NTNU – Trondheim
Norwegian University of
Science and Technology

Development of a Grading Machine for Sea Urchins

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Mechanical Engineering
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Mattis A Tangeraas, Norway Sea Urchin

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Summary

A preliminary study, conducted the fall of 2012, formed the basis for this master thesis. The thesis is issued by NTNU, and it is a part of a project in which Searis AS, Troms Kråkebolle and Norway Sea Urchins are participants. Searis AS is a start-up company, in which the student is a participant. Troms Kråkebolle and Norway Sea Urchins perform aquaculture farming, and wild catch, of sea urchins, respectively.

The project was initated because of the need to automate the manual grading of sea urchins. The grading process is time consuming and increase cost for the customer. The grading involves sorting the sea urchins by their shell diameter, and removing foreign objects like stones.

An iterative product development process formed the foundation for the results in this thesis. The process consited of; analysing user and customer needs and requirements, problem decomposition, development of solutions, ranking and rating, breakdown of principal solutions, tests, discussion and choice of concepts. Input for the designprocess was based on discussion with pilot customers; Troms Kråkebolle and Norway Sea Urchin, creative sessions with Searis AS, search for competitive products, computer simulations, and lab experiments.

A complete system for the grading of sea urchins is proposed at principal level, and design for the for critical components of an automated grading machine is presented.

The result of the thesis is a CAD–modell of a prototype of a grading machine. The CAD-modell consists of dimensions, materials, components, and assembly, and is a sketch on how a the prototype can be constructed.

Experiments and simulations have strengthened the confidence in the solutions. And it is concluded that the design proposed in this thesis will be able to cover the needs for the customers.

There is still parts that needs development before a complete prototype can be constructed.

Norwegian summary

Prosjektoppaven som ble utført høsten 2012, har vært utgangspunktet for den masteroppgaven. Oppgaven er utgitt av NTNU, og er en del av et prosjekt i sammarbeid med Searis AS, Troms Kråkebolle, og Norway Sea Urchin. De to siste er pilotkunder i prosjektet. Og Searis AS er en oppstartsbedrift, som student selv er deltaker i.

Prosjektet ble igangsatt på grunn av et behov for å automatisere sortering av kråkeboller. Sorteringsprosessen er tidkrevende og utgjør en stor utgiftspost for kunden. Sorteringen består hovedsaklig av å sortere etter skalldiameter, og fjerne uønskede objekter som f.eks. stein.

En iterativ produktutviklingsprosess har vært grunnlaget for resultatene i denne oppgaven. Prosessen har bestått av; bruker og behovsanalyse, oppdeling av problemet, utvikling av løsninger, rangering, analyse av prinsipper, tester, konseptvalg. Inndata for oppgaven har vært basert på samtaler med pilotkunder, kreative møter med Searis AS, søk etter lignende produkterm, datasimuleringer og forsøk i lab.

Et fullstendig system for sortering av kråkeboller er foreslått på prinsippnivå, og design av kritiske komponenter er utført.

Resultatet er en 3D-modell av en prototype av sorteringsmaskinen. 3D-modellen inneholder informasjon om dimensjoner, materialer, og sammenføyning, og er en skisse på hvordan prototypen kan konstrueres.

Eksperimenter og datasimuleringer har styrket tiltroen til løsningene. Det konkluderes med at designforslaget vil kunne dekke kundenes behov.

Det gjenstår fortsatt noe utviklingsarbeid før en fullstendig prototype kan bygges.

Preface

This master thesis was issued by the Institute for Product development and Manufacturing (IPM) at the Norwegian University of Science and Technology (NTNU). The master thesis was written in the course TMM4901 Engineering Design, Calculations and Manufacture, spring 2013.

A preliminary study was written the fall of 2012, as a part of the course TMM4501, at the same institute and university as the master thesis.

Acknowledgements

I would like to extend my gratitude to Knut Einar Aasland for the supervision and guidance during the work on the master thesis. I would like to thank him for his professional contribution to the thesis, but also his positive attitude and helpful spirit.

Thank you to Øyvind Jørgensen from Troms Kråkebolle, and Mattis A. Tangeraas from Norway Sea Urchin for your valuable feedback and support.

Credit is also given to the department of engineering cybernetics for offering the workshop used as a laboratory for the experiments, and to the employees of the workshop at institute for product development and manufacturing for their support.

Lastly, I would like to thank Innovation Norway for funding Searis AS with the financial means needed for building a prototype.

Problem description

Sea urchins offers great commercial potential, but is not exploited, in Norway. One of the big challenges is the workload associated with processing, of the sea urchins, which increases cost. Grading by size is one of the important processes for sea urchins from wild catch, and during aquaculture farming.

The candidate has done a preliminary study, where a concept for automated grading of sea urchins was proposed. The master thesis will be supporting a project, initiated by the student and other fellow students, with the goal of producing and commercializing grading machines for sea urchins.

The master thesis will be based on the concept from the preliminary study, and it shall refer to solutions developed by other people in the project group. The proposed solution consists of a camera, a sorting operation, a singularization (separation) operation, and a buffer operation.

The master thesis should result in a complete design for, and – if there is time – a finished, prototype of a grading machine.

The following will be a part of the thesis:

- A review of the chosen concept from the preliminary study, with identification of areas that are particularly important when handling the sea urchins, hygiene, reliability of operation and cycle time, and of areas where existing solutions or standard components can be used.
- Development of the critical components for a prototype.
- Constructing prototype of critical components
- Constructing a test rig based on these components
- Experiments with the components in lab.
- If possible: Testing of equipment at the customers facilities.
- Evaluation and conclusions on the tests and experiments.
- If there is time: Development of final solutions for production and deployment.

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MASTERKONTRAKT

- uttak av masteroppgave

1. Studentens personalia

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2. Studieopplysninger

Fakultet **Fakultet for Ingeniørvitenskap og teknologi**	
Institutt **Institutt for produktutvikling og materialer**	
Studieprogram **Produktutvikling og produksjon**	Studieretning **Produktutvikling og materialer**

3. Masteroppgave

Oppstartsdato **15. jan 2013**	Innleveringsfrist **11. jun 2013**
Oppgavens (foreløpige) tittel **Utvikling av sorteringsutstyr for kråkeboller**	
Oppgavetekst/Problembeskrivelse Kråkeboller har et stort kommersielt potensiale som ikke blir utnyttet i Norge. Mye av grunnen til det, er at det er arbeidskraftkrevende å prosessere kråkeboller, og at det dermed blir dyrt. Sortering etter størrelse er den viktigste operasjonen etter at kråkebollene har blitt fanget og underveis i oppdrett. Kandidaten har i sin prosjektoppgave utviklet et konsept for automatisert sortering. Arbeidet inngår i et prosjekt som kandidaten sammen med en gruppe andre studenter har satt i gang med hensikt å utvikle og produsere sorteringsmaskiner for kråkeboller. Masteren skal ta utgangspunkt i konseptet som ble valgt i prosjektoppgaven, og skal også inkludere (henvise til) løsninger utviklet av de andre i prosjektgruppa. Grovt sett består den valgte løsningen av en kameracelle, en celle for sortering og en celle for singulering og mellomlagring. Masteroppgaven skal resultere i ferdig utviklet, og – hvis tida tillater det – ferdig bygget, prototype av en sorteringsmaskin. Følgende skal inngå i oppgaven: - Gjennomgang av valgt konsept fra prosjektoppgaven, med identifikasjon av områder som er særlig kritiske med hensyn til behandling av kråkebollene, hygiene, driftssik...	
Hovedveileder ved institutt **Førsteamanuensis Knut Einar Aasland**	Medveileder(e) ved institutt
Ekstern bedrift/institusjon **Troms Kråkebolle, Norway Sea Urchin**	Ekstern veileder ved bedrift/instutisjon **Øyvind Jørgensen, Mattis A Tangeraas**
Merknader **1 uke ekstra p.g.a påske.**	

Ord og forklaringer…

ROV – Remotely Operated underwater Vehicle

Pelagic – Living in the water column. (Not on surfaces.)

Contents

Chapter 1.

Introduction

Background

The Norwegian sea urchin industry is facing challenges on achieving efficient and profitable operations.

When collecting sea urchins from the wild it is necessary to grade the sea urchins by size, and to remove by-catch. Sea urchins in aquaculture breeding, or wild sea urchins in the feeding process, needs to be frequently graded by size to ensure optimal growth. Also, before sale, the sea urchins needs to be accurately graded by size.

It is also wanted to keep a record of statistical data of sea urchins from both aquaculture and wild catch.

The workload associated with this processing of the sea urchins is a big challenge for the industry. Today, manual processing of each individual sea urchin is performed to achieve the wanted results. The industrial partners, Troms Kråkebolle and Norway Sea Urchin, want to scale up their production. A considerable part of the production cost for the sea urchins originate from the manual processing. The work is also time consuming and is monotonous. It is therefore wanted to find automated solutions for the grading of sea urchins.

1.1 Scope of the master thesis

The master thesis continues the development from the preliminary study, up to a prototype stage. Machine principals that enable the grading operation are developed and analysed, and necessary tests performed.

The master thesis will outline a complete system for the grading of sea urchins. But the focus will be limited to design of the critical components needed for a practical full scale test of the first prototype. The focus is set on the following functions; manual input, singularization (separation), camera, and sorting (rejection). Where the singularization process is the greatest challenge, and therefore it is the subject examined with greatest focus.

1.2 Motivation

Sea urchins are popular and have old traditions in Asia. The traditional producers of sea urchins; Japan, Chile and Amerika, have seen a decline in production over the last years. And have difficulties supplying the increasing market for sea urchins. (). The decline in production is suspected to originate from pollution and excessive harvesting. The increase in market demand is suspected to be connected to the increase in sushi popularity in Europe and the US. The increase in demand, and the decrease in production, offers great potential for new participant to partake in the global market.

The Norwegian species, *Strongylocentrotus droebachiensis,* is well known for its good quality. And there is assumed to exist large deposits of the species in Norway. In the northern part of Norway it is estimated that there is 80 billion individuals. *Perspektivstudie av kråkeboller 2010).*

Norway is in the front when it comes to research on sea urchins and aquaculture of sea urchins. And it is therefore predicted that a new industry for sea urchins are on the verge in Norway. ()

To exploit ‘new’ marine species, like sea urchins, in Norway have been pointed out for a long time. And the importance of research and the development of new technology for this industry is addressed be leading research resources. ()

The Norwegian industry for sea urchins is in development, and some participants are running small scale operations. They now want to upscale their production, and are calling attention to the need for tailor made technology to be able to meet the demands for profitability.

In KILDE it is claimed that conversations with leading researchers in Norway confirm that there exists no similar technological solutions for sea urchins in the world market. And that they point out that a grading machine also is interesting for other marine species.

Work done by the student during this master thesis have strengthened the claims, as no existing solutions for grading of sea urchins have been found during the research. Also, no existing solutions for other purposes have been found to be applicable on the grading of the sea urchins. Already existing grading solutions have difficulties in meeting the need for gentle handling, combined with the ability to cope with radically different sizes on inputted objects.

1.3 Preliminary work

In 2011 a group of students from NTNU visited the aquaculture convention, in search for unfilled needs in the Norwegian aquaculture industry. Based on the feedback at the convention, they made a trip around the northern part of Norway, visiting Nofima, the university in Tromsø (UiT), and local aquaculture researchers, engineers, and farmers. It was quickly realized that there are immense resources still to be utilized along the Norwegian coastline, but food traditions and lack of technology have been a limiting factor. This resulted in that the company Searis AS was started to support the development of an industry that utilizes sea species that have, until now, been small-scale or unexploited in Norway. Examples of these kinds of species are sea urchins, shells (mussels, horse mussels, abalone, scallop, common whelk, shrimp, and algae)

During 2012 a system for grading sea urchins was developed. Searis AS, supported by a group of students at experts in team (EiT), developed a camera based vision recognition system. [1] A project assignment, referred to as the preliminary study [2], initiated the product development process for the development a machine that enables the grading operation to be fully automated. The project assignment examines the fundamental customer needs and motivations, and proposes principal solutions for a complete system. The conclusion of the paper is that the proposed solution is feasible, and recommends further development and testing of the working principles of the system.

1.4 Sea urchins

Figure 1-1. Picture of adult sea urchins in a crate. (Taken at Norway Sea Urchins facilities)

Sea urchins are invertebrates from the Echinoidea-class. There exists a great variety of different species of sea urchins. [3]

In Norway the species *Strongylocentrotus droebachiensis* is utilized in aquaculture farming and wild catch. This species is known for its quality and taste, and is well received in the global market. [4]

Sea urchins have a shell made of calcium plates. Spikes surround the shell, and is used for protection, manipulation of food, and for propulsion. In addition there is tube shaped feet evenly distributed around the shell. These feet only emerge when the sea urchin is submerged in water. The feet have suction cups that enable the sea urchins to attach to other objects. The sea urchins posses a complicated mouth organ called 'Aristotle's lantern', which can be extended out from the shell and be used to eat sea weed or scrape food of hard surfaces. [3]

As shown in PIC, sea urchins are a rather minimalistic organism that mainly consists of mouth, a digestive system, and the gonad used for reproduction.

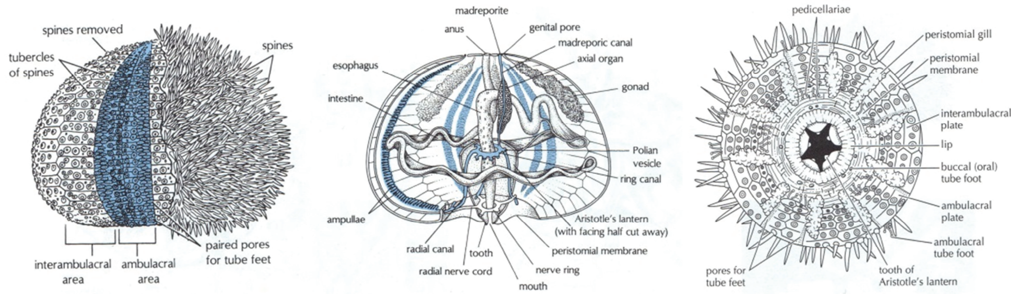


Figure 1-2. Left and right: The sea urchin species Echinus esculentus. Middle: Sea urchin species Arbacia punctulata, inside view. [3]

Sea urchins are mainly sold as food. The edible part is the gonad inside the sea urchin, and it is sold under the description as roe [5]. The gonad has more functions than just a reproductive organ; it is also an organ for storing energy, which can be used when repairing injuries [6] [7].

The gonad is eaten raw, and the sea urchins are mainly exported alive, which leads to strict requirements for gentle treatment [8] [9].

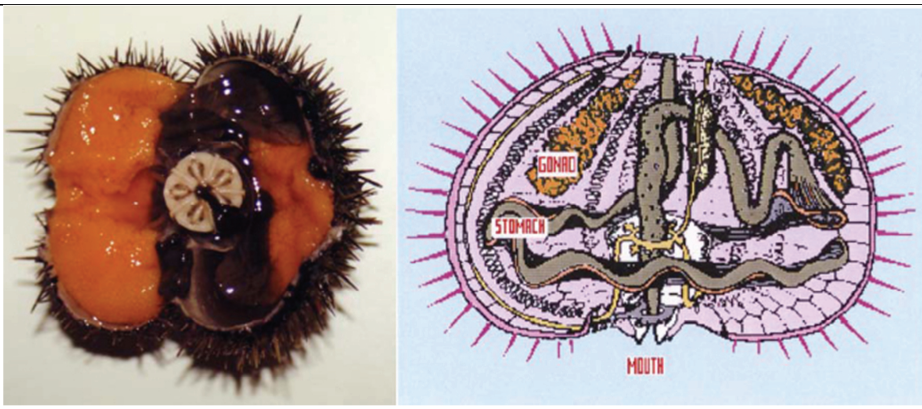


Figure 1-3. Showing the gonad (in orange) inside the shell of a sea urchin. [7]

Chapter 2. Methodology

2.1 Product development

The product development methodology used in this thesis is based on [10] and [11].

