. In this work the confidence in the sensor part is high. This is not seen as an impossible task technologically, and is just a matter of taking the time to discover and develop the missing sub-systems. Finally a “brain” of the smart ski could then be developed. This is left for later work.

Chapter 4
Results

A Conceptual Smart Ski

Starting from scratch on what the concept of a smart ski should consist of, there were no rules or limitations on what the concept should end up with. By doing a lot of probing a good feel for what a smart ski potentially is has been obtained. Some of the parts still need more exploring in order to be fully trustworthy. A conceptual smart ski will be presented in the following based on the findings in this work.

Some of the components explored have proved to be solutions with potential for a commercial product. When it comes to sensors both the accelerometer and barometer have been tested to a large enough extent to verify the usefulness in a smart ski concept. Both have provided good results when tested separately. The accelerometer gives input on the vibrations of the ski, an important characteristics of a ski when skiing. The barometer reads out the barometric pressure, which can derive the vertical speed when recorded over time. These two data inputs could be combined and serve as inputs in a controlling algorithm or a machine learning algorithm.

A lot of probing has been done to discover a principle to effective manipulate the properties of a ski. Some of them have only been checked briefly. Still more exploring can be done. The most promising concept tested during this work was the dynamic mass distribution system. The idea was that a system capable of changing the mass distribution of the ski by moving mass in the form of fluid would make a ski perform better. When skiing on hardpacked snow or during high speeds it was thought of as good to have more mass close to the tip of the ski. During tree skiing the need for a more playful ski where the mass could be located closer to the boot of the skier was found better. With this in mind some probing was done. Unfortunately this work ran out of time before a final solution could be made, but the basic principles were tested and had at least a subjective felt effect when tested on skis. Probing for an actuation system started, but only got a negative confirmation when testing a pump as main part. The impression when ending the probing for an actuator was positive. It was believed that an actuator to move a piston could be made without being too complicated.

Possibilities when it comes to microcontrollers seem to be vast. Computer power is known to improve over time, and processing power is getting smaller and cheaper. This makes the trust in the computational part of the smart ski concept strong. In this work only a simple algorithm was tested. By looking at what have been done in other fields future seems bright. The potential contribution of more computing power together with machine learning can bring smart products to new level in coming years.

Now is the time to draw the lines from the different sub-functions mentioned above to a smart ski concept. Not everything is set when it comes to details. Compared to the starting point where only a vision was set the following suggested concept have a larger confidence and knowledge to base the solutions on. Based on the probing done throughout the work on the thesis the conceptual smart ski consists of:

(I) A sensing part consisting of an accelerometer and a barometer to sense vibration and vertical speed.

(II) A microprocessor analyzing the input. Several states of the ski could be obtained. It should be possible to indicate states where the ski is skied fast or oscillating at unwanted frequencies. Snow conditions could be obtained from the oscillating characteristics.

(III) An actuation system consisting of a fluid capable of changing the mass distribution in the ski. Potentially the system could be two fluid chambers at the front of the ski and two fluid chambers at the back of the ski. Weight balance and mass distribution of the ski can be changed by moving fluid between the two chambers.

(IV) Induction charged batteries.

(V) The system could be expanded to also cover input from the skier with machine learning.

The ideas behind the different bullet points are covered well in earlier sub-chapters and will not be repeated here. The concept is sketched in Figure 36 and gives an impression of how it might be implemented in a ski.

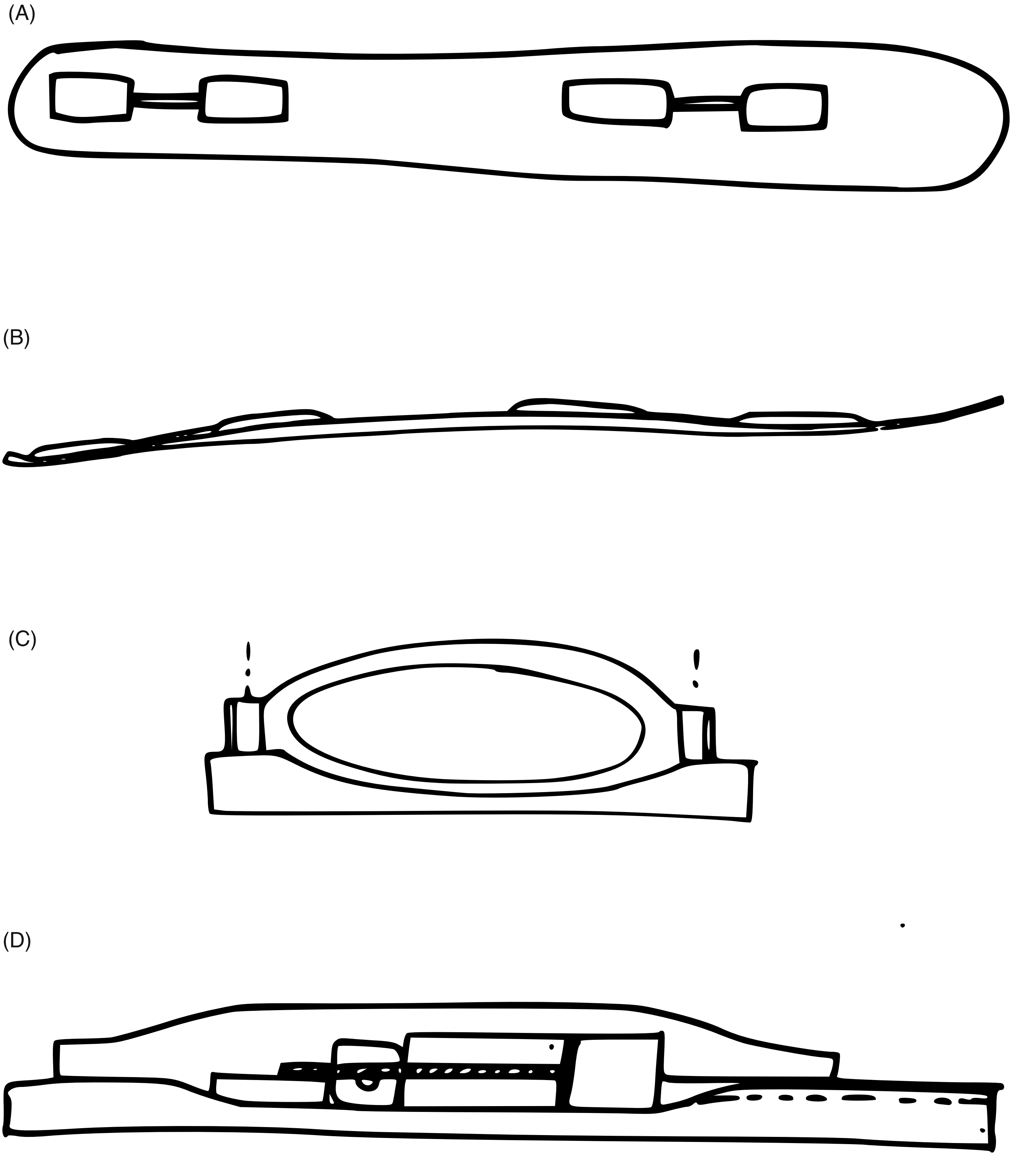


Figure 36: Sketch of conceptual ski. (A) Top view, (B) Side view, (C) Cross-section of piston house,front view, and (D) Cross-section of piston house, side view.

Paper Submission and Potential Grant Proposal

Paper submission

At the end of the work on the thesis an opportunity to a paper submission appeared. Based on the wayfaring towards a smart ski concept and findings from the process reason to make a paper submission to the Sport Engineering journal was found. They were calling for papers to a special issue on Winter Sports Equipment. Some of the core findings from the thesis work were thought of as interesting to share with the sport engineering community. Main content was to define a smart ski by adapting existing definitions of smart products to this applied case. The different sub-functions of a smart ski were exemplified by the different prototypes from this work. A sketch of the paper submission is attached in Appendix A4.

Potential grant proposal to Innovation Norway

The work of the thesis was presented to SGN Skis during a last meeting before the deadline of the thesis. They were positive to the smart ski concept. A potential was also seen in the recording system isolated. To use the system to benchmark ski prototypes in the design process could be an internal application for SGN. The promotional effect could also be a selling point. SGN Skis could make a point out of that they are using advanced measuring equipment in their ski development. To test and benchmark skis for other ski brands, ski magazines and other institutions is another application. In agreement with SGN Skis the rights to develop both the smart ski concept and the recording system were given to the author. It was also agreed on that a grant proposal to develop the recording system should be applied for if the author of the thesis wanted to bring it further.

Chapter 5
Discussion

Discussion of Results

Introduction

This sub-chapter covers the discussion of results obtained in this master's thesis. The methodology will be discussed in the next sub-chapter. The results are discussed first as it is the most important outcome.

Sensors and Recording Equipment

The preliminary testing of the sensors was trying to cover a large span of sensors. By literally testing every available sensor in the workshop of TrollLABS a wide and open approach was obtained. This was believed to be positive to the testing, but it certainly was focusing on quantity over quality. The way it was tested, by the help of an Arduino Uno microcontroller, made it possible to test all the sensors on the same platform. It also made it possible to test several sensors at the same time. This made a fair benchmark of the different sensors. Especially the accelerometer was used to control the other sensors tested. This might have been a source of error. If the accelerometer data was obtained in a wrong matter, conclusions based on the benchmarking might have been wrong. On the other hand the accelerometer data was tested together with a commercial solution, an iPhone with the VibSensor application, and found to give the same results. To test the sensors connected to a professional solution could have been done in order to ensure the accuracy of the self-made recording system. Calibration and benchmarking in comparison to a professional solution could have been done. Another source of error is wiring and coding. When testing several sensors and writing codes to each testing, some wiring or code could have been wired or written wrong. Over time to end up with the accelerometer and barometer have proved to be good solutions. The accelerometer has throughout the project been used to do testing of different solutions, and since it is a solution used in the industry confident have been strong in this solution. The barometer is something already used sport watches when accurate altimeters are needed. The wildcard when evaluating sensors is the piezo buzzer element. This one proved to give results good enough to deliver frequency analyses comparable to the ones obtained from the accelerometer. During the rest of the testing and development this sensor was not tested in a large enough extent. All in all the confidence in the sensors chosen is strong. From this project's scope most of the solution space has been explored to a large enough extend.

When it comes to the recording of sensor data the platform chosen still was Arduino. The microcontroller Arduino Uno is among the simplest microcontrollers with an easy user-friendly coding available. The computing power is minimal, and this can be seen as both positive and negative. The positive part is that if this microcontroller can do the task, then bigger and more advanced microcontroller can do the same tasks. The negative is the simplicity of the Arduino might limit the possibilities. Again, wiring and coding was not done by an electronics expert. There is room for error in several steps. Improvements could possibly be done in terms of shielding wires and to a larger extend have knowledge about electronics and coding. For further development the coding of the devices could benefit from having an expert on electronics and coding. The point-of-view camera was useful and easy to implement while testing. It was a great tool for the analyses and to give an overview of the testing.

Regarding the analysis of the recorded data some parts are easy and other advanced. When it comes to plotting the raw vibration data not much can be done wrong. By using Matlab this was a simple task. In case of the analysis of the vibration data the level of complexity is greater. The method was chosen based on what was experienced to be the standard of vibration. The data input, code and results from the Matlab code could potentially have faults. No external expertise was used to look over the code and results. The results from the analyses have given values that physically make sense, and this give reason to believe them to be reliable. It was meant to be a way of benchmarking the results, not to be an accurate and correct scientific tool.

The system for recording vibrations in field was an Arduino Uno equipped with a SD-card logger and an accelerometer. In addition a remote to control the recordings was made. Based on the findings when testing the sensors an accelerometer was chosen to record vibrations. The sample rate of the recordings was 100 Hz in most cases. Main reason for this was based on the preliminary work with the sensors and the paper of Rothemann and Schretter (2010) saying most frequencies recorded on snow was up to 20 Hz.

This could be a source of error if frequencies above 50 Hz should have been covered. According to the Nyquist rate, the sampling should be twice the frequencies to be measured. Wiring and code could potentially be sources of error. The shielding of the cables and wiring in general have not been checked for crosstalk and electronic faults, this could cause noisy data recordings. The data recorded have generally been making sense in a physical perspective giving reason to trust them.

When looking at how the experiments were run, they were not standardized in length and style of skiing when testing in the field. This could have been done in order to at least have some of the parameters fixed. The placement of sensor was standardized in the way it was fixed at the tip of the ski. When using double-sided tape the core of the tape is soft. This could have a dampening effect on the accelerometer casing. The damping effect of the double-sided tape has not been tested.

Manipulation of Skis

The work on how to manipulate a ski had its basis in the model of a mass-spring-damper system. This is the normal way of modeling an oscillating system in the field of physics. The different parameters in the mass-spring-damper formula were the basis for the investigation done. The formula was not applied in order to get numerical results. This could have been done if more numbers were needed in the results, or if the effect of certain principles was to be theoretically tested. Instead of spending time on pre-calculating the different principles they were tested by low-resolution prototypes. The cornerstone of the measurements was the self-made recording system described earlier. All the measurements done were by this device and analyzed by the PSD Matlab code made for the purpose. Given the device to be stable and reliable, this made the different measurements comparable. If different devices were used they could potentially have given a larger scatter in results. To have the same recorder and Matlab code for all the measurements made at least a platform for comparing the results. It is not claimed that the results are obtained from a perfect scientific method, but the different characteristics obtained were found useful.

With the approach of testing the different principles in a fast way several ideas was tested. Main focus was to do it in fast iterations. Details might have been missed when the iteration speed is high. When looking at the testing in retrospect insights from both testing and from experts were pointing in the same direction. This gives reason to trust the results obtained. When evaluating what has been done in terms of exploring the solution space it is believed that some parts have been covered well, and some parts could have been investigated more. The damping effect of a spring-mass-damper and the effect of adding mass is considered to be covered to an acceptable degree. Solutions to those two effects have not been discovered to the same degree. Same counts for the effect and solutions to manipulate the stiffness parameter. More exploring is needed to master both of them.

Control System

The control system was the last critical function tested of the conceptual smart ski. Unfortunately this meant less time spent exploring the solution space. With the basis in the chosen sensors, a barometer and an accelerometer, some preliminary exploring was done. Once again the Arduino platform was the platform of choice. This was due to the previous positive experience from the other prototypes made earlier in the work. The small capacity of the Arduino might limit the possible solution space microcontrollers in general can offer. For simple algorithms it should be sufficient to use an Arduino. If the tasks are more advanced the choice of microcontroller is more important. Time spent discovering the solution space is perhaps the largest source of error for the control system. By not having done too many probings for a control system, the size of the solution space remains unknown. The probing done only covers a simple sensor input evaluated by a simple algorithm. As a first step the barometer algorithm made was good, but more probing is needed to confirm if there is a larger potential. The control system is based on what kind of manipulation of the ski who is chosen. This was not decided when the work on the control system was started. More work on the actuation and manipulation of skis is needed to better know the true needs of a control system. When this is done, more exploring of a control system can be done. There seem to be a large potential in what machine learning can offer. The example from TrollLABS where a chair is trained to distinguish between different sitting positions is just giving preliminary confirmations on machine learning being suitable for a smart ski concept.

A Conceptual Smart Ski

As an output of this master's thesis the conceptual smart ski is an exemplification of the critical functions a smart ski could consist of. Most of the argumentation for the sub-functions is covered in the paragraphs above. The conceptual smart ski is not thought of as a static concept. The proposed solution might be changed if other ways to manipulate a ski proves to be better or more important to manipulate. The same counts for the sensor and control system. A master's thesis alone is probably not enough to explore the entire solution space for all the sub-functions.

When the choice of sensor(s) for the system was made the accelerometer was the most obvious for several reasons. During all parts of the work it was the sensor supplying data to benchmark results. It is used in the industry for vibration analysis purpose. A source of error in this case could be a fixation to this sensor, leaving little room for other sensors to perform. This might have been the case with the piezo element. This sensor has probably been tested to a smaller extend because the accelerometer was used as reference. For later iterations the accelerometer could be exchanged by the piezo element if and only if it proves to be sufficient.

The largest source of error when looking at the actuation system is the lack of exploring the solution space. Several principles to manipulate the ski have not been tested. From what has been tested the solution of changing the mass distribution was found to be sufficient enough to be part of a system. Other interesting fields to investigate would be to dynamically change the stiffness of the ski with a mechanism or in other smart ways.

For the control system much of the same criticism as for the actuation system counts. Only a limited number of ideas have been tested and checked out. The probing done only covers the simplest form of a smart system. Again, the use of Arduino as a platform for the prototyping has its pros and cons. If this microcontroller can do the task, then it should be possible to make other microcontrollers to do the same tasks. The ease of use is a big advantage when a mechanical engineer student is dealing with electronics and programming code. There is a chance of missing out on more advanced solutions when using the Arduino. For prototyping cause the Arduino have proved to be a useful tool.

Collaboration with SGN Skis

To communicate well with SGN skis have been an important goal throughout the work on the thesis. They have been weekly updated on the process from beginning to end. This was in the form of writing small reports from what had been done during the week. The feedback from SGN was positive to this way of documenting the process. Additionally it also served as a commitment to progress in the work.

Both in the beginning and at the end of the work meetings were held to plan and sum up. To physically meet was found to be a much better way of communication. The value of meeting and to get to know the company was important in order to commit to the project. If improvement should have been made in terms of communication, more frequent meetings would probably have been beneficial for the project.