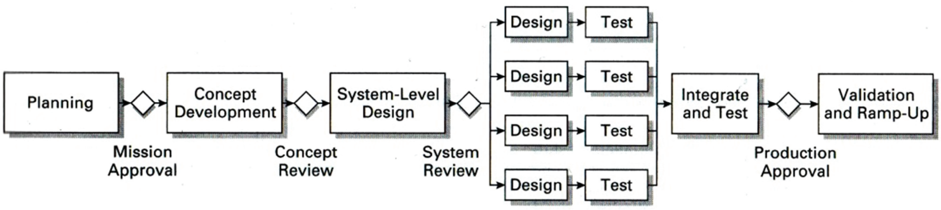


Figure 2-1. An overview of the complete product development process. [10]

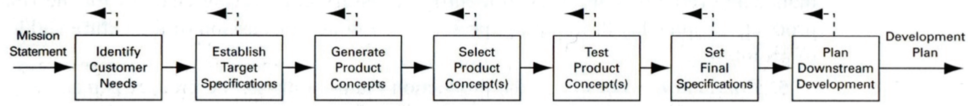


Figure 2-2. The break-down of the Concept Development phase. [10]

Figure 2-3 shows the custom product development process used in this thesis. The process is adapted from the models presented in [10]. The progress from the preliminary study, and the progress planned for the master thesis, is indicated by the thick grey arrows. The figure outlines the main iterations in the design process, but note that as this is a product development process, iterations in design and analysis have been continuously employed at all levels. In the top left corner the input 'Market Opportunity' is shown, indicating that this is a process initiated by 'market pull', meaning that the seller (Searis AS) have discovered a need in the market, and that this process is about finding the correct technologies to meet the customer needs.

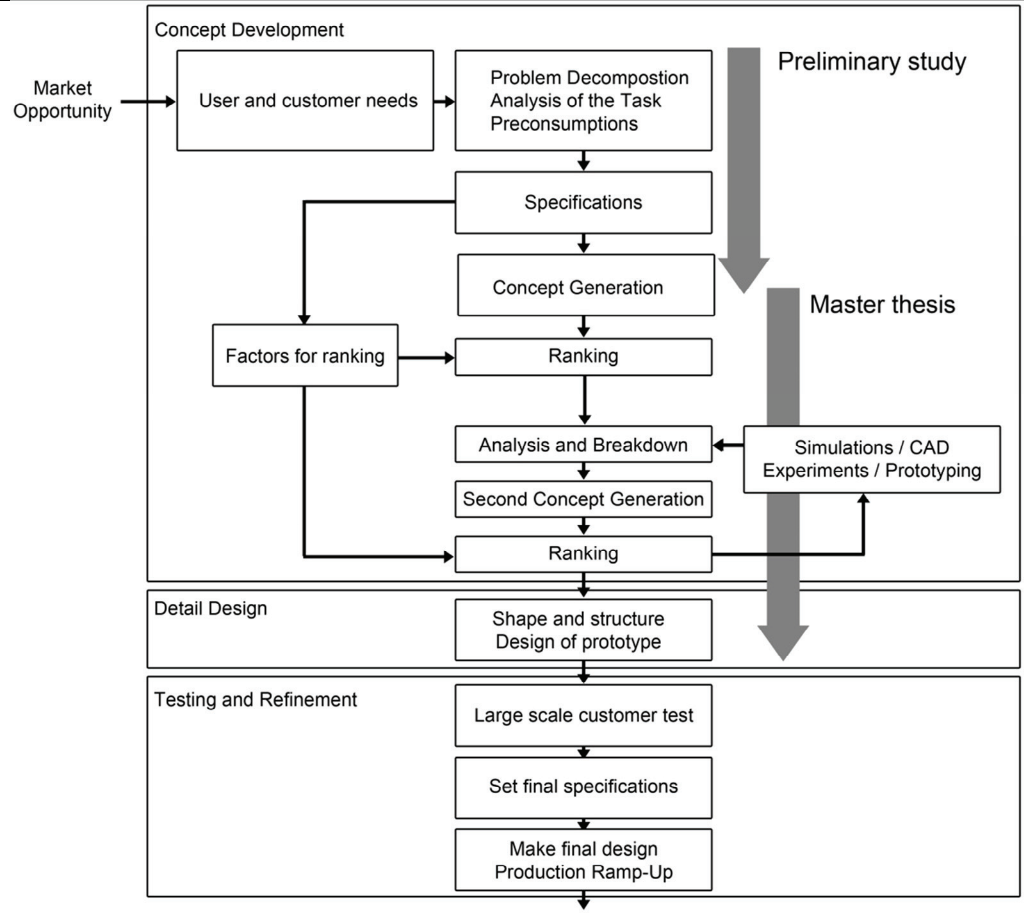


Figure 2-3. The product development process for this project.

2.2 Approach

Input for the design is based on discussions with the two pilot customers; Troms Kråkebolle and Norway Sea Urchin. Prior to the thesis a team from Searis visited NSU's facilities. Communication with NSU has been pr. E-mail during the work of the thesis. During the thesis, a visit to Troms Kråkebolle was carried out. And several video conferences with Troms Kråkebolle have been held.

Computer simulations, and lab experiments, have formed the basis for analyzing and investigating the proposed solutions. Also, the computer simulations enabled an efficient way of testing and exploring new ideas as a part of the creative process.

An extensive literature and market research were conducted to try to find existing solutions that could be reused for the problem. This yielded little results, and it is supposed that this machine will solve a unique problem.

Creative sessions have been performed by the student by drawing on A3 sheets. As recommended by [10], groups should be used for creative processes. Some creative sessions have therefore been held in cooperation with the development team at Searis AS.

2.3 Rating of concepts

Rating and ranking of concept have been an important part of this thesis. For both the main concept choices made in this report, and for the continuous iterations in the design process, the following method was employed.

After rating, [10] suggests that the following questions are investigated:

1. Are there concepts that have a better score over all, contra more extreme scores?
2. Is there any generally good concept which is degraded by one feature? Can a minor modification improve the concept?
3. Are there two concepts that can be combined, preserving the good ranks, and annulling the bad ranks?

Chapter 3.

Requirement analysis

The preliminary study [2] performed an extensive analysis of user and customer needs. The main results have been reviewed, and some new additions have been added based on increased understanding after communication with the pilot customers. The results are summarized in this chapter. More details, and storyboard of today's manual solutions, can be found in the preliminary study [2].

The basic customer needs are:

1. Grade by sea urchin shell diameter
2. Sort out by-catch
3. Sort out injured, dead, and infected sea urchins.
4. Counting of objects
5. Store statistical data

The foundational customer needs are:

1. Decrease costs from time consuming manual labor.
2. Free workers from monotonous labor.
3. Increase growth rate in, and yield from, aquaculture as a result of the ability to perform grading more frequently.
4. Increase yield from wild catch

In addition the customers want to find a way to estimate the gonad content of the sea urchins. Estimating the gonad content, which is the commercial value of the sea urchin, would be very valuable for the customer. Finding the gonad content is out of the scope of this master thesis, but considerations have been made on how to implement this as a part of the grading machine in future (chapter Chapter 7).

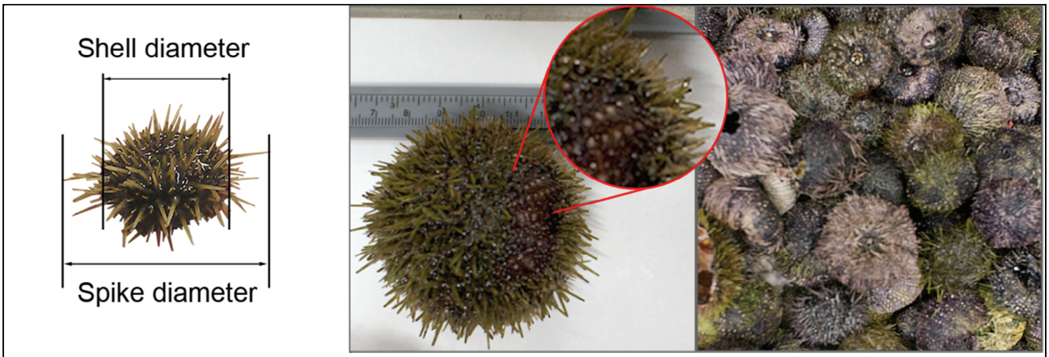


Figure 3-1. Left: Illustration of the difference between shell diameter and spike diameter. Middle: A sea urchin with a minor injury. Right: Dead sea urchins.

3.1.1 Wild catch of sea urchins

Norway Sea Urchin (NSU) performs wild catch of sea urchins. The sea urchins that are above 40-42 mm in shell diameter are brought to a feeding process. The rest is returned to the sea. The feeding process takes approximately two months.

Also, NSU is delegated administrational responsibility for the wild life stocks. It is therefore interesting to log data from the catch.

The catch is done with a Remotely Operated underwater Vehicle (ROV). The ROV uses a pump and a nozzle to suck objects into it's local storage. The ROV is remotely operated by a user onboard a nearby boat. The user has some control on which objects he gathers, but there will still be a lot of by-catch. The urchins and objects that are gathered will be in the range of 10 – 100 mm.

Today the limit for grading is set to 42mm inner shell diameter. But the limit may be adjusted at any time. This calls for flexibility in the grading solution. In future it may also be of interest to keep the non-commercial sized urchins for the purpose of feeding them.

The water suction principle of the ROV will collect all types of objects. An estimation of a distribution of the different kinds of objects, based on [12], is illustrated in Figure 3-2. The objects gathered can be whatever is located on the seabed surrounding the sea urchins. This may typically be sand, stones, seaweed, and other seabed species.

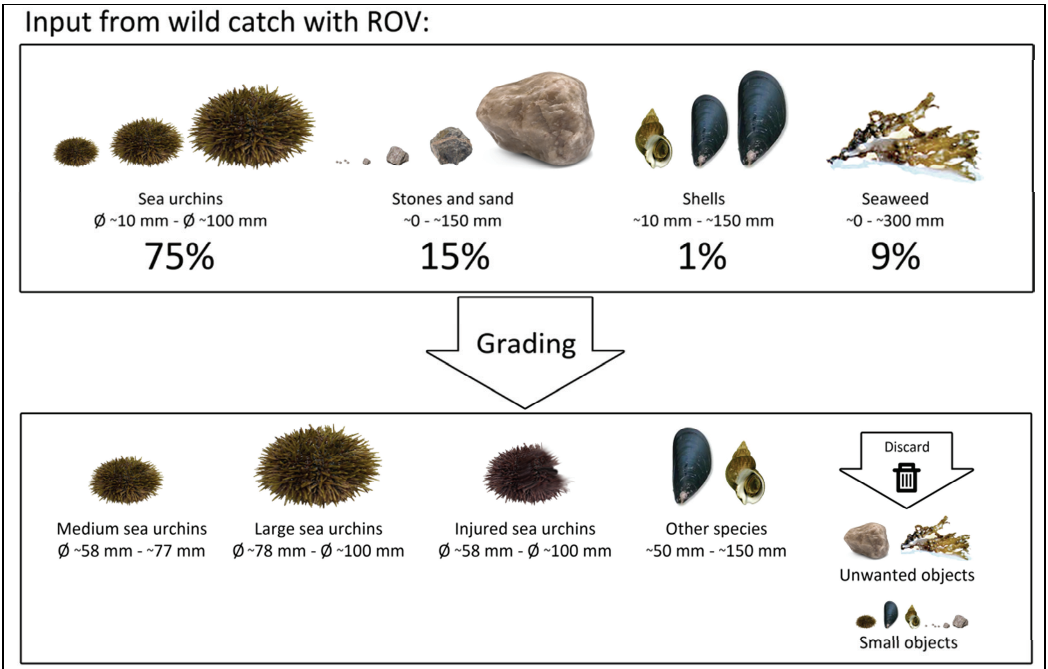


Figure 3-2. Illustrating the input (top), and the wanted classes to sort into (bottom). The percentage numbers shows the estimated distribution of objects.

3.1.2 Aquaculture farming of sea urchins

Troms Kråkebolle perform a full cycle of breeding sea urchins. The sea urchins start out as eggs and larvae before they become pelagic creatures, meaning that they are swimming in water. After about a month they attach themselves to surfaces and begin transferring into sea urchins. At this stage the sea urchins can be as small as 0,3mm. After about 4 months, the sea urchins are around 4 mm large, and they are ready to be transferred to aquaculture pools. Already at this stage it is interesting for the customer to perform grading by size. After 7 months the sea urchins are around 12 mm, and they get transferred into crates that are put into the ocean. After about 14 months the sea urchins are ready for sale.

Continuously through the breeding process there is a need for grading. Optimally a grading should be performed every month. The main reason for grading is that smaller urchins will not grow when they are dominated by larger urchins, and if the difference in size is too big; cannibalism can occur.

In contrast to the sea urchins from wild catch, there is no need to sort out foreign objects from by-catch. Still, there is a need for grading the sea urchins by shell diameter, and to sort out injured or infected sea urchins.

There is also considerable research conducted on the breeding of the sea urchins. Consequently, the recording of statistical data about size and growth would prove invaluable.

A coarse filter grading process of the sea urchins in aquaculture farming is interesting. Especially for the smallest sea urchins, the accuracy on grading by size is not that important. The yield will increase with increased accuracy, but by making a coarse grading the yield will improve significantly. A disadvantage with coarse filtering is also that it cannot record data for each individual, neither sort out injured or infected individuals. Still, a coarse filtering process is recommended for the smallest sea urchins (below 1cm). The grading machine considered in this thesis takes aim at being able to grade sea urchins from 1cm and up to 80 cm in spike diameter. It is important to note though, that the size difference within one batch cannot be that large.

Chapter 4. The Sea urchins

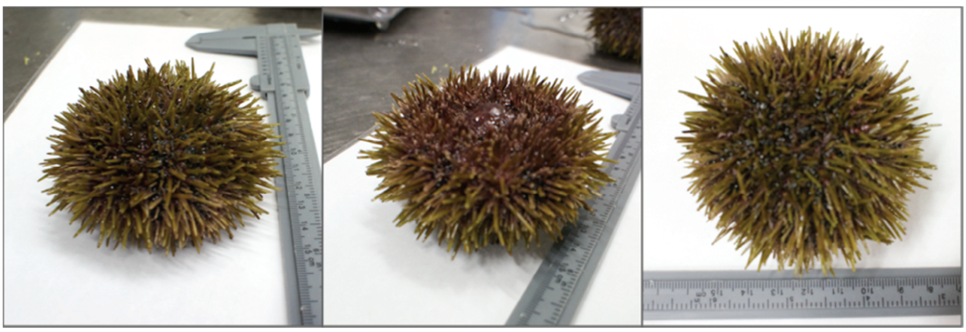


Figure 4-1. Pictures of a specimen of the sea urchin strongylocentrotus droebachiensis, harvested in northern Norway by Mattis A Tangeraas. Outer (max.) diameter ≈ 90 mm, inner shell diameter ≈ 70 mm. From the left: Top-side view; bottom-side view; straight top-view.

The sea urchins are generally challenging objects to handle and grade with automated machinery. Their shape is uneven, and they are more elliptical than round. Their spikes make them prone for hooking into each other, or machine parts. The sea urchins are to be graded while alive, and they have the ability to move around using their spikes, both in and outside of water. In addition the sea urchins are fragile creatures; a number of factors need to be attended to if the sea urchins are to be kept alive:

Water

A conservative rule for the maximum time allowed out of water is recommended by Nofima, which have written a instruction manual for aquaculture of sea urchins. They suggest that to ensure that the sea urchins does not dry out, they should not be kept out of water for more than 10 minutes. [7]

Research has suggested that the time out of water can be increased if the air humidity, or the general moistness, around the sea urchins is high. The time may perhaps be increased up to 24 hours, if the sea urchins are kept moist. [13]

Mechanical damage

The sea urchins a receptive to mechanical damage. Nofima's guide stresses that the sea urchins must be treated gently. It is even recommended to be careful with stacking too many sea urchins in the height, when outside of water, because of the chance for damage generated by the pressure forces. [7]

The sea urchins can break spikes very easily, and they are susceptible for internal damage. In the worst case, the shell may crack.

Tube feet

When submerged in water the sea urchins use their tube feet to attach and climb on their surroundings. Great care has to be taken when trying to de-attach the sea urchins. Especially if a particular sea urchin has become stressed and attached itself extra hard, it should not be forced off. This is because of the chance for ripping of the tube feet and spikes. [7] [12]

Figure 4-2. Picture of an unknown species of sea urchin, using it's tube feet to attach to a stone. [16]

Temperature and light

The recommended room temperature is below 15 degrees Celsius, and in water the recommended temperature is below 10 degrees Celsius. In addition the change of temperature, given any initial temperature, should not be to quick, as this will lead to mortality. It is also recommended that the sea urchins are not exposed to direct sunlight because they cannot endure too much UV-light exposure. [7]

Effect on gonad quality

The gonad growth and quality, along with shell growth is proved to decline considerably when the sea urchins are healing themselves after any kind of injury. [7] [13]

Dying slowly

Sea urchins may are slowly dying creatures. Bad treatment of a sea urchin may cause it to die several weeks after the treatment. [7]

Experiments have shown that sea urchins may die of bad treatment up to 4 weeks after. [13]

This makes it difficult to determine the cause of death on sea urchins. If the machine is to be tested for sea urchin mortality, it will be important that the sea urchins are in their normal conditions both before and after testing. This implies that the test needs to conducted at the customer's facilities.