Discussion of Methodology

Wayfaring

The wayfaring approach has been the way of organizing the work and the fundamental mindset throughout the work on the thesis. The way this has been done in practice is as follows. From the needfinding done in the pre-master's project a vision of a smart ski was obtained. In more detail the ski was thought of to sense input, analyze it, and then react on it in order to make a better performing ski. This was the leading star or vision for the thesis. To have a vision is not unique for this model of organizing product development. Other models might continue to define in more detail how things should be done and what to do. While doing wayfaring the functions believed to be critical are the ones who will be probed for first. In this case sensors were found to be the first critical function to be probed for. In retrospect too much time was probably spent probing for a good way of sensing and recording vibrations. This points out one of the aspects of the wayfaring model that can be challenging. When probing for new learning of a critical function, when is the point of going further? The timing aspect of each probing can be hard to manage when in middle of the action. Without an awareness of progression a wayfaring might get stuck in the first probing identified. With a focus on doing fast probing much can be done, but it needs to focus on the (current) target of the vision. On the other hand, to have a sensor and recording system working was important in order to have a platform for what followed when evaluating actuation. The perhaps unbalanced time management came more clear at the end of the work when the two critical functions, actuation and control system, was lacking some exploring. It is also a challenge to define what to expect from each probing in terms of how deep the knowledge should be. If the reason for wayfaring is to end up with a conceptual product, not all the detailing is needed in order to conclude with a certain sub-function being sufficient. By comparison a production-ready concept needs to have a much greater level of details. The awareness of the different aspects of wayfaring might improve if the process has been applied several times. Then it might be easier to identify when progress is slow.

When comparing the wayfaring mindset to traditional scientific work some differences appear. To a larger extend the cause and effect is more important than exactly knowing how the mechanism is functioning. When doing a traditional research not only the cause and effect is important, the reason for the effect and how it works in detail is important. An example from the thesis is the electronics. Not a single calculation was done to ensure if the wiring and components were fine in terms of burning of the electronics. It was mostly based on schematics found from other projects. If time were spent to know everything in detail, then this thesis most likely would have stopped progressing much earlier. In some cases this might be a drawback of the process, leaving too many unknowns in the solution found. This is something to be aware of, and if a deeper focus is needed the wayfaring approach is not the limiting factor.

To never go hunting alone is the first "rule" of the wayfaring model. This was a rule broken during this thesis. An agile team with a diversity in skills was not the case in all the decisions to be made and when making prototypes. The thesis would definitely have benefitted from having a team dedicated to the same task. This is perhaps one of the biggest shortcomings of the thesis. A team could have produced solutions with larger diversity. Luckily, in this case several co-students together with the supervisors were updated on the project frequently and contributed during several small meetings and mini-workshops.

Prototypes

The use of prototypes was an important tool during the entire thesis. To do probing by the help of low-resolution and low-fidelity prototypes was helpful. When designing parts for prototypes several of the steps were prototype-driven, e.g. making physical cardboard models to decide measurements and design of a CAD-model. This way the dimensions and design was "tested" before it was built as an actual model. Errors could be corrected earlier in the process when the "sketching" was in the physical domain. By doing most of the thinking and sketching in the physical domain ideas was tested and evaluated in something believed to be a much more fair way compared to when drawn or thought of. The evaluation of sensors was conducted by applying the sensors to measure vibrations. Some extra time might have been spent to do the wiring and preparing of the sensors, but the new learning and the synergy effect from testing the sensors in a real situation was seen as useful. To get the same feedback and knowledge from benchmarking the sensors only from reading the specification seems hard to do within the same time frame. If the wrong technique for prototyping is chosen, time and cost can become higher than what is reasonable.

Chapter 6
Conclusion and Further Work

Conclusion

In this thesis, the methodology of Wayfaring was successfully applied to a product development case. This was done by establishing a vision, identifying critical functions, and probe for solutions and new learning. By means of low-resolution, low-fidelity prototypes new learning and progress in the project was made. The following is a result of the method applied. A smart ski was defined based on general smart product definitions from previous works, e.g. the work of Dawid et al. (2016) and Meyer et al. (2009), together with findings from prototypes made during this work. The smart ski definition stated was:

(I) The ski should have sensors to gather data either from the ski itself or the environment that is related to the ski. The kind of sensor and data is dependent on the purpose of the smart ski.

(II) There should be an intelligent component analyzing the data. The analyzed data should control an actuator and/or be visualized to the user.

(III) The actuator should manipulate the skier/ski/environment directly or indirectly as a reaction to the analyzed data.

Based on the knowledge gained during the work, a conceptual smart ski was suggested where the most promising findings were included. The critical functions of a smart ski were identified from the definition and probing done. Critical functions tested were sensors, actuators and control system. The following is the solutions included in the conceptual smart ski. To verify and test the need of a sensor, a range of sensors was tested. Accelerometer and barometer were found to be a good way of measuring ski performance because of the accuracy and relevance of the data delivered. Several concepts of manipulating skis were tested both in lab and field. A conceptual dynamic mass distribution system was tested and found interesting as a way to dynamically change the properties of a ski. The solution utilized fluid as a way to move mass by a system of cylinders. A simple algorithm that by help of threshold values could distinguish between different descending speeds confirmed the potential in using algorithms to control smart skis. Additionally a large potential was seen in machine learning algorithms.

As a result of insufficient analyzing tools available a self-made test setup was developed in order to measure ski performance when skiing. Based on an Arduino Uno equipped with a Sd-card writer an sampler capable of sampling 4 analog channels at sample rates up to 400 Hz was made. A Matlab code was written to analyze recorded vibration data. All this made a good platform to benchmark different ways of manipulating skis during this thesis.

Further Work

There is still much to explore when it comes to a smart ski concept. This thesis has started to investigate and define what a smart ski possibly could be. The sensing part has been discovered fairly well. To sense, record and analyze have been done. Some more sensors would be interesting to test tough. To put strain gauges on a ski would be interesting, and could potentially obtain data on both vibrations and displacement. To look at possibilities on installing optical fibers in a ski could be another interesting way of measuring ski performance. The piezo element should also be given another round and be tested together with an accelerometer in real world situations.

There is always room for improvement in the solutions already made. The recording equipment has worked well in this project but could benefit from being externally reviewed. Since the data only have been an internal tool to benchmark different solutions compared to each other this would make sense. To verify the sampling results, and to check the results from the analyses in comparison to scientific proved equipment can be useful for further work on the recording system. A specific challenge found interesting regarding vibration analyses is to add a device to monitor the impulses given to the ski. By knowing the impulse one could extract it from the vibration data analysis.

When it comes to manipulation of skis there is definitely more to explore. Effects have been investigated to some degree, but solutions on how to control ski characteristics have a lot of potential work left. It would be interesting to find a smart way to have a space effective mass damper where the spring constant is low enough to dampen a ski efficiently. Stiffness is another interesting parameter of the ski that could have been investigated in more detail. What briefly was touched, but not tested, during the thesis was to dynamically manipulate the moment of inertia. This could probably be done in a more energy effective way compared to moving mass.

Entering the field of computers and cryptic codes challenges and opportunities arise. Only the surface was scratched during this thesis. To make a smart system where machine learning is included in the control system was seen as something that could push boundaries in what a smart ski could be. In order to implement this in a system the actuator of the system should be working. There are several examples of the possibilities machine learning can offer. This gives reason to believe impressive and smart solutions could be implemented even in a product like a ski.

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Appendices

Contens

A1: HSE assessment

Enhet: Institutt for Produktuvikling og Materialer **Dato: 2016.02.02**

Linjeleder: Torgeir Velo

Deltakere ved kartleggingen (m/ funksjon): Carlo Kriesi/Stud.ass, Einar S. Wergeland/Student, Øystein Bjelland/Student

Kort beskrivelse av hovedaktivitet/hovedprosess: Masteroppgave: Utvikling av skikonsept. Produktuvikling

Er oppgaven rent teoretisk? Nei

Signaturer: *Ansvarlig veileder: Martin Steinert* *Student: Einar S. Wergeland*

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

3	Eksperimentelt arbeid	ESW	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	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.

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.

A2: ISPO Report

ISPO 2016

Where: Munich, Germany
When: 25th to 27th of January
Who: Einar S. Wergeland

Intro:

The reason for going to ISPO 2016 was to get an idea of the future of skiing. ISPO in Munich is the biggest sport exhibition in Europe/the world. The biggest companies in the business is present, but also newcomers are taking part in ISPO Brandnew. With the basis in my premaster work, most of my interest were to pick up the trends in technology in skis.

Smart technology found at ISPO:

ZSafeTech

One of the first things found which was technology based was a ZSafeTech, a ski beacon and theft alarm. It is a bluetooth based solution with a beacon sender on your skis, and an app on your phone. People at the ski company Zag is the ones behind the idea.

http://www.zsafetech.com

Similar theft alarm/tracker alternative (not at ISPO):
https://www.kickstarter.com/projects/1468348447/alpinehawk-never-lose-your-skis-or-snowboard-again?ref=discovery

Avatech

American based tech company. They have a probe who can analyze the snowpack and then upload it to a database with a human friendly user interface. High tech solution with several sensors (IR, pressure, Bluetooth etc.) They also provides an app/online service for safe travel in avalanche terrain. Observations of the snowpack and route planning.

http://avatech.com

Carv

Real-time monitoring of skiing position. Can detect pressure distribution from the feet by a sensor sole. In addition angle of feets are detected. The system can tell if your skiing position is correct when skiing. The data can be used to give feedback on technique, and also give lessons and ski-technical challenges/contests in the mobile application. Technically it is a sole between the inner and outer ski boot shell with pressure sensor with several zones collecting pressure data. Additionally an accelerometer unit tells the orientation of the boot. Via Bluetooth technology the data is transmitted to an app on your smartphone. Approximate 50 Hz sample rate.

http://www.carvnow.com

pomocup

A smart ski-wearable concept for ski mountaineering. Can measure vertical speed, amount of kickturns, steepness of the slope, and so on. The data can be downloaded to a smartphone app / desktop computer in order to do further analysis.

Technology from Gaitup:
http://www.gaitup.com/wp-content/uploads/Brochure_Datasheet_PhysilogRTK.pdf

WOO sports

Kiteboard wearable to measure air-time when kiting.
Waterproof casing with accelerometer+GPS(?)+Bluetooth. Communicates with smartphone app. Gamefication of stats etc. Scoreboard and so on.

http://woosports.com

evalu

Wearable running device. Gives feedback on running technique. A inlay sole with several sensors (pressure and accelerometer?) and communication via bluetooth(?) with an smartphone app.

http://www.evalu.xyz

Meetings/Talks

DPS

Pelle Odebrant is DPS' sales manager in Scandinavia. During a conversation we entered several interesting topics. Most of our time were spent discussing how smaller companies have to struggle to get into the bigger sport shops. In Norway there are almost no independent sport shops left. The way they are organized gives less room for smaller brands who lack bigger distributors and importing agents etc. They cannot challenge the deals the bigger players in the industry can offer. What can a smaller company like SGN and DPS do to be more attractive? Ski magazines have most likely become less important after internet became part of many people's life. Blogs, video blogs and other sources available at the internet have become important sources of information for this generation of buyers. Having the right blogs to presentate a product can potentially have a large impact on a lot of buyers.

Other ideas on having a stronger impact on users might be to have ski test in the right environment. If you want to sell touring and freeride skis, the environment should be suited for such skis. Sogndal or Hurrungane could potentially be test sites better to sell SGN or DPS skis.

To be able to have a wider appeal to foreign users, is the super-local names and layout good? An Austrian guy will probably not have any associations to the name or graphics on the local Norwegian ski areas. It is a balance

A side note: Völkl make 40000 prototypes and testpairs of skis a year.

ISPO Open Innovation

ISPO Open Innovation (IOI) is a part of the ISPO organization where collaboration between users and companies is offered to develop new products. Companies pay to get access to IOI's pool of test users. IOI can also offer services like teams of experts in the field of work of your company.

https://innovation.ispo.com

Other new stuff at ISPO 2016:

Generally most of the new stuff at ISPO is incremental innovations. Where small changes in material and construction are advertised as game changers. One trend that seems to be the use of more complex shapes of the ski cores. Fischer, Black Diamond, Scott and G3 are examples of brands who make skis with cores with a non-rectangular cross-section. This is mainly to save weight and to have more torsional stiff constructions. Carbon fiber is still a word that make products more attractive to customers. Even just small amounts of carbon fiber qualify to call a product a “carbon product”.

Dynastar: Visco elastic material in side walls:
http://www.ispo.com/en/products/id_76712372/winners-of-the-segment-ski.html/vid_0

Elan Ripstick 96:
“Ripstick is built to excel for all skiers on the steepest terrain and in the most challenging conditions. TNT Technology combines TubeLite Woodcore with VaporTip inserts. The result is an “energy efficient” performance that encourages a proper parallel position, enhancing the natural technique and ability of a wide range of skiers in the most demanding situations. Whether hiking the backcountry or skiing in-bounds a lighter ski always saves.” [from ISPO site]

Sideways rocker for less edge catching.

2 in one ski:
http://www.ispo.com/en/products/id_76717302/ispo-award-2016-2017-gold-winners-ski.html/vid_3

K2 asymmetrical ski tips:
http://www.ispo.com/en/products/id_76717302/ispo-award-2016-2017-gold-winners-ski.html/vid_3

Lonley Mountain Skis, eco hand-made skis:
http://www.ispo.com/en/products/id_76717302/ispo-award-2016-2017-gold-winners-ski.html/vid_3

Pindung
New binding concept who combine tech toe with traditional alpine binding construction.
http://www.bavarianalpinemanifest.com/en/

Westkust surf boards
A company that offer build-yourself-kits for surfboards out of laser cut cardboards. Something for skis?

http://westkustsurf.nl/?page_id=21786

Other Kickstarters (not at ISPO):

Slope measure sticker for poles:
https://www.kickstarter.com/projects/slopescience/neva-evolution-of-the-ski-pole?ref=discovery

Ski theft alarm/tracker alternative (not at ISPO):
https://www.kickstarter.com/projects/1468348447/alpinehawk-never-lose-your-skis-or-snowboard-again?ref=discovery

A3: Sensor Matrix

Sensor Matrix

Category	Sensor	First tought	Tested?	How did it work?	Promissing?	Pros	Cons	Can measure	Sensivity	Power consumption etc	Price	Links
Sensing vibrations	Digital Accelerometer	What they use in the industry. Same type of sensor tested when using a smartphone to record vibrations.	Yes	Really good. Had some problem with coding. Should perhaps try it out once again. Should consider resolution +/- 6g	Yes	Accurate	Price	Vibration, tilting		3.3V / 5V	$15	
	Analog accelerometer	What they use in the industry. Same type of sensor tested when using a smartphone to record vibrations.	Yes	Really good. Gives a lot of data. Can measure a lot. Maybe better to have a resolution of +/- 6g?	Yes	Accurate	Price	Vibration, tilting	Best so far.	3.3V / 5V	$15	
	Piezo element	Used for sensing vibrations, earthquakes, could be something to sense vibrations	Yes	Good. Less sensitive than accelerometer. Can probably amplify the signal.	Yes	Cheap, simple	Non-directional	Vibration, force	Good enough to FFT the reading. Must check how it perform when blued in	No additional power consumption, the element generates power who can be read from an analog input.	$1,5	http://www.seeedstudio.com/wiki/Grove_-_Piezo_Vibration_Sensor , https://www.arduino.cc/en/Tutorial/Knock
	Vibration sensor switch	If the right sensivity: could work	Yes	Work the same way as the piezo element, but in general stronger readings, more noise or cathing different frequences	No	Cheap, simple	"Mechanical", fatigue? Noise				$1	http://www.adafruit.com/products/1766
	Piezo vibration sensor	Is this a simple way of measuring vibrations?	Yes	Bad. Mounted it in three ways. Attached to the ski, and vibrating above the ski. Got 50Hz noise (because the Arduino was connected to the computer charger) + the frequency the ski vibrates.	No	Cheaper than acc	Must vibrate to read accurate					
	Piezo buzzer	Same as piezo element, but this time the element can vibrate more freely	Yes, several	Got the same results as with the piezo element. Probably better than piezo element. Tryed to see if it could handle sideways vibrations, but it was not able to distinguish between the directions.	Yes	Cheap, simple		Vibration		No additional power consumption, the element generates power who can be read from an analog input.	$2	
	Piezo buzzer (perpendicular)	Wanted to measure side-ways vibrations by putting the piezo buzzer perpendicular to the the side-way hits.	Yes	Was not able to measure the side-hits. The normal vibration signals only got weaker compared to the original position of the buzzer.	Yes	Cheap, simple		Vibration		No additional power consumption, the element generates power who can be read from an analog input.	$2	
	Micropohone	"=piezo?"	No									https://www.sparkfun.com/products/8635
	Strain gauge	Could measure both displacement and vibrations	Should		Yes			Vibration+bending			$5	
	Geophone	Too much mass	No									
	Displacement	Hard to do on snow?	No									
	Flex sensor	Could work if sensitive enough	Yes	Bad. Got a lot of noice when trying to measure a vibrating ski. The flexer is not accurate enough to give usable data	No			Flex, not vibration				
	Ultrasonic range finder	20 Hz reading rate, too slow	No		No				20 Hz reading rate, too slow			https://www.sparkfun.com/products/639
	Infrared proximity sensor	Might be error-prone because of light and snow conditions in a skiing environment	No		No							https://www.sparkfun.com/products/12728
	Optical Detector/Phototransistor	Might be error-prone because of light and snow conditions in a skiing environment	No		No							https://www.sparkfun.com/products/246
	Light Sensor	Might be error-prone because of light and snow conditions in a skiing environment	No		No							https://www.sparkfun.com/products/9088
	Hall effect sensor	Probably similar to the vibration sensor switch	No		No							http://www.adafruit.com/products/158
	IR Break Beam sensor	Can a mechanical break beam thingy work as a vibration sensor?	No		No							http://www.adafruit.com/products/2167
	Image recognition (camera+fixed points on ski)	By using a high speed camera mounted on the ski, e.g. a GoPro camera, together with image recognition in Matlab, one could possibly measure vibrations AND torsional vibrations.	No		Yes							
Temperature	Temperature sensors	Do ski charateristics change much with temperature? The barometer tested have a thermometer built in	No									
Speed	Barometer	By using a barometer one could calculate vertical speed, which could be a measurement of the speed of the skier.	Yes	Tested a self-built setup by running down stair. Was able to put in threshold values to distinguish between walking flat, walk down stairs and run down stairs. In addition several test of the concept have been done when skiing with a sport watch with a altimeter.	Yes	Simple, fast	Only vertical speed, Price $15	Barometric pressure/Altitude	Good for vertical speed measurements, it is what commercial products for altimeters use.	3.3V / 5V	$15	http://www.seeedstudio.com/depot/Grove-Barometer-Sensor-p-1199.html
	GPS	If the GPS reception is good then this should be a good way of getting the instant speed.	Yes	During skiing a sport watch with GPS have been worn.	Yes and No	Can measure speed in all directions	Price high, accuracy in vallies bad	Position/Altitude				
Visualization	Point-of-view camera (GoPro Hero3)	By using a camera with a high frame rate, one could visualize the vibrations and do a "human analysis" of what kind of vibrations is going on etc.	Yes	Good. The visualization of the ski was good, making it possible to tell more about the motions of the ski.	Yes					Farly high when shooting video	$500	http://shop.gopro.com/hero4/hero4-black/CHDHX-401.html
	Point-of-view camera (GoPro Hero3)+vibration data	Is it possible to combine the vibration dataset with the point-of-view camera?	Yes	By the help of some Matlab code found on the internet, I was able to get syncronized video and vibration graph	Yes							