Typical shape and size

The sea urchin species *Strongylocentrotus droebachiensis* is rarely larger than 100 mm, outer spike diameter. Typical shape, height, diameter, and spike sizes are shown in Figure 4-3. The figure shows a small and a medium sea urchin. It is interesting to note that the spike size does not increase significantly; the spikes on the small sea urchin is around 4,5 mm, and on the medium sea urchin they are around 9 mm. The small sea urchin has longer spikes relative to its shell size, than the medium one. The density of spikes is larger on the medium sized sea urchin, making it harder to measure the real shell diameter.

Sea urchins of the same shell diameter may have radically different spike sizes, the spike size will depend on the living conditions the sea urchin has grown in. Thus, for sea urchins from aquaculture breeding the spike sizes are similar.

Government regulations are often given in the shell diameter size.

The weight of a sea urchin of medium size, like to one in Figure 4-3, is around 50 – 60 grams. The dimensions and weights are based on measurements made on sea urchins that was sent by plane from Troms Kråkebolle.

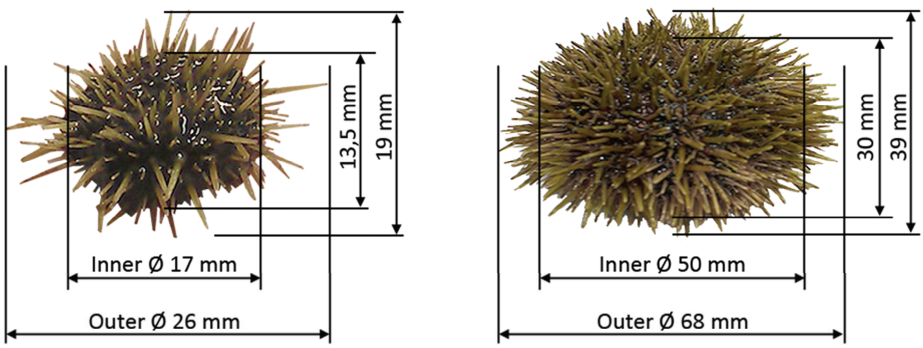


Figure 4-3. Dimension for sea urchins. One small (left) and one medium sized (right). The samples are from Troms Kråkebolle sea urchin farm. (Image not to scale.)

Chapter 5. Product requirements

The product requirement specification table is based on the requirements from [2] with minor changes.

Requirement specification			
Grading machine for sea urchins		18.05.2013	
Pkt.	Description	Specification	Required
1	**Funksjonskrav**		
	Fully automated		Must
	Tact time	[0 – 4 sec.]	Must
	Accurate grading	+- 2,5 mm	Should
	Sort sea urchins by shell size		Must
	Sort out by-catch, like stones and other seabed species		Must
	Sort out injured sea urchins		Must
	Sort out dead sea urchins		Should
	Weigh the sea urchins		Future
	Place sea urchins in crates		Future
	Transport sea urchins to and from pools		Future
	Pick out sea urchins from crates		Future
	Store data		Must
	Sort into several classes	Up to 6	Must
	Object sizes		
	Flexibility in object size	From 10 – 100 mm	Must
	Able to handle batches with variety in size	Wild catch: 40 – 80 mm (max diameter) Aquaculture: 2 – 8 mm, 9 – 17 mm, 20 – 40 mm. (Skalldiameter)	Must
	Handle small sea urchins	0,3 – 10 mm	Another machine
	Gentle	Less mortality than by manual	Must

		grading	
	Prevent the sea urchins from drying out	Max. 10 minutes out of water	Must
	Prevent the sea urchins from cracking their shell		Must
	Prevent the sea urchins from loosing spikes		Must
	Prevent internal damage in the sea urchins	Slow accelerations	Must
	Prevent contamination of the sea urchins	Follow sanitary rules	Must
	Prevent UV rays to damage the sea urchins	No direct sunlight	Must
2	**Operational requirements**		
	There should be no need for manual interaction with the machine during normal operation	At least 12 hours operation without manual interaction.	Must
	The user can controll the machine from a computer		Must
	The user can controll vital functions of the machine on a onboard control panel		Must
	Emergency stopp switch		Must
	Easy to use without technical knowledge		Must
3	**Production**		
	Modular parts of the system, so that tailor made solutions can be made for each customer.		Should
	Use of standard components	As much as possible	Must
	Reliability	Minimalized wear parts	Must
	Reliability	Build «more than durable enough»	Must
	Reliability	Correct materials for corrosive environment	Must
4	**Environment**		
	Corrosive salt water environment	Endure corrosive environment after industry standards.	Must
	Access to power		Must
	Floor	Robust	Must
	Water drain	On floor	Must

Chapter 6. Problem decomposition

Figure 6-2 and Figure 6-3 show the complete system of functions along with the input and output, in the grading process for wild catch and aquaculture of sea urchins, respectively.

The focus in this paper, for the building of the first prototype, is set on the critical functions of the core grading process, as illustrated in Figure 6-1.

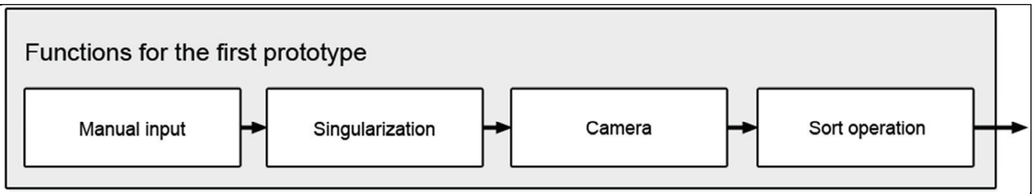


Figure 6-1. The core functions prioritized for the development of the first prototype.

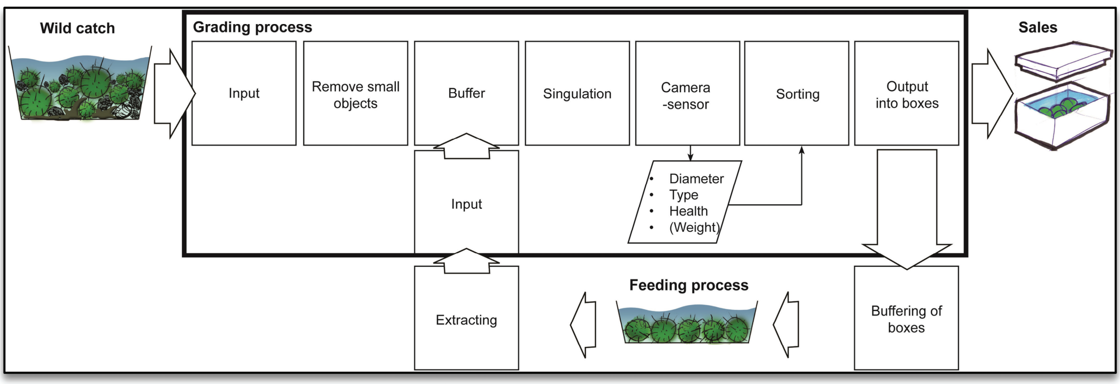


Figure 6-2. The functions in the process of grading sea urchins from wild catch.

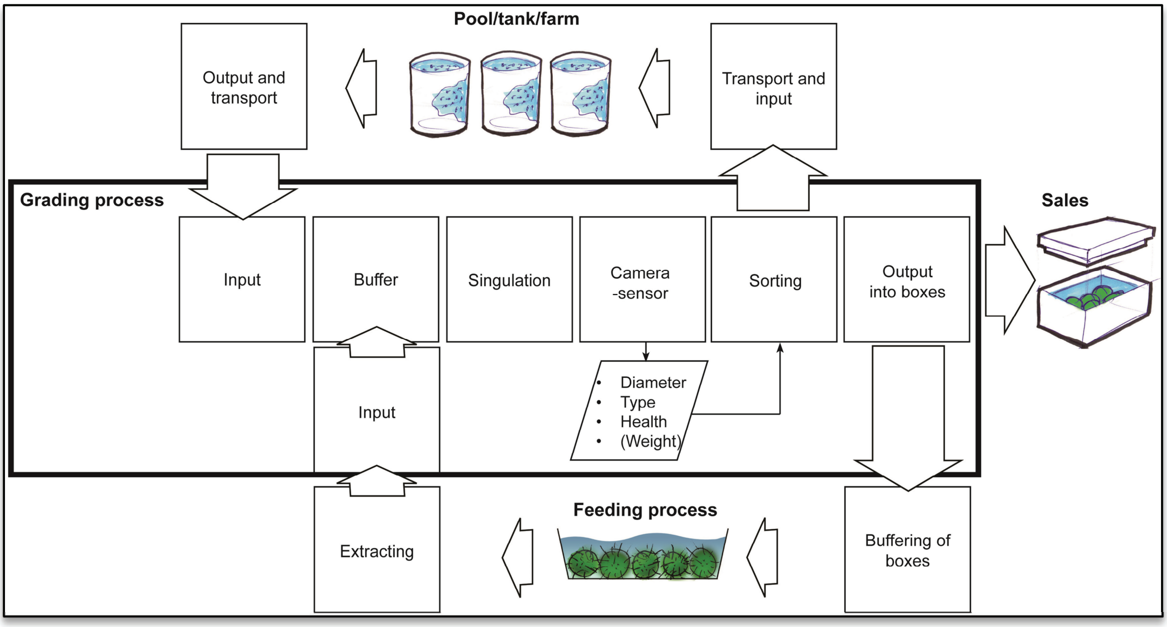


Figure 6-3. The functions in the process of grading sea urchins from aquaculture farms

Chapter 7. Preliminary choices

7.1 Camera

The customers have two main needs; grading sea urchins by shell diameter, and grading by gonad content. A study [1] considered technologies for estimating both gonad content and shell diameter. The study found that spectroscopy with near infrared or visible light is an interesting candidate, but that there is considerable time and cost connected with the research effort needed.

Using an optical camera in the grading machine is a preliminary choice based on several facts. The technology for optical imaging is simple, cheap, and easily available. The camera can be used to inspect shell diameter, injuries, discoloring and object type. With optical inspection it will not be possible to inspect the gonad content, but the surrounding mechanical system developed in this thesis may be readily reused if a sensor for estimating gonad content is available in future.

The preliminary work done in [1] and by Pearis AS [14] have shown that with a single optical camera taking 2-dimensional images it is possible to achieve the wanted visual inspection features to grade by shell diameter and object type.

7.2 Filter

A simple filtering system that is not sufficient to solve all the needs of the customer. It will not be able to grade the sea urchins directly by the inner shell diameter. It would have to use statistical data, which will not be as accurate as measuring directly. Also, it will be difficult to sort out foreign objects, like stones, that have the same shape as the sea urchins.

For grading of the smallest sea urchins (below 8mm), the accuracy is not that important. These sea urchins are also originating from aquaculture, meaning that there is no foreign objects that have to be sorted out. Grading of the small sea urchins is out of the scope of this master thesis. But it is suggested that a mechanical filtering solution could work well for the small sea urchins. For example a drum filter type machine could be used.

There may be a need for a coarse filtering process for the grading of objects originating from wild catch of sea urchins. Those batches may contain objects of a great variety in size, which will make it difficult for the machine to perform well. The batches will also contain very small objects like sand, this should be removed to prevent wear on the machinery. Some kind of coarse filtering processes is therefore considered in this thesis.

7.3 Semi-manual prototype

The development of a complete and fully automated system is not practical or realistic at the current stage. The time limit and the scope of this master thesis, require that the problem is narrowed down. Also, in practice it is better to perform costumer based large scale tests of the core functions of the system, and find whether these perform as wanted, before investing considerable effort in completing the system.

The preliminary choice for a semi-manual solution implies that there will be manual input and output of objects to and from the system. Crates of objects will be manually emptied directly into the system. This will be done continuously as the machine operates, implying that there will not be a large buffer for objects built into the prototype. The output will sort objects into crates, but the switching and replacing of crates will have to be done manually.

Some development will still be focused on the input and output functions. This is to ensure that the whole picture is taken into account when designing the core functions.

Another argument for this preliminary choice is that a semi-manual solution still, in contrast to fully automated, still is an interesting system for the customer. Even a semi-manual solution where only the camera is used, and there is manual input and sorting of each individual object, would be better than today's solution. [8]

Chapter 8.

Choosing a concept

In the preliminary study [2] a concept was presented, outlining the working principals of a grading machine for sea urchins. The concept that was presented in the preliminary study consists of a combination of the most promising sub concepts that were investigated in the preliminary study. The conclusion of the preliminary study is that the presented concept is feasible, but that a more detailed concept screening and ranking should be executed.

The sub solution concepts generated in the preliminary study were reinvestigated in this study, and new combinations and additions were introduced. A structured screening of the sub concepts was performed, and they were categorized and combined to generate the concepts that are presented in this chapter. The concepts are ranked by their score on several factors. These factors are based on input from the requirement analysis. Based on the concept rankings, and a general discussion, a main concept is chosen for further investigations and development.

Arguments for, and detailed definition of, the factors used for concept ranking is discussed in the following.

8.1.1 Cost

The product is to be sold to an industry that is under development in Norway. The two pilot customers in this project own no considerable assets for investing in expensive equipment . Also the seller (Searis AS), being a tech start-up company, does not have adequate assets to build an expensive machine without instant payment from the customer. (There is money reserved for the building of a prototype). The business plan of Searis is to get profit over time, and have the customer pay for just the material and assembly costs of the machine at the start. The lack of capital available for early investment in the machine makes building costs for the machine a critical factor when choosing a concept.

The cost of the machine is defined as the cost of designing parts, buying materials, producing components, and assembling the system. The underlying factors for estimating the cost are:

1. Machine complexity. The amount of parts, and the level of details and accuracy needed in the machinery.
2. The amount of work put into development and manufacture of special parts. Contra using commercial off-the-shelf components
3. The quantities of parts and material, and the pricing on these.

8.1.2 Gentle handling

As mentioned, sea urchins are delicate creatures that are prone for receiving injuries by stress, mechanical damage, and lack of water. It is therefore important that the handling of the sea urchins is as gentle as possible.

Gentle handling will be rated by the expected gentleness of the concept in question. The gentleness is estimated by considering if there is applied any rapid application of forces, high static forces, small pressure points, possible tearing of spikes from the sea urchins, or any rapid change in acceleration/de-acceleration of the sea urchins.

8.1.3 System reliability

The system reliability will in this case be defined as the likeliness that the machine will perform its tasks in a stable manner, and also by estimating the likeliness that the machinery and its components do not fail. The underlying factors for estimating the reliability are:

1. Machine complexity. The amount of parts, and the level of details and accuracy needed in the machinery.
2. The amount of self-developed special components contra using commercial of-the-shelf components. (The commercial components are expected to be more reliable.)
3. The complexity, and/or nature, of the principals used by the machine to perform its tasks.

8.1.4 The use of standard components

The specification states that the use of standard components is preferred.

The use of standard components, instead of custom made components, is wanted because it is assumed to influence the following factors:

1. Cost. (Commercial components are in the first place estimated cheaper than self-developed components.)
2. Reliability.
3. Replace and repair may be easier when using commercial components. The availability of parts is better, and the cost affiliated with replacing them is estimated to be cheaper.

8.1.5 Flexibility

The flexibility will, for the purpose of choosing a concept, be defined as the machinery's ability to handle objects of different sizes and shapes.

There are two kinds of flexibility considered:

1. The ability to handle batches containing of objects with variation in dimension. The variation was found to be varying with a factor of up to 2.

2. The ability to handle different types of batched size groups. Where the difference in size of objects, from the smallest object in the smallest size group to the largest object in the largest size group, may by a factor of up to 15.

8.1.6 Easy to maintain

How easy is it to wash the machine. Are there many wear parts. Is it easy to apply the necessary lubricants etc.?

8.1.7 Confidence factor

The degree of confidence in that the working principles will be able to perform as expected when executing their given tasks. The degree of confidence is based on subjective apprehension.