A4: ISEA Paper Proposal

[Working Title: Smart ski]

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Abstract [To be done]

Keywords [Sport equipment, Ski, Smart products]

1 Introduction and motivation

The start of this work was a design challenge given by the Norwegian ski brand SGN skis. The challenge sounded like this: "What is the next generation of skis manufactured in Norway?". From this question a product development task was explored by the use of a wayfaring approach [1,2] in the TrollLABS environment at the Norwegian University of Technology and Science (NTNU). This was an early phase exploratory work who ended up with a vision of a smart ski concept. The idea was to have a ski that could sense the conditions, and by utilizing actuators change the properties of the ski to make it perform at a high level. When doing background research, we could not find papers or work that defined a smart ski with the present knowledge and technology. By writing the work at hand we hope to give the reader an introduction into what we define as a smart ski.

The word smart is used in many settings to describe products, and in many cases without being smart at all. For this work the definition of smart products will be "..smart products are defined as consumer products that are equipped with intelligence-generating technologies including (i) sensors and/or actuation, either to gather data from the environment or to use the data to change the environment, (ii) computing power for data analysis, and (iii) optional interfaces to exchange information with their environment" [3]. Examples of smart products and technology are Appel's smart watch "Apple Watch" [4], Oral-B's bluetooth toothbrushes [5] and systems to detect elderly people's wellness based on sensor data [6]. Another term used for smart products are "intelligent products" [7]. In the work of Meyer et al. [7] a three-dimensional model of intelligent products are presented. The three axes are "Location of intelligence", "Level of intelligence" and "Aggregation level of intelligence". The pure example of an intelligent product is a product where the intelligence is at the object, the object are doing decision making and it can be aware of its role in a system. Given the example of Oral-B's bluetooth toothbrushes, they are offering a solution who gives instant feedback to the user on how to improve their toothbrushing. The intelligence is inside the product system, where the toothbrush provides sensor data to the smartphone who processes the data to give feedback to the user. This leaves the toothbrushes with a fairly high score on all of the axes in the intelligence model of Meyer et al. [7]. Our perception of a smart product is that the intelligence should be in the product or system itself, being able to process and react on input in an autonomous way. We will start by briefly present some of the smart technology products found in the sporting goods industry today. Following this, a presentation of what we argue should be key elements in a smart ski, and how we tested the definitions.

2 Smart technology in the sporting goods industry

2.1 Three examples

The first example of smart technology in the sporting goods industry is the increasingly amount of activity monitors, and in particular we will look at Fitbit [8]. This wristband wearable is equipped with sensors to monitor activity. When the activity level is below certain threshold values, the Fitbit will remind the user with notifications. The goal of the activity monitor is to motivate the user to be more physically active.

A recent example of products previous being "dumb" now becoming smart is the Altra IQ Smart Shoe [9]. It is a running shoe with embedded pressure and accelerometer sensors and bluetooth communication. The shoe can transmit the sensed data to an iFit wearable or an android/iOS smartphone application. With the help of the smartphone application the runner can get feedback on his or her performance in terms of running cadence, foot strike zone, ground contact time, balance between left and right foot, the specific pressure for each foot. This kind of real-time feedback is helpful to improve the running form, and then potentially reduce the risk of injury. The classification of intelligence according to model of Meyer et al. [7] is high. The location of intelligence is at object, at least if the system of the smart shoe and smartphone is counted as a unit. The level of intelligence can at least be classified as a problem notification if not decision making. The argument for calling it a decision making system, is that based on the sensor input the system not only notifies the user about current state, it also provide advices on how to improve running form.

In the world of tennis, Babolat [10] , a tennis racket manufacturer, have introduced smart technology in their Babolat play products. By embedding accelerometers, gyroscope and piezoelectric sensors into the tennis racket they are tracking tennis performance. The data is transmitted to a smartphone after the session and then providing statistics and analyzed data as feedback. Part of the solution is close to a "gameification" [11] of the tennis session, where your improved performance is awarded by receiving higher scores, e.g., higher scores in technique, power and endurance. When classifying this product, it is more of an analytic tool. The feedback is not instant, and the learning loop is slow and to certain degree left to the user to fulfill. The system collects data, analyze it, and finally present it as human-friendly statistics giving the user the ability to track performance and improvement.

2.2 Smart Technology in the skiing industry

Let us narrow the focus and give some ski related examples. First, we bring in Madshus' "empower" cross country skis who are equipped with a RFID chips [12]. Here, each ski is physically tested for flexural characteristics and given a unique profile, and then connected to the specific ID of this ski. These characteristics are important to match with the physical measures and skills of the skier when selling and using a ski, especially when the level of the skier is above intermediate. Another way to use the flexural characteristics is when applying ski wax. Among the factors to consider when applying wax is the flexural characteristics of the ski, the skier's weight and skills, and snow and weather conditions. The additional smartphone application can guide the skier on what type of wax and how long the wax zone should be. If a classification of this solution were to be made, it would in our opinion be classified far below the given example of the Altra IQ smart shoe. Reason for this is the RFID only containing information about the product itself, and the location of the intelligence is outside the product. Main feature of this smart technology is an advisory service based on static data obtained during manufacturing. The product is lacking sensors and actuators to sense or act on input, and according to the definition by Dawid et al. [3] of a smart product we would argue the Madshus empower ski not being a smart product in its true form.

A visit to the ISPO Munich 2016 trade fair [13] was made to get insights in the smart products present in the winter sport industry today. There we found products who wears the label "smart" without, at least in our opinion, being near what smart is based on the definitions given by Dawid et al. [3] and Meyer et al. [7]. Following are two examples of smart products worth mentioning from the ISPO Munich trade fair.

First out is the startup company Pomocup. They showed a prototype of a ski wearable for the backcountry skier who collects uphill performance data and monitors key performance data on a small screen [14]. The core of the product is a set of motion sensors that is recorded at a high sample rate. Further the data is analyzed, and important measurements like vertical speed, temperature and slope angle are displayed on a small monitor on the unit. If we want to categorize this product, it falls more into the instrument or monitor category. The product has sensors, it has smart algorithms to analyze the sensor data, but the output is only quantifiable numbers monitoring the performance. In our opinion this kind of smartness does not fully qualify to be a truly smart product. After the ski session a more detailed analysis can be obtained in the supportive software.

MotionMetrics' product Carv, is a good example of how far the implementation of technology have come [15]. Their product is a ski wearable who can give real-time feedback on skiing technique. With pressure sensors installed in two insoles together with motion sensors the unit is able to sense important characteristics of skiing technique. With the help of a smartphone and an application the recorded data can be processed and live instructions given in the smartphone's ear plugs. This product is not only sensing the physical phenomena and monitoring data, it is also processing the data and converting it into advisory response to the skier. In terms of both the work of Dawid et al. [3] and Meyer et al. [7], we are classifying Carv as a smart product. Compared to the other ski related examples, Carv has a higher degree and location of intelligence.

When looking back in time there have been examples of technology that potentially could be qualified as smart or partial-smart. The two ski brands K2 and HEAD implemented piezo fibers in order to damp skis [16-18]. The systems consist of three parts, piezo fibers for sensing/power generation, a chip, and piezo fibers for actuation [19]. The question to be asked would then be; is it a truly smart ski? It has a sensing system, processing of the signals and an actuating part. Both the sensor and actuator qualifies to be part of a smart product, but the grade of intelligence is, at least in our opinion, not qualifying this concept to be called a truly smart product.

3 A smart ski

3.1 What is a smart ski?

Our goal with this paper is to define a general definition of a smart ski, and exemplify it and its sub-systems by prototypes. In our view a ski or an auxiliary system mounted on a ski who fulfill the definitions given by Dawid et al. [3] and Meyer et al. [7] is a smart ski or smart ski device/wearable. What does this mean in practice? First of all, the grade of smartness is not something we have considered, and we are not suggesting a way of grading smartness in a ski, such details are left for later work. There should somehow be a certain threshold to qualify for being a smart ski. We suggest the following as a definition of a smart ski:

(I) A smart ski should have sensors to gather data either from the ski itself or the environment that is related to the ski. What kind of sensors and data is dependent on the type of smart ski.

(II) There should be an intelligent component who analyze the data. The analyzed data should control an actuator and/or be visualized to the user.

(III) The actuator should manipulate the skier/ski/environment directly or indirectly as a reaction to the analyzed data.

The following sub-chapters will cover our approach to verify and discuss (I), (II) and (III). Since this was an early phase exploratory work where the wayfaring method XX was applied, the search was broad and opportunistic. In order to learn and verify ideas fast the process was to a high degree prototype-driven, where the term prototype is covering everything that answers a design question, including existing objects [20-23].

3.2 Sensors

"How many ways can we measure ski performance?" was the question asked when the search for a ski sensor started. Insights were gained in what a good ski sensor could be by doing several iterations of prototyping and testing of sensors. Off-the-shelf sensors were prioritized. One of the key properties identified to sense for a smart ski were vibrations. Reason for this was that the ski's edge hold is much dependent on how much the ski is vibrating while skied. The lack of low-cost sampling equipment made us make our own. With the base in an Arduino [24] microcontroller a 4-channel analog sampler capable of sampling at sampling rates up to 200-300 Hz was made. The main focus was to find sensors who collected data with sufficient quality for analysis and further processing.

For our purpose an accelerometer was found to be the best sensor for vibrations. This is in accordance with what is used in other domains for measuring vibrations [25]. A free oscillating ski sensed by the accelerometer and logged by the purpose-built Arduino sampler is shown in figure XX. What also gave good results when measuring vibrations were a piezo element. The accuracy was not the same as for the accelerometer, but to identify vibrating frequencies it was sufficient enough. For a price one tenth of an accelerometer, the piezo element is something to consider when looking at commercial use and high production volumes.

Another property identified as important to monitor was speed. This could be done by GPS, but since skiing often is done in narrow valleys where GPS signals are weak, this solution might be inaccurate. When skiing an inclined slope the speed can be decomposed into vertical and horizontal speed. A good way of measuring vertical speed is by barometer. This is already done in sport watches as barometers have a high accuracy compared to GPS when measuring altitude. To confirm the usefulness of a barometer, a small prototype was built and tested. As shown in figure XX, the different descending speeds from walking down a stair can be distinguished by the barometer.

In order to also get feedback from the skier him- or herself a button to pinpoint "bad" ski behaviour was made. In the term "bad" ski behaviour we mean the feeling of the ski under-performing according to expected performance. An example could be if the ski shatters when doing a turn on hardpacked snow. This kind of input was considered important when learning about what kind of impact different ski conditions could have for the skier's perception of skiing. For the analysis of the collected data, this was found useful, but more importantly we saw it as a future feature for machine learning of a smart ski. As an addition to the the feedback button a point-of-view camera capable of shooting at a frame rate of 120 frames per second was mounted to the ski. This was a good way of monitoring the behaviour of the ski, but also to verify the unwanted behaviour in a visual way.

3.5 A suggested solution and further work

We still have a vision of a smart ski concept. We still think it is realistic and possible to be made. This is based on the prototypes we have made during our work, and the answers given by them. The prototypes are also evidence in the suggested definition of a smart ski being realistic. To sum up on what could be a smart ski solution we will briefly present a possible solution. The ski could sense vibrations by an accelerometer and vertical speed by the help of a barometer. The sensed data could either be processed by simple algorithms or more advanced machine learning algorithms. Finally an actuator could take care of the manipulation of the ski, this could be a mass distribution system, a damper or spring changing the ski's properties. The prototypes made for the different categories can confirm the sub-functions of the smart ski, and hopefully combining them into a final solution should be possible. Projects like CH.AI.R confirms some of the possibilities smart products can offer and gives confidence in this project being realistic.

There is still much work to be done in order to make a fully functional smart ski. The technology is not the limiting factor in our opinion. It is rather a question of putting together the components and utilize software and technology in a smart way. That being said, it is not a simple challenge, but examples from other fields state the possibilities. This work have explored the main components of what we think a smart ski should consist of. Some of the potential research uncovered during this work will be mentioned in the following.

To continue the exploration and development of the different components of a smart ski is needed to make the solutions ready for consumers. Especially the intelligent part have great potentials. Actuators and feedback given to the user can be investigated in greater detail, and could potentially have a large span in what the solution could be.

A framework for grading the level of smartness in sporting goods products could also be investigated in future work. It is likely that there will be more smart products in this field the coming years. To categorize the different products might be useful both for consumers and developers/manufacturers.

4 Conclusion

In this work we have been trying to make a definition on what a smart ski is. Based on existing and more general definitions of smart products we have adapted them to the case of a smart ski. Through several loops of prototyping and testing, with a wayfaring approach, we have been verifying the different components of a smart ski. The most important points on what we think a smart ski should be, is: (I) A smart ski should have sensors to gather data either from the ski itself or the environment who is related to the ski. (II) There should be an intelligent component who analyze the data. The analyzed data should control an actuator and/or be visualized to the user. (III) The actuator should manipulate the skier/ski/environment directly or indirectly as a reaction to the analyzed data. There is still much work to be done in order to have a fully functional consumer product with basis in our project, but the definitions we suggest can be a framework for categorizing future development of smart skis.

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AC1: Knock_Accel_500Hz

```
//Timer to make the delay between samples
#include <TimerOne.h>


// these constants describe the pins. They won't change:
const int ppin = A0;                    // the piezo is
connected to analog pin 0
const int vpin = A4;                    // piezo vibration
switch
const int xpin = A1;                    // x-axis of the
accelerometer
const int ypin = A2;                    // y-axis
const int zpin = A3;                    // z-axis (only on
3-axis models)


volatile int sensorValueP;              //this is the
variable used in the Interrupt Service Routine (ISR) for
'reporting' the potentiometer value to the main loop.
volatile int sensorValueAY;
volatile int sensorValueAX;
volatile int sensorValueAZ;
volatile int sensorValueV;
volatile unsigned long sensorTime;     //this is the
variable use in the ISR to record the time when the sensor
was readout.
volatile byte sensorFlag;

void setup()
{
   Serial.begin(115200);
   Timer1.initialize(2000);             // initialize
timer1, and set a 2 ms second period for the interrupt
interval (i.e. the ISR will be called
                                        //every 2000 us to
read out the potentiometer that simulates a sensor in this
tutorial.
  Timer1.attachInterrupt(readoutSensors);  // attaches the
readoutPotentiometer() function as 'Interrupt Service
Routine' (ISR) to the timer1 interrupt
                                        //this means that
every time 500000 us have passed, the
readoutPotentiometer() routine will be called.

}

void loop()
{
```

```
  String dataString = "";              //instantiate (make)
an object of the string class for assembling a text line
of the datalog

  if (sensorFlag ==1)                  //if there is a
sensor reading...
  {
    dataString = String(sensorTime)+String(",") +
String(sensorValueAX) + String(",") +
String(sensorValueAY)+ String(",")+
String(sensorValueAZ);//+ String(",")  +
String(sensorValueP);
                                       //concatenate (add
together) a string consisting of the time and the sensor
reading at that time
                                       //the time and the
reading are separated by a 'comma', which acts as the
delimiter enabling to read the datalog.txt file as two
columns into
                                       //a spread sheet
program like excel.
    Serial.println(dataString);        // print the string
also to the serial port, so we can see what is going on.
    sensorFlag = 0;                    //reset the sensor
reading flag. This prevents the loop from running until a
new sensor reading comes from the ISR.
  }

}

void readoutSensors()                  //this is the ISR
routine that is executed everytime the timer1 interrupt is
called.
{
  //sensorValueAX = analogRead(xpin);   //read out the
accelerometer X
  //sensorValueAY = analogRead(ypin);   //read out the
accelerometer Y
  sensorValueAZ = analogRead(zpin);   //read out the
accelerometer Z
  //sensorValueP = analogRead(ppin);    //read out the
piezo
  //sensorValueV = analogRead(vpin);    //read out the
piezo
  sensorTime = millis();               //note the time
  sensorFlag = 1;                      //set the flag that
tells the loop() that there is a new sensor value to be
```