Factors for concept scoring	**Importance. (1-5)**
Cost	5
Gentle handling of sea urchins	4
System reliability	4
Use of standard components	4
Flexibility	4
(Easy to maintain and wash)	3
Confidence factor	3

Chapter 9. Concepts

9.1 Concept 1 (2) 'Mechanized'

The 'mechanized' concept investigates the use of mechanical movement to manipulate objects.

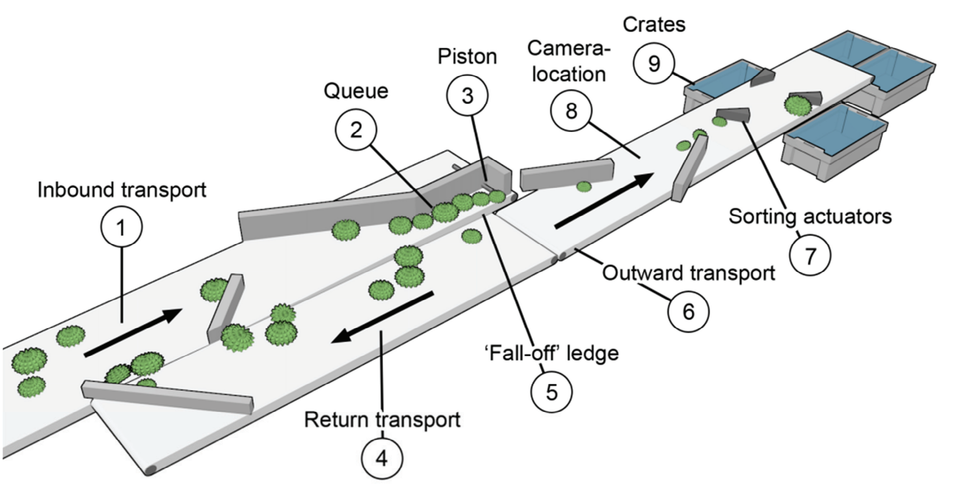


Figure 9-1. The 'mechanized' grading concept.

The grading is done as follows. Objects to be graded are introduced on a transporter (Figure 9-1, note 1). An angular blockage on the transporter leads the objects to be graded into a line. (Figure 9-1, note 2) Excessive objects will fall out of the side of the transporter and land on another transporter that will return them back to the start of the first transporter. (Figure 9-1, note 4 and 5.) The loop created by these two transporters act as a buffer that stores excessive objects. This enables the system to accept periodically large input of objects. The objects that are lined up will form a queue at a pick up location. (Figure 9-1, note 3). (The idea for the buffer and pick up location was presented in [15].)

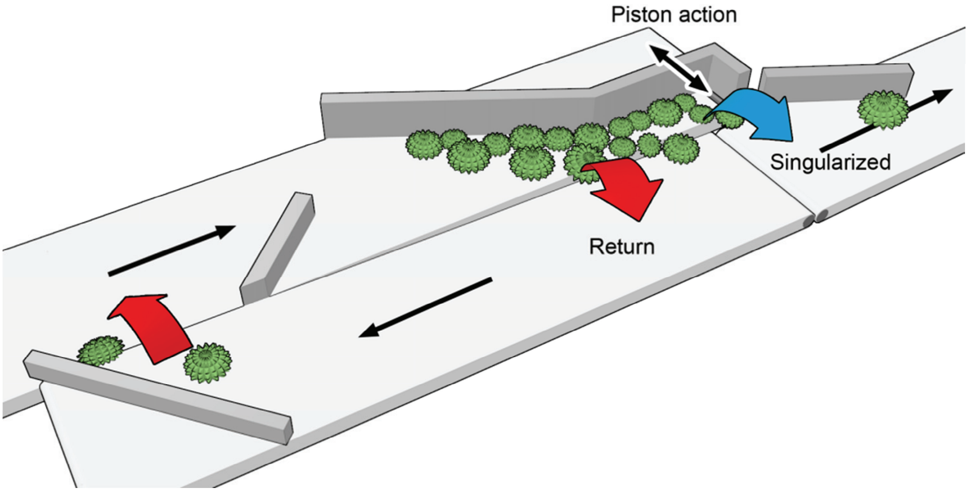


Figure 9-2. The buffer and singularize process in the 'mechanized' concept.

Singularization is achieved when the objects that are lined up in the queue is picked out one by one. This can be done with a simple piston (Figure 9-3, a and b) which can be used to push the objects onto a new transporter. To mitigate problems with jamming and the potential damage infliction that follows (Figure 9-3, c), an ‘open’ design is used. The ’open design’ allows for the objects in the ‘pick up’ position to fall back onto the returning transport without colliding with any surrounding structure (Figure 9-2).

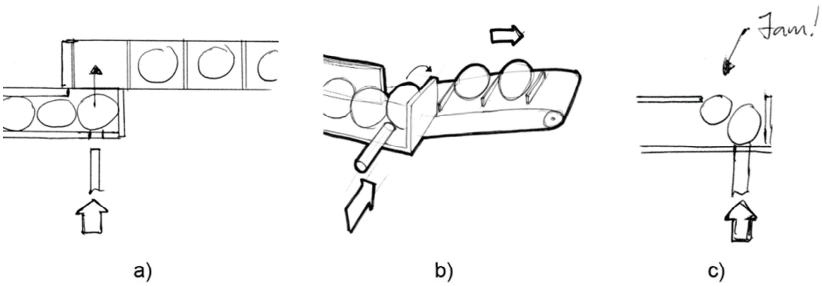


Figure 9-3. ‘Push-off’ piston for singularization. a) Top view. b) 3D view. c) 'jamming' of objects. [Kilde: Prosjektoppgaven!]

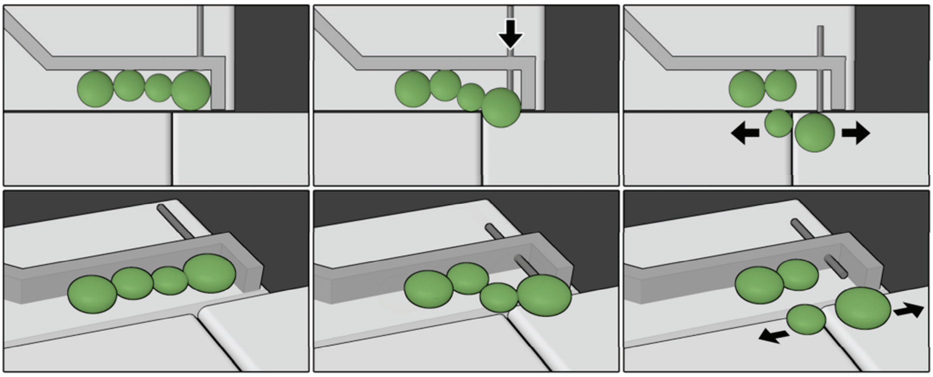


Figure 9-4. From left to right: Displays time lapse of the 'open design' singularizing piston. (Top: Top view. Bottom: 3D view.)

The objects that are pushed out of the queue will land on a third transporter that will carry the objects downstream.

Only one object should be pushed over on the new transporter at the same time. If any objects 'stick' to each other and get pushed by the piston simultaneously, the excessive object should fall back onto the returning transport (Figure 9-4). If two objects enter the transporter at the same time, problems may occur in the sorting operation further downstream.

A variation of the 'pick out' operation may be by using a rotating wheel to push the objects (Figure 9-5). The wheel pushes outward as well as forward, and might be better at de-attaching clustered objects, thus discouraging two objects to be pushed over to the transporter at the same time. The wheel consists of flaps that are cut in an angle, in a way that allows for interaction with both small and large objects without influencing any object that may be next in the queue.

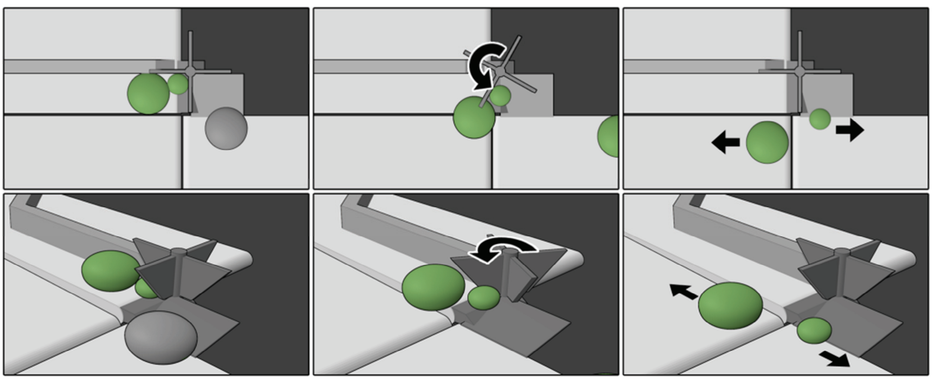
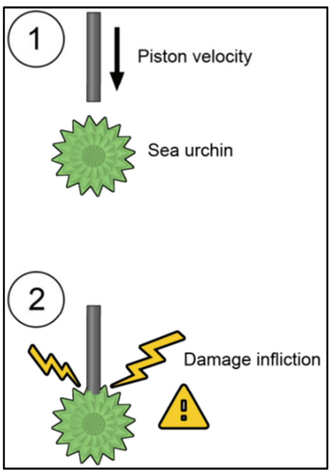


Figure 9-5. From left to right: Displays a time lapse of singularization by a rotating wheel.

The objects that have been pushed over on the new transporter are singularized and on a line. The objects will further downstream pass under a camera, and a computer will determine how the particular object is to be graded.

The objects are sorted after they have been registered by the camera. The objects continue downstream and will be pushed of the transporter at the correct time, causing them to fall into their respective containers. The objects are being transported at a constant speed, enabling easy calculation of the objects position downstream. The push actuation can be either directly applied by a piston, or indirectly by a guide. A perpendicular piston action will apply force quickly in one direction and may cause injury. Therefore a screw-like application of force is suggested. Soft piston tips have also been considered. An alternative is to use guides that can be removed or introduced when necessary (Figure 9-6). The removing and



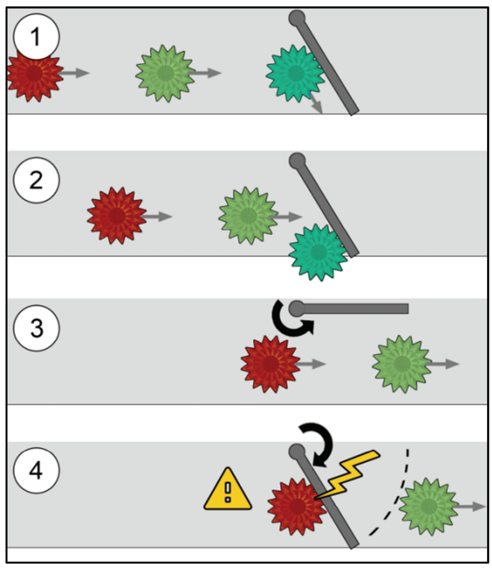


Figure 9-6. Guides for sorting

introducing of the guides may also cause damage if they are to hit the objects.

A rotating triangular guide as therefore suggested. (Figure 9-8). The triangular guides rotate and push the objects either left or right. The actuation of the rotating triangles is initiated after the objects have made physical contact with the triangle. By placing a number of these rotating triangles in sequence, it is possible to control where the objects are pushed of the transport and into their respective containers.

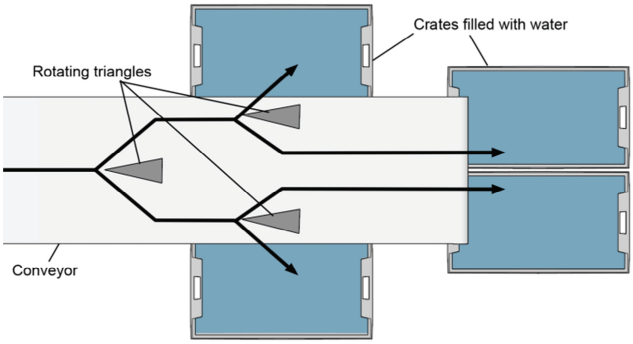


Figure 9-7. The possible transport routes (black arrows) when sorting with 'rotating triangles'.

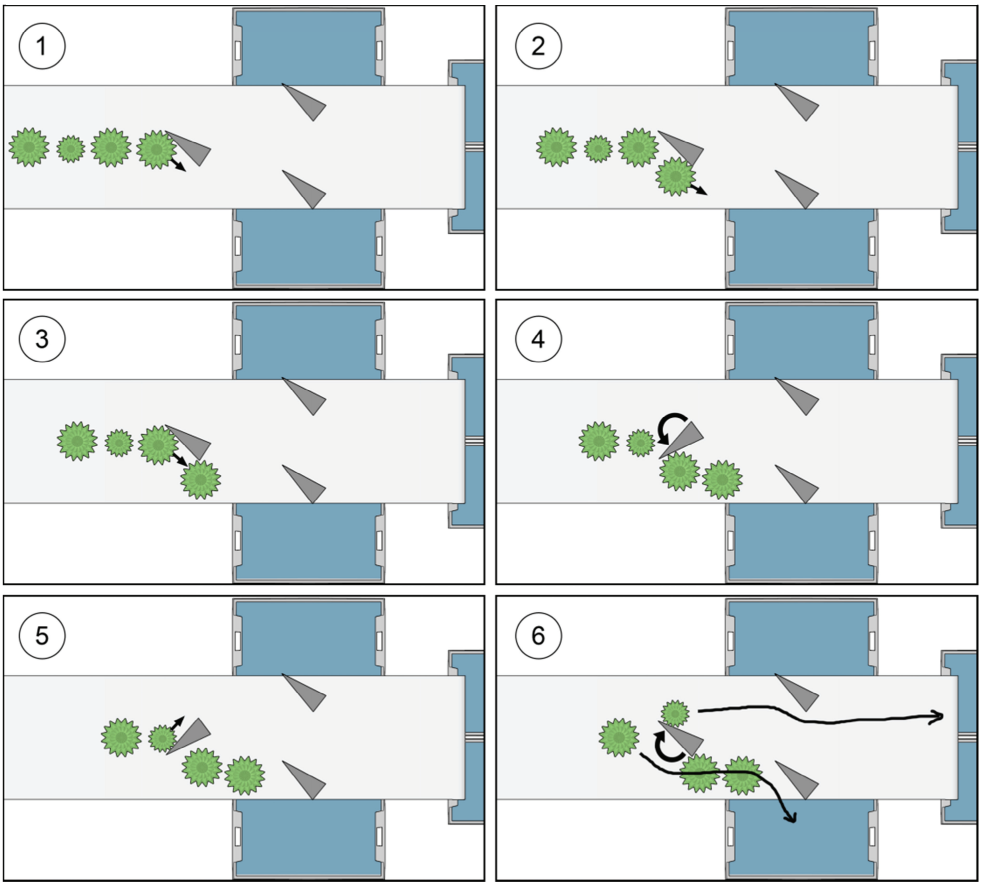


Figure 9-8. The principle for sorting with 'rotating triangles'. The triangle acts as a guide that leads the objects in one direction. When the next object in line is to be guided in a different direction, the triangle rotates while still in contact with the previous object (image 4 and 6.).

The main challenge with all of the concepts that are based on mechanic interaction is the lack of ability to cope with variation in object size. The objects to be graded may, as specified, vary in size with a factor of up to 2 within the same batch. The variation of object size between batches may vary by radically larger factors. Figure 9-3 shows examples where variation in object size is the cause of 'jamming'. Figure 9-9 shows an example where variation in object size is the cause of bad singularization, where two objects enter the 'outgoing' transport at the same time. By "clever" design one may be able to mitigate the problems with variation in size within one batch. But when changing between batches that consist of objects with radically different sizes, it is difficult to find a design that will not require physical readjustment.

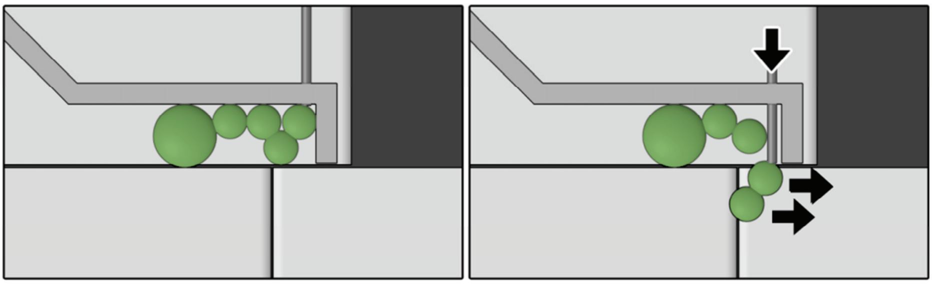


Figure 9-9. Illustrates an example of poor singularization, where two objects gets pushed out at the same time.

The 'mechanized' concept is, of the three concepts presented, the one that will demand the highest amount of custom made parts. Standard conveyor belts can be used as transporters. Also, standard actuators (i.e. electric motors) can be used for generating motion. But to ensure accurate application of the motion, custom parts are needed for the movable and the supporting –components. The specification states that standard parts (commercially available) should be utilized to the largest extent possible.

Actuated components are prone to inflict damage to the objects to be graded. Damage may occur if the speed is too high, or if there is too high pressure forces. The proposed solutions for the 'mechanized' concept, tends to demand a trade-off between sufficient gentleness and the speed of handling. As mentioned earlier there is zero tolerance for causing injury to the sea urchins, thus the speed of operation must be downgraded. Also, any error or misconfiguration in the system may cause unexpected damage to the objects. I.e. if the motion of the piston in the singularizer is skewed it may squeeze the sea urchins against the surrounding wall. This may be mitigated by the use of pressure sensing relief mechanisms that will limit the maximum force applied. But since introducing those kinds of mechanisms will contribute to the complexity of the system, they are not desired.

The overall complexity of the system generally increases with the amount of components that is actuated. The actuated components should work reliably and deliver force accurately. To achieve this, the system must be well designed and made of machine parts with low tolerances on dimensions. Also, actuated components introduce wear and maintenance issues. Considering that the machine is meant to operate in a highly corrosive environment, it is essential that the design minimizes wear and environmental influence. This type of design considerations contributes to increased complexity in the machine. The complexity of the system ultimately leads to increased costs because of the costs affiliated with development and production of parts, and maintenance costs. The increase in complexity also negatively affects the confidence in that the machine will perform reliably.

The buffer has a limiting factor. It there is continuous input of objects into the system, some objects may loop around the buffer forever. This is a problem because of the potential for the sea urchins drying out. Even with a water sprinkling system that keep the sea urchins moist, it is possible that the time spent in the buffer is too long. This can be avoided if there are regular pauses in the input that allows for all of the sea urchins stored in the buffer to go through.

9.2 Concept 2 (1) ‘Water’

The focus of this concept is to use water as a mean for transport and manipulation of objects. The basic idea is that the use of water will minimize the mechanical stress inflicted on the sea urchins during grading. Also the urchins are kept in their ‘natural state’ (in water), thus there is no concern of the sea urchins drying out.

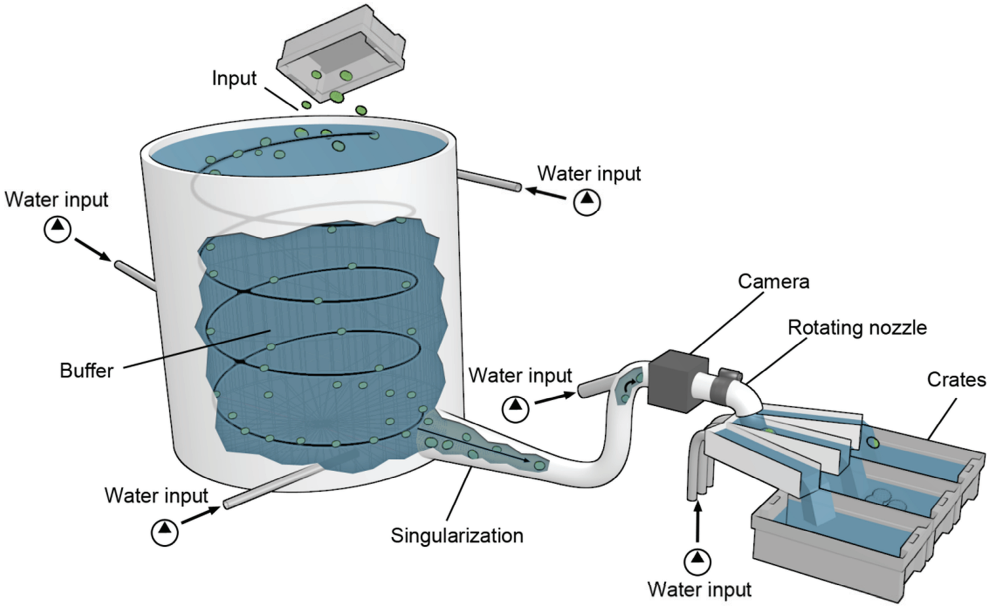


Figure 9-10. The 'water concept', a proposal for a complete system for grading of sea urchins.

The objects to be graded are introduced into a pool of water. The water surface of the pool allows for soft input of sea urchins. Crates of sea urchins can be efficiently poured into the pool (Figure 9-10). The pool of water acts as a buffer zone which stores the objects before they are taken out into the next step of the grading. The water is sent into a spiraling motion by water jets around the wall of the pool. This ensures that the objects will spend time in the buffer zone while sinking to the bottom of the pool. The spiraling motion of the water is also meant to prohibit the sea urchins from getting the opportunity to attach to the walls of the pool.

At the bottom of the pool the objects are directed into a tube. Excessive objects will keep spiraling around the floor of the tank. Water is pumped into the pipe creating water current that sucks objects out of the buffer pool. The pipe decreases gradually in diameter to accelerate the flow of water, and in this way, aid in separating the objects from each other. A bend in the pipe, at the point where the water from the pump enters, may further assist in the separation of objects. For these separation principles to work efficiently it is essential that there is a low flow of objects from the buffer pool into the tube. To ensure this there should be a strong spiraling current in the buffer, while there is a weaker current going into the tube.

A camera acquires images of the objects when they flow inside the tube. The images are processed by a computer algorithm that classifies the objects. The computer controls the motion of an actuator that performs the sorting operation. At the end of the tube a nozzle, or a bent tube, is actuated in rotary motion. The nozzle can rotate to predefined positions, thus enabling the sorting of objects into their respective classes. The time it will take for objects to move from the camera to the end of the tube is calculated by measuring the speed of the objects when they pass under the camera.

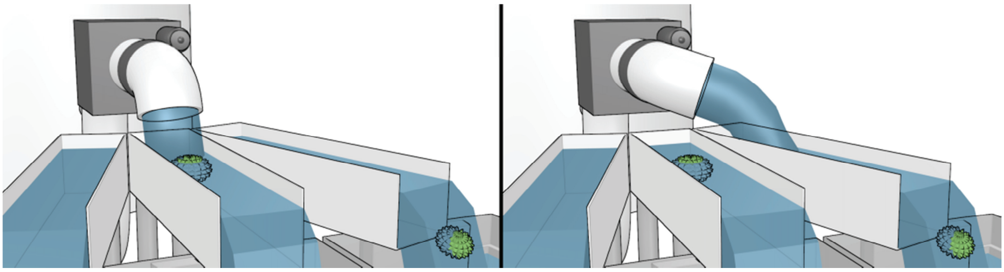


Figure 9-11. Principle for sorting objects with a rotating nozzle.

The need for water poses a challenge. A supply of oxygenized and fresh salt water is wanted for the wellbeing of the sea urchins. The water might be recycled for a limited time to limit the quantity of water needed. But still, pumps are needed to generate a current of water in the spiraling buffer and in the tube. With a large pool of water, and a tube diameter of 15-20 cm, the amount of pumped water needed is considerable. For aquaculture farmers the infrastructure may exist from beforehand, and there might only be a need for an extra upgrade of the capacity. For the users which conducts wild catch of sea urchins this infrastructure may not exist. The infrastructure for the water system introduces extra costs, and is therefore a major drawback for this concept.

The water current may encourage the sea urchins to use their suction feet, and encourage the sea urchins to attach to the inside of the tube or to each other. Research [12] suggests that movement in the water might cause sea urchins to grip on more firmly. If the sea urchins cluster together or attaches to the surface of the tube, it might clog the system.

Incorporation of individual sea urchin weighing might be difficult in the 'water concept'. Weighing of the sea urchins is marked as possible future feature of the grading machine. To weigh the sea urchins while they are in water, a closed control volume of water must be used, this might be difficult to do without stopping the flow. Other solutions will require addition of new steps in the machine where the objects are taken out of the water. The difficulties of adding weighing features may cause extra costs at the time, in future, when weighing is to be implemented.

The equipment for capturing images of the objects is more sophisticated for the ‘water concept’. The objects that flow in water will have a random orientation at the time they pass by the camera sensor. With a random orientation the current camera will not be able to correctly identify the sea urchins diameter. To solve this, a camera system that acquires 3D images could be used. This will add to the complexity and cost of the machine.

Another disadvantage is that the design of the rotating nozzle will have a limit on how many classes that the objects can be sorted into.

9.3 Concept (3) ‘Acceleration’

The main point of this concept is to minimize directly applied mechanical interaction with the sea urchins. The preliminary study resulted in the establishment of this concept. The concept was recommended because of the flexibility in object size acceptance, and the use of standard components.

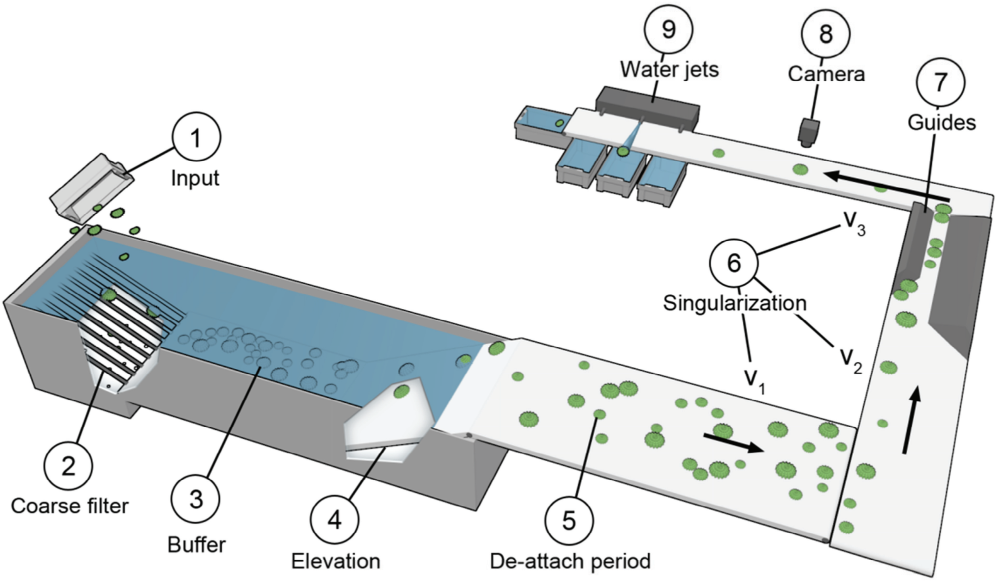


Figure 9-12. The 'acceleration concept', a proposal for a complete system for grading of sea urchins.

The grading is done as follows. The objects to be graded are introduced into an oblong pool of water. The objects are poured into the pool of water which offers a soft introduction for the sea urchins. (Figure 9-12(1)) A filter in the pool sorts out the smallest objects. The filter is made up of bars mounted with a predefined gap between them. The angle on the bars will allow the objects that are large to slide downward until they fall on a conveyor belt at the bottom of the pool. The filter may need to be actuated in a reciprocating up and down motion to avoid clustering and to ensure that the urchins do not attach to the filter. (Figure 9-12(2) and Figure 9-13)

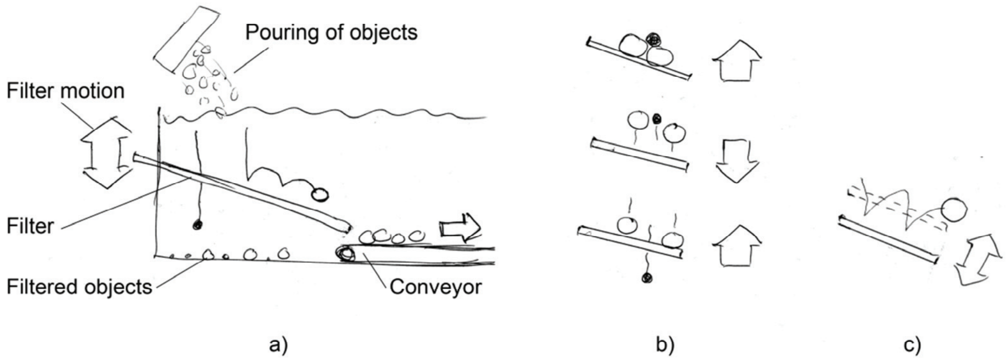


Figure 9-13. a) Illustrates the up-and-down motion of the filter inside the buffer pool. b) Illustrates how the motion of the filter prohibits bad filtering as a cause of clustering. c) Illustrating that the up-and-down motion encourage the objects to slide downwards, and prohibit the sea urchins from attaching to the filter.

The floor of the pool is made up of a conveyor belt that transports the urchins forward and out of the water. The water pool acts as a buffer, and can keep the sea urchins alive and well, even if there should be any unexpected stop of the system. When the sea urchins have been transported out of the pool they will, while still resting on the same conveyor belt, dry and start to release the grip on the belt.

The conveyor belt transports the objects out of the pool in an angular slope. The angle on the conveyor belt makes sure that the heap of objects is not stacked too high when entering the singularization operation. A transversal blocking beam may be added to assist in limiting the height of the stack. (Figure 9-14)

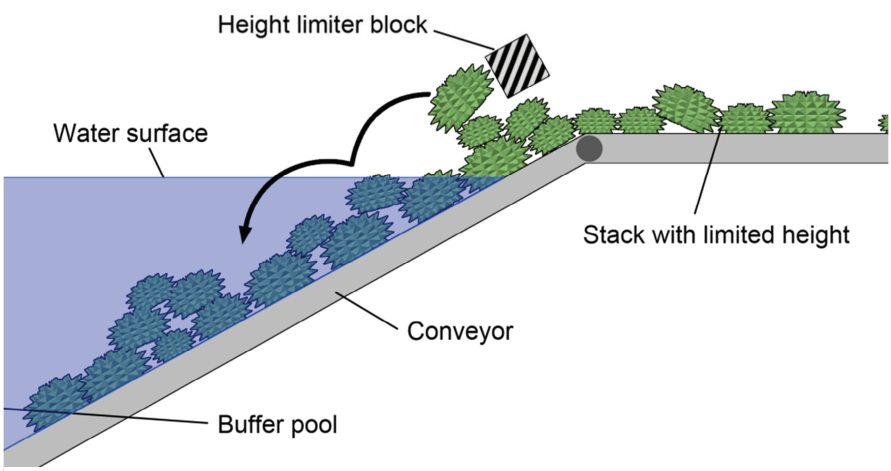


Figure 9-14. Sloped conveyor and height limiter block ensures that the stack of extracted objects is limited in height.

Singularization of the objects is achieved by consecutive conveyor belts that each has an increased transport speed in relation to the previous conveyor. As illustrated in Figure 9-15, the first conveyor moves slowly and allows for a limited amount of objects to fall over on the next conveyor. When the objects fall over on the next conveyor they are no longer stacked in height, and should be in a line. To ensure that the objects always are in a line on the second conveyor there are guides (Figure 9-12(7)) on top of the belt. The objects in a line on the second conveyor fall over, one object at a time, to the third and quickest moving, conveyor belt.

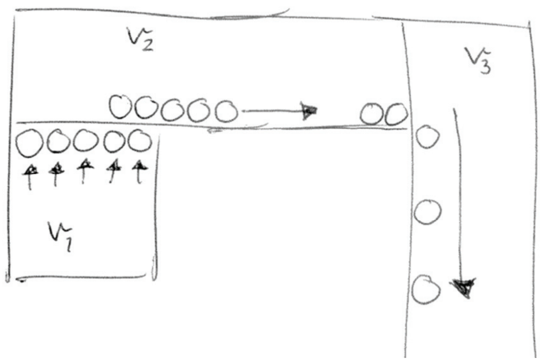


Figure 9-15. The singularization principle for consecutive conveyors with increased transport speed. v1 < v2 < v3.

The singularized objects pass under a camera, and are classified by the software system. Valves control water jets that can push the objects of the conveyor belt and into their respective crates or pools. One class of objects can also fall of the end of the conveyor belt without the use of a water jet (Figure 9-12(9)).