AC2: Barometer_sensor_logger

```
/* Barometer demo V1.0
* Based largely on code by  Jim Lindblom
* Get pressure, altitude, and temperature from the BMP085.
* Serial.print it out at 9600 baud to serial monitor.
*
* By:http://www.seeedstudio.com
*/
#include "Barometer.h"
#include <TimerOne.h>
#include <Wire.h>
#include <SPI.h>
#include <SD.h>

const int chipSelect = 10;


float temperature;
float pressure;
float atm;
float altitude;
Barometer myBarometer;

const int redPin = 4;                  // Red LED connected to digital pin 4
const int yellowPin = 2;               // Red LED connected to digital pin 2
const int greenPin = 3;                // Green LED connected to digital pin 3
const int  buttonPin = 5;              // the pin that the pushbutton is attached
to digital pin 5
const int  buzzerPin = 9;              // buzzer to digital pin 9

//volatile int sensorValueAZ;
//volatile int sensorValueV;
volatile unsigned long sensorTime;     //this is the variable use in the ISR to
```

```
record the time when the sensor was readout.
volatile unsigned long sensorTimeStart; //To "reset" the timer of millis()
volatile byte sensorFlag;

int buttonState = 0;                   // current state of the button
int lastButtonState = 0;               // previous state of the button
String dataString = "";

void setup()
{
  //Serial.begin(9600);
  myBarometer.init();

  pinMode(redPin, OUTPUT);             // sets the digital pin as output
  pinMode(yellowPin, OUTPUT);          // sets the digital pin as output
  pinMode(greenPin, OUTPUT);           // sets the digital pin as output
  pinMode(buttonPin, INPUT);           // initialize the button pin as a input:

  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect))
  {
  digitalWrite(redPin, HIGH);        // sets the Red LED on
  return;
  }

  dataString.reserve(11);

  digitalWrite(greenPin, HIGH);        // sets the Green LED on
  digitalWrite(yellowPin, LOW);        // sets the Yellow LED off
  digitalWrite(redPin, LOW);           // sets the Red LED off
  delay(3000);
```

```
}

void loop()                                    // MAIN LOOP
{
buttonState = digitalRead(buttonPin);

if(buttonState==HIGH)                          // Check if botton is pressed
 {
  digitalWrite(yellowPin, HIGH);              // sets the Yellow LED

  // create a new file
  char filename[] = "LOG00.CSV";
  for (uint8_t i = 0; i < 100; i++) {
    filename[3] = i/10 + '0';
    filename[4] = i%10 + '0';
    if (! SD.exists(filename)) {
      // only open a new file if it doesn't exist
      break;  // leave the loop!
    }
  }


 File dataFile = SD.open(filename, FILE_WRITE);

 if (!dataFile)                       // if the file isn't open, turn on Red LED
      {
      digitalWrite(greenPin, LOW);        // sets the Green LED off
      digitalWrite(yellowPin, LOW);       // sets the Yellow LED off
      digitalWrite(redPin, HIGH);         // sets the Red LED on
      }








  delay(1000);                                                     // 3 sec Delay
  tone(buzzerPin,261,1000);                                        // 1 sec tone
  delay(2000);                                                     // 2 sec Delay


  digitalWrite(redPin, HIGH);               // sets the Red LED on while recording
  sensorTimeStart = millis();              // To "reset" the timing for each recording
  sensorTime = millis()-sensorTimeStart; // note the time

  Timer1.initialize(100000); // initialize timer1, and set a 10 ms second period
for the interrupt interval (i.e. the ISR will be called
 // every 5000 us to read out the potentiometer that simulates a sensor in this
tutorial.
  Timer1.attachInterrupt(readoutSensors); // attaches the readoutPotentiometer()
function as 'Interrupt Service Routine' (ISR) to the timer1 interrupt
// this means that every time 5000 us have passed, the readoutPotentiometer()
routine will be called.



    while (sensorTime<20000)                // RECORDING LOOP for 20 sec
    {


    if (sensorFlag ==1)                     // if there is a sensor reading...
      {
      File dataFile = SD.open(filename, FILE_WRITE);  // open the file. note that
only one file can be open at a time,
                                                      // so you have to close this
one before opening another.
      String dataString = "";                                   //
```

```
instantiate (make) an object of the string class for assembling a text line of the
datalog
      dataString = String(sensorTime)+String(",") +
String(pressure);         //String with the data to write to SD
      dataFile.println(dataString);
      dataFile.close();
      sensorFlag = 0;                                                       //
reset the sensor reading flag. This prevents the loop from running until a new
sensor reading comes from the ISR.


      if(! dataFile)
      {                         // if the file isn't open, pop up an error:
      digitalWrite(greenPin, LOW);      // sets the Green LED off
      digitalWrite(yellowPin, LOW);     // sets the Yellow LED off
      digitalWrite(redPin, HIGH);       // sets the Red LED on
      break;
      }



      }
    }
    void detachInterrupt();             // disables readoutSensors
    dataFile.close();
    digitalWrite(redPin, LOW);          // sets the Red LED off
    digitalWrite(yellowPin, LOW);       // sets the Yellow LED off
    tone(buzzerPin,261,100);            // 1 sec tone
    delay(150);
    tone(buzzerPin,329,100);            // 1 sec tone
    delay(150);
    tone(buzzerPin,392,100);            // 1 sec tone









  }
}

void
readoutSensors()                                                            //this
is the ISR routine that is executed everytime the timer1 interrupt is called.
{
  //temperature =
myBarometer.bmp085GetTemperature(myBarometer.bmp085ReadUT());   //Get the
temperature, bmp085ReadUT MUST be called first
  pressure =
myBarometer.bmp085GetPressure(myBarometer.bmp085ReadUP());         //Get the
temperature
  //altitude =
myBarometer.calcAltitude(pressure);                                //Uncompensated
caculation - in Meters
  //atm = pressure / 101325;
  sensorTime = millis()-
sensorTimeStart;                                        //note the time
  sensorFlag = 1;     //set the flag that tells the loop() that there is a new
sensor value to be printed.
}
```

AC3: LowLatencyLogger

```
/**
 * This program logs data to a binary file.  Functions are included
 * to convert the binary file to a csv text file.
 *
 * Samples are logged at regular intervals.  The maximum logging rate
 * depends on the quality of your SD card and the time required to
 * read sensor data.  This example has been tested at 500 Hz with
 * good SD card on an Uno.  4000 HZ is possible on a Due.
 *
 * If your SD card has a long write latency, it may be necessary to use
 * slower sample rates.  Using a Mega Arduino helps overcome latency
 * problems since 13 512 byte buffers will be used.
 *
 * Data is written to the file using a SD multiple block write command.
 */
#include <SPI.h>
#include "SdFat.h"
#include "FreeStack.h"

  // The pins used
  const int redPin = 4;                    // Red LED connected to digital pin 4
  const int yellowPin = 2;                 // Yellow LED connected to digital pin 2
  const int greenPin = 3;                  // Green LED connected to digital pin 3
  const int  buttonPin = 5;                // the pin that the pushbutton is
attached to digital pin 5
  const int  buzzerPin = 9;                // buzzer to digital pin 9

  //Variables
  int buttonState = 0;                     // current state of the button
  int lastButtonState = 0;                 // previous state of the button
```

```
//------------------------------------------------------------------------------
// Set useSharedSpi true for use of an SPI sensor.
const bool useSharedSpi = false;

// File start time in micros.
uint32_t startMicros;
//------------------------------------------------------------------------------
// User data functions.  Modify these functions for your data items.
#include "UserDataType.h"  // Edit this include file to change data_t.

// Acquire a data record.
void acquireData(data_t* data) {
  data->time = micros();
  for (int i = 0; i < ADC_DIM; i++) {
    data->adc[i] = analogRead(i);
  }
}

// Print a data record.
void printData(Print* pr, data_t* data) {
  pr->print(data->time - startMicros);
  for (int i = 0; i < ADC_DIM; i++) {
    pr->write(',');
    pr->print(data->adc[i]);
  }
  pr->println();
}

// Print data header.
void printHeader(Print* pr) {
  pr->print(F("time"));
```

```
  for (int i = 0; i < ADC_DIM; i++) {
    pr->print(F(",adc"));
    pr->print(i);
  }
  pr->println();
}
//==============================================================================
// Start of configuration constants.
//==============================================================================
//Interval between data records in microseconds.
const uint32_t LOG_INTERVAL_USEC = 10000;
//------------------------------------------------------------------------------
// Pin definitions.
//
// SD chip select pin.
const uint8_t SD_CS_PIN = SS;
//
// Digital pin to indicate an error, set to -1 if not used.
// The led blinks for fatal errors. The led goes on solid for SD write
// overrun errors and logging continues.
const int8_t ERROR_LED_PIN = -1;
//------------------------------------------------------------------------------
// File definitions.
//
// Maximum file size in blocks.
// The program creates a contiguous file with FILE_BLOCK_COUNT 512 byte blocks.
// This file is flash erased using special SD commands.  The file will be
// truncated if logging is stopped early.
const uint32_t FILE_BLOCK_COUNT = 256000;

// log file base name.  Must be six characters or less.
#define FILE_BASE_NAME "data"
```

```
//------------------------------------------------------------------------------
// Buffer definitions.
//
// The logger will use SdFat's buffer plus BUFFER_BLOCK_COUNT additional
// buffers.
//
#ifndef RAMEND
// Assume ARM. Use total of nine 512 byte buffers.
const uint8_t BUFFER_BLOCK_COUNT = 8;
//
#elif RAMEND < 0X8FF
#error Too little SRAM
//
#elif RAMEND < 0X10FF
// Use total of two 512 byte buffers.
const uint8_t BUFFER_BLOCK_COUNT = 1;
//
#elif RAMEND < 0X20FF
// Use total of five 512 byte buffers.
const uint8_t BUFFER_BLOCK_COUNT = 4;
//
#else  // RAMEND
// Use total of 13 512 byte buffers.
const uint8_t BUFFER_BLOCK_COUNT = 12;
#endif  // RAMEND
//==============================================================================
// End of configuration constants.
//==============================================================================
// Temporary log file.  Will be deleted if a reset or power failure occurs.
#define TMP_FILE_NAME "tmp_log.bin"

// Size of file base name.  Must not be larger than six.
```

```
  Serial.begin(9600);

  pinMode(redPin, OUTPUT);              // sets the digital pin as output
  pinMode(yellowPin, OUTPUT);           // sets the digital pin as output
  pinMode(greenPin, OUTPUT);            // sets the digital pin as output
  pinMode(buttonPin, INPUT);            // initialize the button pin as a input:

  // Wait for USB Serial
 // while (!Serial) {
 //   SysCall::yield();

 //When setup is good, light up green light
  digitalWrite(greenPin, HIGH);         // sets the Green LED on
  digitalWrite(yellowPin, LOW);         // sets the Yellow LED off
  digitalWrite(redPin, LOW);            // sets the Red LED off







  //Serial.print(F("FreeStack: "));
  //Serial.println(FreeStack());
  //Serial.print(F("Records/block: "));
  //Serial.println(DATA_DIM);
  //if (sizeof(block_t) != 512) {
    //error("Invalid block size");
  //}

  // initialize file system.
```

```
  if (!sd.begin(SD_CS_PIN, SPI_FULL_SPEED)) {
    sd.initErrorPrint();
    fatalBlink();
  digitalWrite(greenPin, LOW);                              // sets the Green
LED off
  digitalWrite(yellowPin, LOW);                             // sets the Yellow
LED off
  digitalWrite(redPin, HIGH);                               // sets the Red LED
on
  }
}
//--------------------------------------------------------------------------------
void loop(void) {
buttonState = digitalRead(buttonPin);

if(buttonState==HIGH){                                          // Check if
botton is pressed

buttonState==LOW;

delay(10);
  digitalWrite(greenPin, HIGH);                              // sets the Green
LED on
  digitalWrite(yellowPin, HIGH);                             // sets the Yellow
LED on
  digitalWrite(redPin, LOW);                               // sets the Red LED
off

delay(10);                                                // 0,01 sec Delay
  tone(buzzerPin,261,100);                                   // 0,1 sec tone
  delay(110);
```

```
logData();

delay(10);
  digitalWrite(greenPin, HIGH);                                 // sets the Green
LED on
  digitalWrite(yellowPin, HIGH);                                // sets the Yellow
LED on
  digitalWrite(redPin, LOW);                                   // sets the Red LED
off
    tone(buzzerPin,261,100);                                     // 0,1 sec tone
    delay(150);
    tone(buzzerPin,329,100);                                     // 0,1 sec tone
    delay(150);
    tone(buzzerPin,392,100);                                     // 0,1 sec tone


binaryToCsv();

delay(10);
  digitalWrite(greenPin, HIGH);                                 // sets the Green
LED on
  digitalWrite(yellowPin, LOW);                                // sets the Yellow
LED off
  digitalWrite(redPin, LOW);                                   // sets the Red LED
off
  tone(buzzerPin,261,100);                                       // 0,1 sec tone
  delay(110);

}

delay(10);









}
```