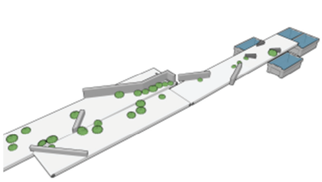
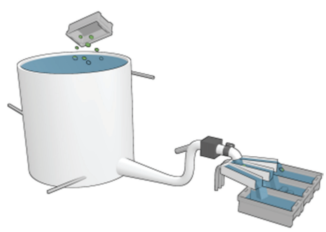
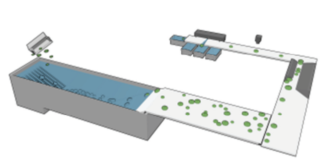
The principle for singularization is promising because of its high score in several factors. The physical handling of the sea urchins is gentle and will only depend on the angle of the guides, and the height of the fall-of-edge between the consecutive conveyors. The singularization and the distance between objects can easily be regulated and optimized by varying the conveyor velocities. Also, subjective analysis and simulations have given great confidence in the general working principle and the ability it has to singularize with large variety in object sizes.

The input and buffer pool poses several challenges. The sea urchins will attach to the conveyor and will need time to de-attach, secondly it is very probable that the sea urchins will start to attach and climb on the walls of the pool. The behavior of climbing up the walls of pools was observed in the pools and crates at Troms kråkebolle's and Norway Sea Urchin's facilities (Figure 10-3). If sea urchins attach to the walls, it will render the conveyor on the floor unable to extract them from the pool. Another disadvantage with the buffer pool and the filter design is that it is fairly complex and will need several custom made parts, thus counteracting the specified requirement for wide use of standard components. It is a premise that this part of the machine will be further developed or changed, thus the faults of this part can be overlooked in the ranking of the concepts.

9.4 Concept ranking and summary

Table Table 9-1, summarizes the three concepts along with their advantages and disadvantages. Each concept has been given scores for the following factors; cost, standard components, gentle handling, flexibility, maintenance, reliability, and confidence. These factors are defined in Chapter 8. The scores are given from 1-5, where 5 is best. The scores are ,in Table 9-2, combined with the relative importance for each factor. This is done by multiplication of the factors importance and the given score. The resulting scores are summarized and form a total resulting score, as illustrated in Figure 9-16.

Table 9-1. Summary of main concepts

'Mechanized concept'	'Water concept'	'Acceleration concept'
		
+ Fairly easy to visualize and test - Poor flexibility in object size acceptance, without readjustments. - Complexity and use of non-standard parts.	+ Gentle handling - Water usage - Possible clustering of sea urchins - Implementation of object weighing. - 3D camera	+ Easy to visualize and test + Standard parts - Usage of floor area - Some water usage. - Buffer and filter need to be revised.

- Moving parts make need for precision, and introduces wear issues.	- Limited amount of outputs in the sort operation.	
Low cost: 3 Std. components: 3 Gentle:	Score: BIG NUMBERs Weighed score:	

Table 9-2. Concept scores. (Result scores equal the product of the given score and the importance factor.)

		'Mechanized' concept		**'Water' concept**		**'Acceleration' concept**	
	Importance	Score	Result	Score	Result	Score	Result
Low cost	*5*	3	**15**	2	**10**	4	**20**
Std. components	*4*	3	**12**	3	**12**	4	**16**
Gentle	*4*	2	**8**	5	**20**	4	**16**
Flexibility	*4*	2	**8**	4	**16**	5	**20**
Easy to maintain	*3*	2	**6**	3	**9**	3	**9**
Reliability	*4*	2	**8**	3	**12**	4	**16**
Confidence factor	*3*	2	**6**	3	**9**	4	**12**
SUM:		16	**63**	23	**88**	28	**109**

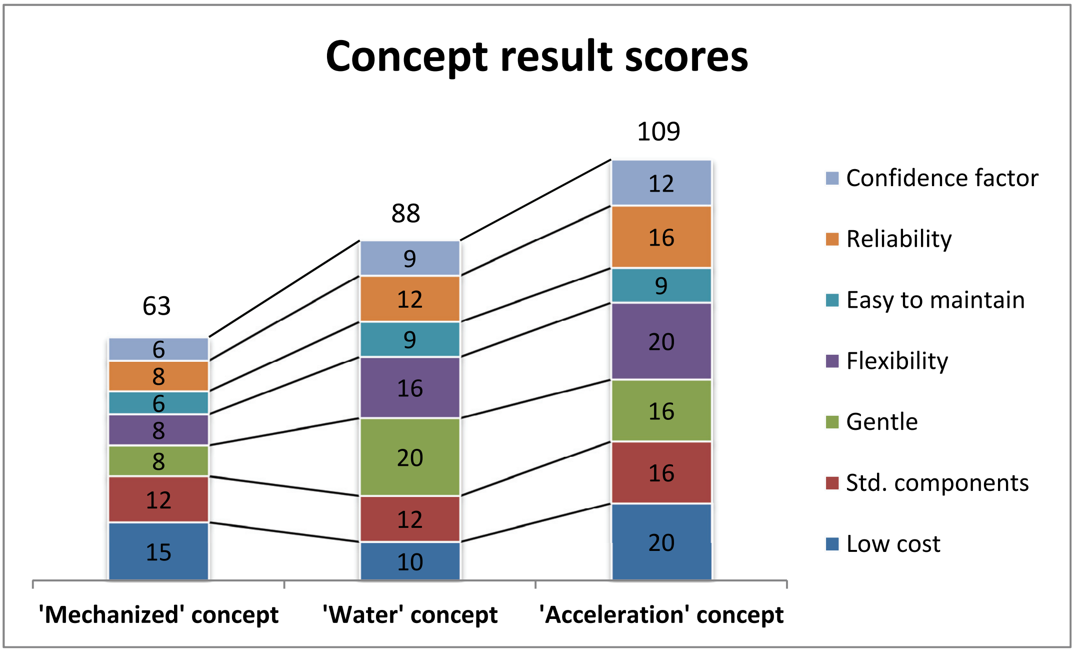


Figure 9-16. Graphic presentation of the concept result scores.

The concept scores display a clear winner. The 'acceleration', 'water' and 'mechanized' concepts are ranked as first, second, and third, respectively. The mechanized concept got a low score on most of the factors because of the disadvantages that follow with actuated components. The water concept is interesting because of its estimated ability to perform well, but lose points, especially in cost, because of the need for a large water supply. The 'acceleration' concept scored as the best candidate on the total scores, both before and after multiplying with the importance of the factors. Also, the 'acceleration' concept scored highest over, or similar with, the other concepts on all of the single factors, except one. The only exception is for the 'gentle' factor, where the 'acceleration' concept scored 4, and the 'water' concept scored 5.

The factor for gentle handling is, in contrast to the other factors, a factor where it may not be optimal to achieve the highest score. As long as the machine treats the sea urchins gentle enough so they do not suffer any injuries, the requirement has been fulfilled. There is no need to compromise with extra cost for increased gentleness, if the solution is gentle enough. This may be the case in this situation, where there is confidence in that the 'acceleration' concept is gentle enough. As this is based on subjective opinion, the gentleness of the concept should be verified by tests.

The only compromise that will have to be made by choosing the ‘acceleration’ concept is increased area usage. This does not influence the scores in the ranking, and should neither influence in the concept choice, the reason being that it is not in conflict with any requirements from the user and customer needs.

The scores are mainly based on subjective intuition. Exceptions are that the factor ‘use of standard components’ can be counted and given account for. And the ‘confidence’ factor has been investigated by experiments of thought, 3D-modelling, and simulations. But even with subjective scoring, the process has helped in facilitating a productive discussion about the solutions, and it has helped in narrowing down the solutions space, as well as give confidence in the chosen solutions.

The concepts are not precisely defined at this stage. The ranking of main concepts helped in setting out the general direction and approach for the solutions. The ‘acceleration’ concept formed a good basis for improvement by further iterations in product development. The result from further development is documented in the rest of this document, as each of the sub functions is revised.

Chapter 10. Input

As explained in chapter **Error! Reference source not found.**, this thesis will focus on the core functions (singularization , camera and sorting operation) in the grading machine, and present manual alternatives for the input and output operations for the first prototype.

The main function of the input operation is to accept an input of objects and introduce them to the operation for singularization. There are several sub-functions for the input operation, illustrated in Figure 10-1.

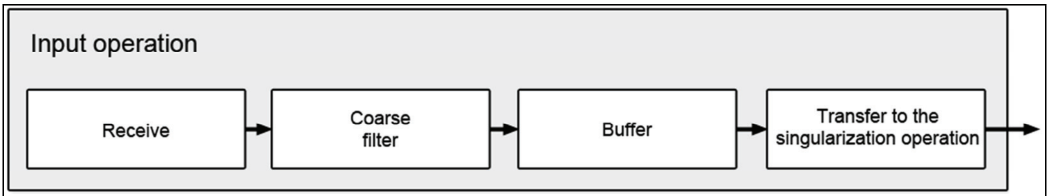


Figure 10-1. The sub-functions in the input operation

Receive

The input operation must be able to receive objects of a variety in size and type. (See **Error! Reference source not found.**). The sea urchins are delivered in crates, and will have to be extracted or poured out of the crates. This can be done, by tipping the crate and let the sea urchins fall out on a table. A gentler version may be implemented in future, where the sea urchins are poured out into a pool of water (as presented for the 'acceleration concept' in chapter 9.3). In future it is also reasonable too look at ways to convey the sea urchins through a duct or channel directly from the aquaculture pools.

Coarse filter

For an input of objects that origin from wild catch of sea urchins it is advantageous to perform some kind of pre-filtering. The smallest items, like stones and sand, is not of value to the customer. Also, it is difficult to find singularization principles that perform well when handling a batch of objects with this kind of radical difference in size.

Buffer

The buffer is an important feature. It temporarily store objects, enabling the user to insert large quantities of objects in a short period of time, followed by leaving the machine to itself. The reason that the buffer is needed is because the rest of the machine cannot handle too large quantities at one time. Another important aspect is therefore the control and limit on the amount of objects being transferred out from the buffer.

The buffer, presented as a part of the chosen concept in chapter 9.3, had to be further developed. An alternative solution have been made after realizing that the sea urchins may endure a considerable longer time out of water if they are just kept moist. A water sprinkling system could be used to keep the sea urchins moist while they are being conveyed on a long and/or slow moving conveyor (Figure 10-2). Controlling the amount of objects transferred can easily be done by adjusting the transport speed. In contrast to the buffer presented in chapter 9.3, this buffer is not in a pool of water, the input of urchins will therefore be less gentle.

The buffer with water sprinkles (Figure 10-2) is recommended for further investigations for the potential use in the future fully-automated version of the grading machine. The confidence in the solutions is good, and the design is simple and it utilizes standard components.

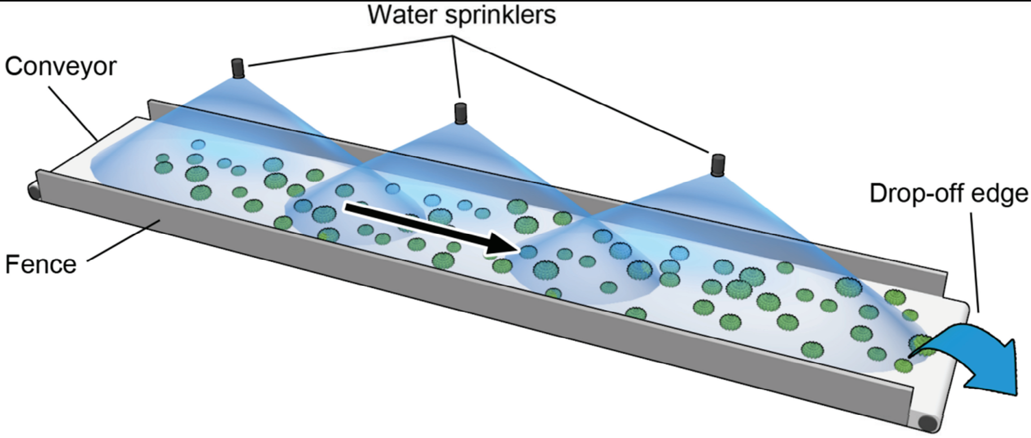


Figure 10-2. Suggested design for a buffer

De-attaching

As mentioned in Chapter 4 there is a challenge in that the sea urchins have tube feet which they use to attach themself to surfaces. The tube feet emerge when the sea urchins are submerged in water. The behavior is often that the sea urchins start to climb up the walls of the pool. This have been observed on visits to the customers facilities, and in the laboratory used in this thesis (See Figure 10-3). One of the biggest challenges with attached sea urchins is that they may suffer injuries if too much force is used to de-attach them.

Some effort was made in the preliminary study [2] to find solutions for de-attaching the sea urchins. Some of these were: waiting time, scraping, vibrations etc. It has been found that, because of the risk for damage, the best solution is to wait until the sea urchins de-attach by themself.

There were also given a hint by Troms Kråkebolle that a chemical substance might be used, but at that stage there were still uncertainties. New information from Troms Kråkebolle gives confidence in the chemical substance. It is very probable that they will be using this substance in their production. The substance can be solved into the water in the pools, making the sea urchins de-attach. The sea urchins could then be flushed out and funneled to the grading machine. [9]

But it is recommended to try to avoid designing a grading machine that is dependent on the use of a chemical substance. This is because the added logistics needed will be an inconvenience for the customers that perform wild catch of sea urchins. Also, the long term effects of the substance is not fully understood yet,

The solution proposed for use in the first prototype is to let the crates of sea urchins rest outside water until the sea urchins are de-attached by themselves.

Figure 10-3. Left: Showing adult sea urchins attaching to the walls of a crate. The picture was taken just seconds after the crate was taken out of water at Norway Sea Urchin's facilities. Right: Small sea urchins (aprox.1,5 cm diameter) climbing on the glass wall of an aquarium in Searis's laboratory.

Manual input

Some of the solutions for manual input have been inspired from the manual grading tables that are currently in use. Examples on these tables are shown in Figure 10-4.

Figure 10-4. Tables used for manual coarse grading of sea urchins. Left: From [1]. Right: From [12].

When introducing the objects manually, and without any buffer in the machine, it will be important that the user is introducing the correct amount of objects. This will require the user to have the ability to observe how well the machine performs, and be able to adjust the input amount based on that.

To extract the sea urchins from their crates it is recommended that the crate is flipped less than 90 degrees, and that the sea urchins are dragged out by hand. This will make sure that the height of the sea urchins fall is limited. Care should be taken not to injure the sea urchins in this operation.

When manually introducing the sea urchins it is also possible to perform some coarse sorting. Sea weed and clearly damaged sea urchins can be removed on sight.

Also it suggested implementing some kind of grid, to filter out sand and the smallest stones.

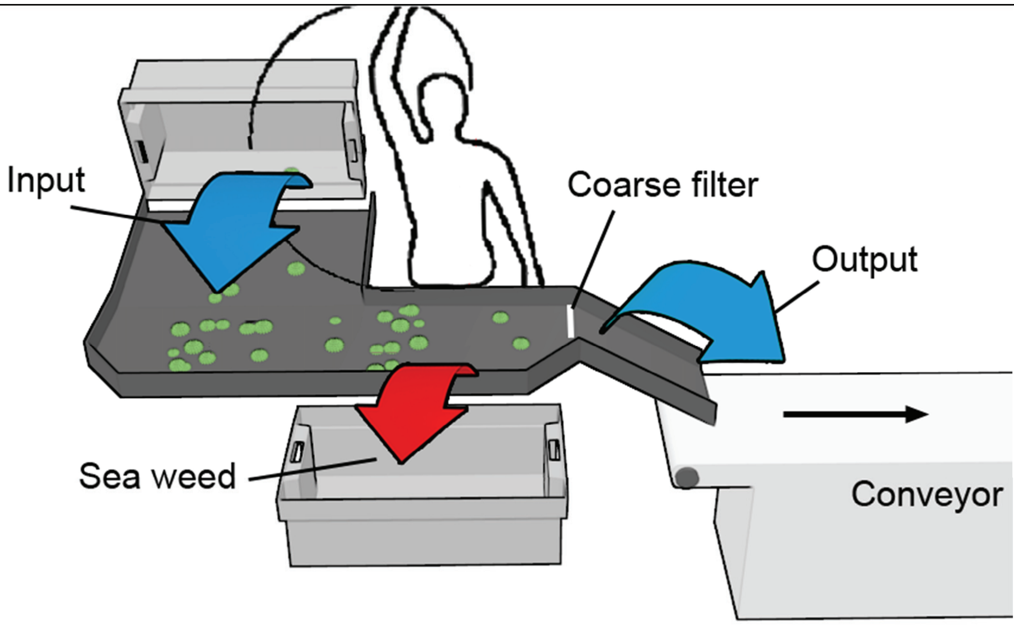


Figure 10-5. Manual input table

The solution displayed in Figure 10-5 enables the user to pour sea urchins on a table, distribute them into heaps of low height, and sort out sea weed. The sea urchins are then pushed by hand into an angled plate that leads to a conveyor belt. The width of the angled plate can be limited, thus limiting the flow of objects transferred to the conveyor.

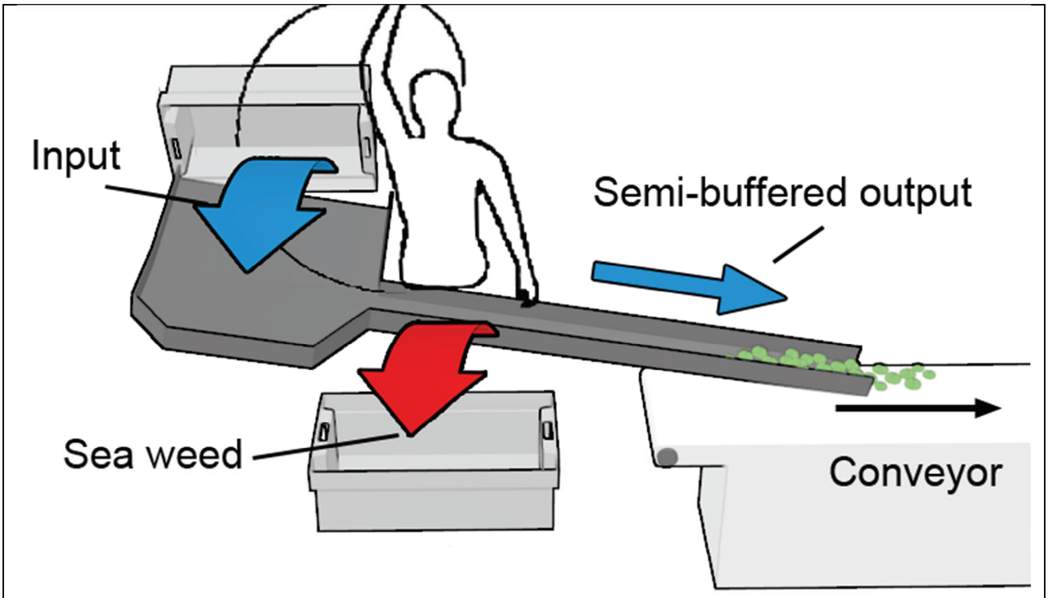


Figure 10-6. Manual input table with a buffered output.

A variation of the input table is illustrated in Figure 10-6. This solution utilizes a long and narrow chute, mounted in an angle, leading to the conveyor. The idea is that the objects in the oblong chute will build up, and gradually enter the conveyor as free space is opened up by the forward motion of the conveyor. This have the function of a small buffer, freeing the user from the need to continuously pay attention to how many objects he is pushing into the conveyor.

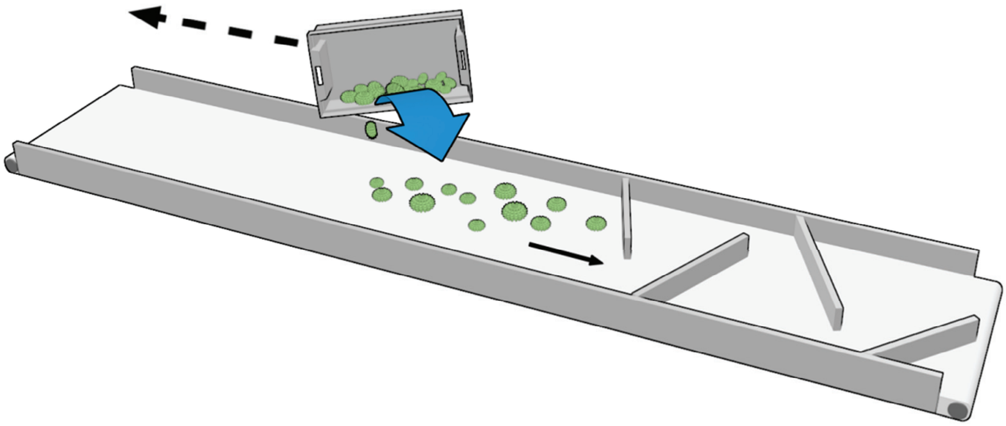


Figure 10-7. Manual input by distributing the objects over a long part of the conveyor.

The objects could also be poured directly onto the main conveyor. But this would require the user to stand and wait, holding the crate, while gradually emptying the crate. An alternative is therefore suggested (Figure 10-7), where the objects are poured out and distributed over a longer part of the conveyor. This is similar to the buffer suggested in Figure 10-2. But since this is not on a separate conveyor, there could be accumulation of downstream if the inputted distribution on the conveyor is too dense.

The advantages and disadvantages for each alternative for manual input are listed in Table 10-1.

Table 10-1. Alternatives for manual input.

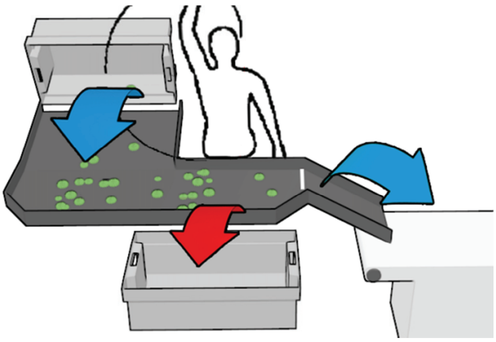
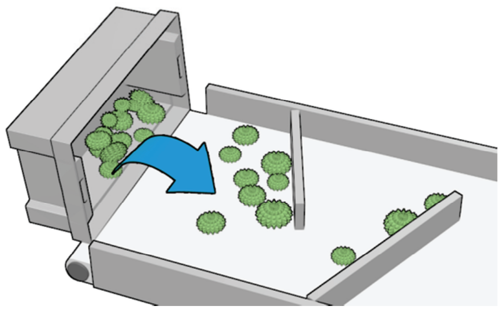
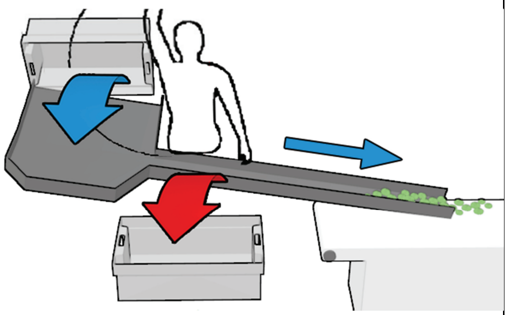
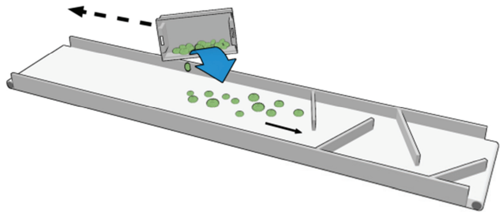
Sorting table	Directly
	
+ Familiar for the user + Good control on input amount - Continuous attention on input amount	+ Simplicity - Continuous attention on input amount - Not as easy to perform manual sorting of sea weed - Requires the user to stand and hold the crate while gradually emptying the crate. - Stressful

Table with small buffer	Directly on a long conveyor
	
+ .. + Semi-buffered output - ?will it work.. the buffer?	+ Simplicity + Semi-buffer - Not as easy to perform manual sorting of sea weed - Requires free space on conveyor - The user needs to estimate the perfect density on the object distrubution

A simple version of the input table will be used in the first prototype. The choice is made because this is familiar for the user. It is also a pretty simple solution; the customer could modify one of the already existing tables for this purpose.

Pouring directly onto a long conveyor would perhaps be the best solution in the long run. But since it is probable that future developments will include a separate buffer conveyor, it would render the free space reserved on the prototype conveyor redundant.

Chapter 11. Singularization

11.1 Singularization purpose and function

The sub-functions of the singularization operation are:

1. Accept a heap of objects from the input operation.
2. Introduce objects in a fashion that enables the camera and sensors to take separate measurements of each object.
3. Introduce objects in a fashion that enables rejection of any individual object by the sorting operation.

Practically, this implies that the singularization operation must be able convert a heap of objects into a singulated line of objects, and deliver them on an outgoing transporter.

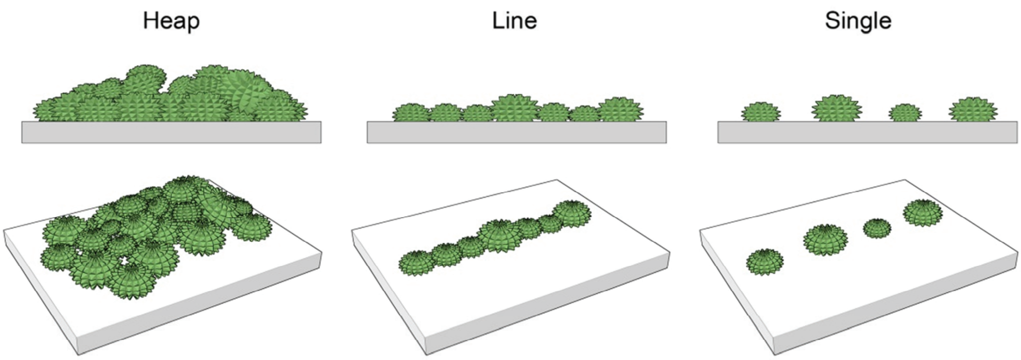


Figure 11-1. Definition and illustration of different types of object distributions.

The requirement for object separation will in this case be governed by the sort operation. The camera may accept that there are several objects in the camera's field of vision at the same time; this can be solved by software. The software could be made to recognize individual objects even if they are touching each other. The sort operation requires sufficient separation so that the removal of one object can be done without dragging nearby objects along. The objects must also be presented on a line for the sort operation to function properly. The required separation distance between objects, has been set to be, as a minimum, the same as the object diameter.

11.2 Principle for singularization by increased velocity / Analysis

The concept chosen in chapter 9.4 achieves singularization of objects by introducing an increase in transport velocity, as they are transported downstream. This causes the objects further downstream to accelerate away from the objects upstream, resulting in separation.

For this principle to work there are two conditions that must be fulfilled:

1. An increase of transport speed downstream. (Figure 11-2)
2. Sufficient amount of changes in transport direction, so that the objects are guided into a line. (Figure 11-3)

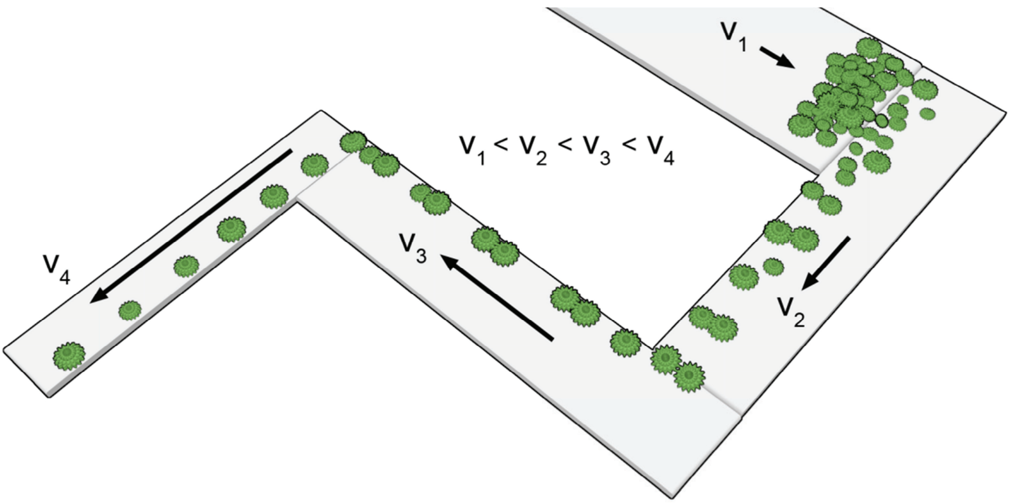


Figure 11-2. Singularization of objects by consecutive conveyors with increased transport velocities (v).

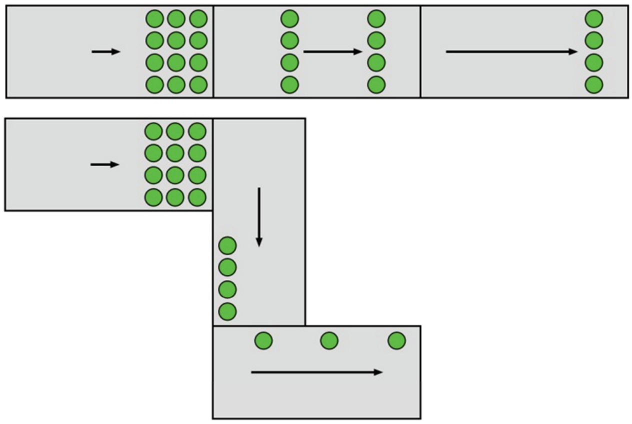


Figure 11-3. Illustrating how changing transport direction, in combination with increased velocity, causes the objects to form a line

Realizing that there must be the same throughput [objects/sec] at the input (transporter nr.1) and at the output (transporter nr.4), and since there is a larger distance between objects at the output, it becomes clear that the transport velocity must increase. By using these facts, and by estimating a pre-defined object distribution at the input and output, it is possible to calculate the change in speed that is needed for singularization.

Figure 11-4 illustrates the boundary conditions for the calculations. At the input (Figure 11-5, left) the objects are being transported with velocity v1, and a predefined amount of objects per second will fall down on the next transporter. If the object diameter is set to be 70mm, and the transporter is 500mm wide, there is room for 7 objects in the width. Some stacking of the objects is also estimated, as illustrated in Figure 11-6 left, making a total of 10.5 objects for every u = 70 mm in the transported direction. At the output (Figure 11-7, right) the wanted distribution is a line of single objects. The distance between the objects on the last transporter is set to be 2u, where u is equal to the object diameter. The velocity on the last transporter will have a maximum value given by the requirements from the sorting operation and/or the shutter time of the camera. As a basis, the velocity of the last transporter is set to be v_4 = 0,2 [m/s], which is the velocity that was used by the conveyor used in the experiments (Chapter 15).

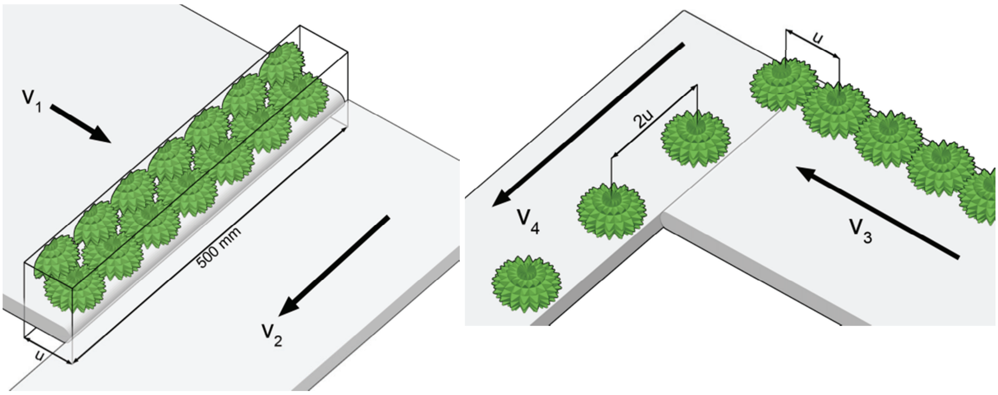


Figure 11-8. Boundary conditions for calculation of velocity. Left: 10,5 objects pr. u, at the input from transport#1. Right: Single objects with a separation of 2u, at the output (transport#4).