AC4: Verticalspeed_avg

```
//MEASURE VERTICAL SPEED
#include "Barometer.h"

float temperature;
float pressure1=0;
float pressure2=0;
float pressure3=0;
float pressure4=0;
float pressure5=0;
float pressure6=0;
float pressure7=0;
float pressure8=0;
float pressure9=0;
float pressure10=0;
float pressureNow;
float pressureWas;
float atm;
float altitude;
Barometer myBarometer;
volatile byte state=0;

const int redPin = 4;                   // Red LED connected to digital pin 4
const int yellowPin = 2;                // Red LED connected to digital pin 2
const int greenPin = 3;               // Green LED connected to digital pin 3


volatile unsigned long
Time1=0;                                                   // Timestamp 1
volatile unsigned long
Time2=0;                                                   // Timestamp 2
volatile unsigned long
Time3=0;                                                   // Timestamp 3
```

```
volatile unsigned long
Time4=0;                                                   // Timestamp 4
volatile unsigned long
Time5=0;                                                   // Timestamp 5
volatile unsigned long
Time6=0;                                                   // Timestamp 6
volatile unsigned long
Time7=0;                                                   // Timestamp 7
volatile unsigned long
Time8=0;                                                   // Timestamp 8
volatile unsigned long
Time9=0;                                                   // Timestamp 9
volatile unsigned long
Time10=0;                                                  // Timestamp 10
volatile unsigned long TimeNow;                            // Time at the moment
volatile unsigned long TimeWas;                  // Time at last measurement
volatile unsigned long TimeStart;                // The time the measurements start

float threshold_0=3.5;
float threshold_1=2.7;
float verticalSpeed;

void setup()
{
Serial.begin(9600);                                                         //
Serial port to monitor when programming

myBarometer.init();

pinMode(redPin, OUTPUT);                                                    //
sets the digital pin as output
pinMode(yellowPin, OUTPUT);                                                 //
```

```
sets the digital pin as output
pinMode(greenPin, OUTPUT);                        // sets the digital pin as output

digitalWrite(greenPin, HIGH);                 // Sets the Red LED on

TimeStart = millis();                 // To "reset" the timing for each recording



}


void loop()                                                        // MAIN LOOP
{
                                                                   //CALCULATE VERTICAL
SPEED
TimeNow = ((millis()-TimeStart));                                 // The time now
pressureNow = myBarometer.bmp085GetPressure(myBarometer.bmp085ReadUP());
// Pressure Now

verticalSpeed=(pressureNow-pressure1)/(round((TimeNow-Time1)/1000));
// Calculate vertical speed

Time1=Time2;
Time2=Time3;
Time3=Time4;
Time4=Time5;
Time5=Time6;
Time6=Time7;
Time7=Time8;
Time8=Time9;
Time9=TimeNow;









pressure1=pressure2;
pressure2=pressure3;
pressure3=pressure4;
pressure4=pressure5;
pressure5=pressure6;
pressure6=pressure7;
pressure7=pressure8;
pressure8=pressure9;
pressure9=pressureNow;


if (state==0)                                                                          //
Check state
{
    if (verticalSpeed>threshold_0)
// Check vertical speed against threshold value
    {
    state=1;
    digitalWrite(redPin, HIGH);
// Sets the Red LED ON
    }
    if (threshold_1<verticalSpeed<threshold_0)
// Check vertical speed against threshold value
    {
    digitalWrite(yellowPin, HIGH);
// Sets the Yellow LED ON
    }
    if (verticalSpeed<=threshold_1)
// Check vertical speed against threshold value
    {
    digitalWrite(yellowPin, LOW);
```

```
// Sets the YELLOW LED OFF
    }
}
else
{
    if (verticalSpeed<=threshold_1)
// Check vertical speed against threshold value when in
    {
    state=0;
    digitalWrite(redPin, LOW);
// Sets the Red LED OFF
    }

}


delay(1000);                            // waits for one seconds
}
```

MC1: fft

```matlab
%FFT of accelerometer data

%Get data from file
filename='data00';
accdata = dataset('File',...
   '/Volumes/LOGGER/data07.csv',...
   'Delimiter',',');
accdata.Properties.VarNames{1} = 'T';
accdata.Properties.VarNames{3} = 'SB';
accdata.Properties.VarNames{3} = 'X';
accdata.Properties.VarNames{4} = 'Y';
accdata.Properties.VarNames{5} = 'Z';

time=double(accdata (:,1));
functionX=double(accdata (:,2));
accelerationX=double(accdata (:,3));
accelerationY=double(accdata (:,4));
accelerationZ=double(accdata (:,5));

%Do the FFT
Fs = 100;                               % Sampling frequency in Hz
Nq = Fs/2;                              % Nyquist says half the sampling freq

M=accelerationY;                         %Should not have any Nan!
L=length(M);

NFFT = 2^nextpow2(L);                   % Next power of 2 from length of y
Y = fft(M,NFFT)/L;
Y2=(2*(abs(Y(1:NFFT/2+1))).^2);
f = Fs/2*linspace(0,1,NFFT/2+1);


% Plot
figure
subplot(2,1,1);
plot(time,M)
title('Acceleration vs Time')
xlabel('Time [ms]')
ylabel('Acceleration')
%xlim([0 20000])

subplot(2,1,2);
plot(f,Y2)
title('Single-Sided Amplitude Spectrum')
xlabel('Frequency [Hz]')
ylabel('|Y(f)|^2')
xlim([1 Nq])
```

MC2: Logarithmic decrement

```
%LOGARITHMIC DECREMENT
acc2=acc2-602;
acc2=-acc2;

[pks,locs] = findpeaks(acc2);
timepks=time2(locs);


n=length(pks);
inner=pks(1)/pks(n);

delta=((1/n)*log(pks(1)/pks(n)));

zeta=1/(sqrt(1+((2*pi)/delta)^2))

%plot
figure
plot(time2,acc2)
hold on
plot(timepks,pks)
```