Definitions:

$Velicoty\ on\ transporter\ nr.i\colon\ v_i\ \left[\frac{m}{s}\right]$

$Object\ diameter\colon\ d\ [m]$

$Distance\ between\ objects\colon u_i\ [m]$

$Number\ of\ objects\ (from\ stacking\ in\ widht\ and\ height)\colon\ n_i\ [objects]$

$Frequency\ of\ objects\ on\ transport\ \#i\colon\ f_i = [\frac{objects}{s}]$

Pre-conditions:

$$v_1 < v_2 < v_3 < v_4$$

$$f_1 = f_4$$

$$v_4 = 0{,}2\ [\frac{\text{m}}{\text{s}}]$$

Calculating velocity:

$$By\ using\ that\colon\ f_i = \frac{v_i \cdot n_i}{u_{i,}}, and\ that\colon f_1 = f_4, we\ get\colon$$

$$v_1 = \frac{n_4 \cdot v_4 \cdot u_1}{u_4 \cdot n_1}$$

Boundary conditions:

$$u_1 = 1d = 0{,}07\ [m]$$

$$n_1 = 10{,}5\ [objects]$$

$$u_4 = 2d = 0{,}14\ [m]$$

$$n_4 = 1\ [objects]$$

$$v_4 = 0{,}2\ \left[\frac{m}{s}\right]$$

By inserting $u_1 = d$, and $u_2 = 2d$:

$$v_1 = \frac{n_4 \cdot v_4 \cdot u_1}{u_4 \cdot n_1} = \frac{n_4 \cdot v_4 \cdot d}{2d \cdot n_1} = \frac{n_4 \cdot v_4}{2 \cdot n_1}$$

Which show that the change in velocity needed is independent of the object diameter, and only dependent on the difference between objects at the input and output. By inserting the values of the boundary conditions we get:

$$v_1 = \frac{n_4 \cdot v_4}{2 \cdot n_1} = \frac{1 \cdot v_4}{2 \cdot 10{,}5} = \frac{1}{21} \cdot v_4$$

This shows that, for the conditions illustrated in figure 11-9, it is required that the velocity of the first transporter is less than 1/21 of the velocity of the last transporter. With a transport velocity of $v_4 = 0{,}2$ [m/s] at the last conveyor, the first conveyor will need a velocity of approximately < 1 [cm/s]. This may at first glance seem low. To find out whether this is a realistic velocity, a calculation can be made to investigate if the machine will be able to cope with the customers production volume.

The frequency of objects is:

$$f_1 = \frac{v_1 \cdot n_1}{u_1} = 1{,}43\ [\frac{objects}{s}]$$

Estimated yearly production volume is…1 300 000 sea urchins [KILDE: eit]

Time consumed becomes:

$$Time = \frac{Yearly\ production\ volume}{f} = 15 days$$

Which show that the current transport velocity enables the machine to perform well within the customer requirement.

The frequency of f_1=1,43 [objects/s] gives an output rate of 0,7 [s], which means that one object is completed every 0,7 seconds. This is well within the initial requirement of an output rate below 4 seconds [2], specified in the requirement specification from the preliminary study.

Keeping the transport velocity low will contribute to the gentleness of handling, and it will make it easier to perform the sort operation. But the final design must make sure that the sea urchins do not exceed their allowed time out of water.

Another important consideration of this singularization principle is the difference in velocity between the two last transporters. It is this difference that will control the guaranteed minimum spacing between the singulated objects. If the distance between the objects are supposed to be doubled on transporter #4, when going from a condensed line on transporter #3, the transported speed will also have to double:

$$f_3 = f_4 => \frac{v_i \cdot n_i}{u_{i,}} = \frac{v_i \cdot n_i}{u_{i,}} => v_4 = 2v_3$$

11.3 Next iteration. Videreutvikling.

Based on the analysis made on understanding the principle of singularization by increased speed downstream, a new generation of solutions were developed and investigated. This next iteration in product development yielded many solutions that had to be narrowed down. The most interesting of these results and alternatives are discussed in the following.

11.3.1 Increased velocity

The concept chosen in chapter 9.4 utilizes three transporters in succession, with increased velocity downstream, and combined with changes in transport direction. There is also a blocking obstruction placed on transport nr.2.

The block is there to ensure stable singularization. When objects fall down from transport nr.1 to transport nr.2, some of the objects that are stacked may fall longer (or bounce/roll) across the surface of transport nr2. This may cause two objects to land side-by-side, and will in turn lead to bad separation at transport nr.3, as illustrated in Figure 11-10. The obstruction will make sure that the objects are always on a perfect line on transport nr.2 before being transferred to transport nr.3, as illustrated in Figure 11-11.

There are some issues to consider with obstructing and blocking objects. It will cause the objects to slow down at the point of blockage, making it possible for objects upstream to catch up. This may cause the objects to accumulate at the blockage. It is therefore important that the input amount of objects is low enough. Also, blocking the objects will make the solution rate lower on the gentleness on object handling

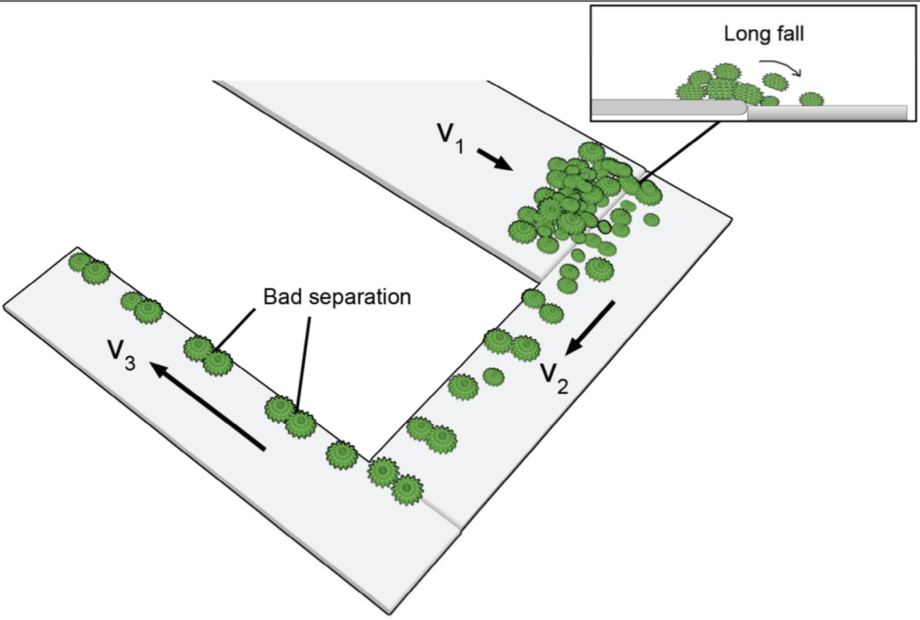


Figure 11-10. Illustrating bad separation at transport nr.3. Caused by 'long fall' from transport nr.2 to nr.3.

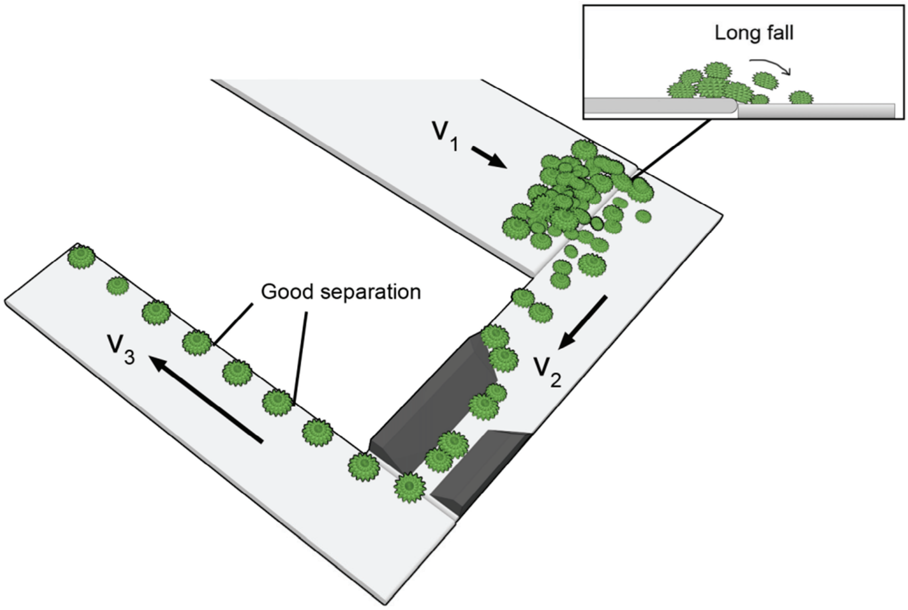


Figure 11-11. Singularization by increased velocity on three succeeding transporters. Obstructions make sure the objects always are on a line before they exit transport nr.2.

Another alternative for solving the problem with bad separation at transport nr.3 is to introduce a fourth conveyor (Figure 11-12). Since the objects on transport nr.3 seem to always come on a line, there will be stable separation when transferring objects to transport nr.4. This solution solves the problem of bad separation while keeping the gentleness on handling. On the negative side, increasing the number of conveyors will increase the complexity and cost for the machine.

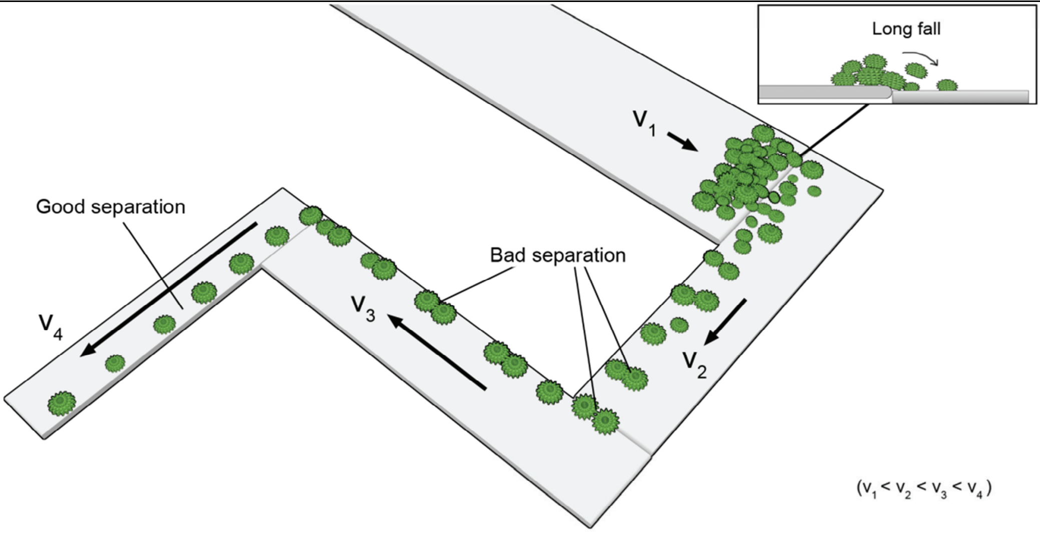


Figure 11-12. Four succeeding transporters with increased transport velocity, enabling good separation in the singularization operation.

A third solution for preventing the bad separation seen at transport nr.3 is by using a ‘v-shaped’ conveyor for transport nr.2 (Figure 11-13). The ‘v-shaped’ transport will ensure that the objects form a line, before transfer to transport nr.3. The principle for the ‘v-shaped’ transporter is dependent on that one of the walls in the ‘v-shape’ has a different transport velocity than the other. This causes stacked objects in the ‘v-shape’ to fall into a line (Figure 11-14).

The v-shaped transporter is more complex than a normal flat conveyor; more parts and accurate adjustments are needed. I.e. if the transporters in the ‘v-shape’ are mounted in a slight angle dragging the objects into the bottom of the ‘v’, it may cause damage to the objects. Also there are some uncertainties connected with the design; the gentleness on object handling is difficult to foretell, and the subjective confidence in the working principle is lower than for the other solutions.

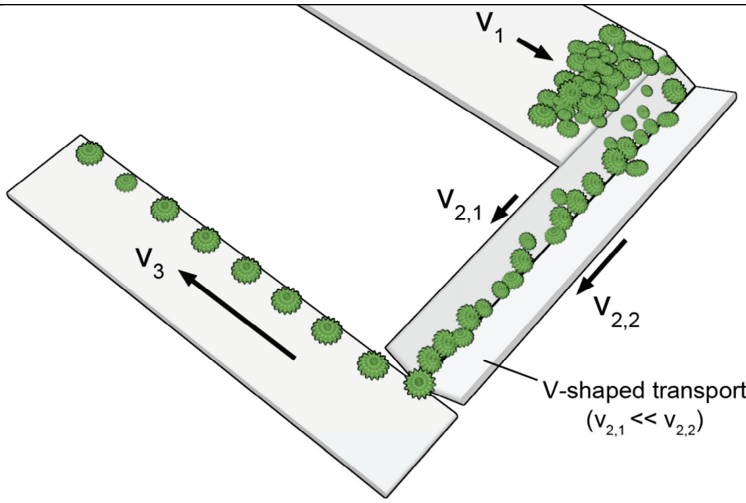


Figure 11-13. A v-shaped conveyor makes a perfect line of objects before transfer to transport nr.3.

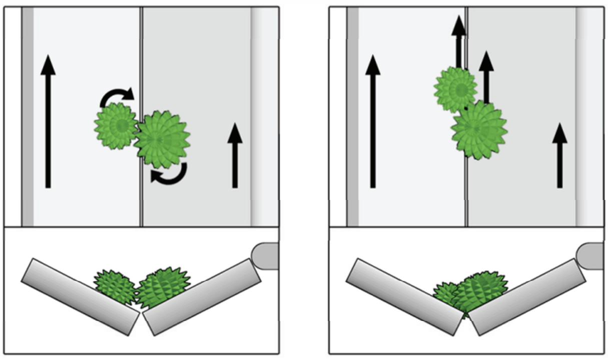


Figure 11-14. Principle for the 'v-shaped' transporter. The difference in transport velocity on the two sides of the 'v', force the objects to form a line.

11.3.2 Decreased velocity

The principle for singularization by increased velocity can be flipped around. Instead of increasing the speed downstream one can decrease the amount of speed prohibited downstream. In other words, instead of applying increased speed, the difference in speed can be caused by decreased velocity upstream by breaking or changing direction of travel.

By using several obstructions on a conveyor belt, it is possible to gradually decrease the amount of breaking applied in the transported direction. Figure 11-15 show several obstructions on a conveyor belt. The obstructions causes the objects to slide sideways thus decreasing the objects velocity along the transported direction. By gradually increasing the angle on the obstructions, the speed prohibiting can be decreased sequentially downstream.

There are several challenges with this design, but it is still one of the most interesting ones. As explained earlier, the blocking may cause accumulation of objects if there is too large amount of objects continuously entering the system. Also, the extensive use of blocking and sliding of objects may cause the conveyor belt to wear out quicker. The confidence in performance and gentle handling is questionable for this design. Although, tests and experiments (Chapter 15) have shown great potential. The design is very simple and consists of few components, and it makes for a high score on low complexity, low cost, and the use of standard parts. It is therefore recommended to perform a large scale test of this principle to investigate whether it will perform with acceptable performance.

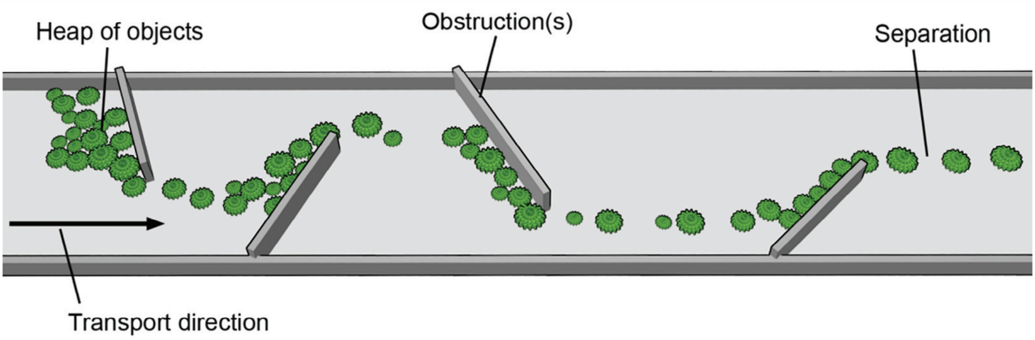


Figure 11-15. Singularization caused by several obstructions on a conveyor belt.

An interesting variation of the principle of ‘decreased velocity’, is a design which utilizes a rotating disc as a mean for transport. The objects are transported on top of the rotating disk, and are obstructed by a linear obstruction (Figure 11-16), in a similar way as the obstructions on the conveyor belt (Figure 11-15). The main idea of the rotating transport is that, since the disk will have a higher velocity at higher radius, the objects being obstructed will move quicker at the end of the obstruction compared to the start of the obstruction (Figure 11-17). The increase in speed along the obstruction may cause better separation of the objects.

Simulations show that the effect of increased speed along the obstruction gives better separation of the objects sliding along the obstruction. The simulations show that gaps appear between the objects, and the gaps grow as the objects continue to slide outwards. But the effect of this does not really reach its full potential unless there is a low input of objects. This is because new objects from the input will come and fill the gaps as they are created. This effect is illustrated in Figure 11-17.

The disadvantage with this design is that it requires a custom made, and complex, construction for the rotating transporter.

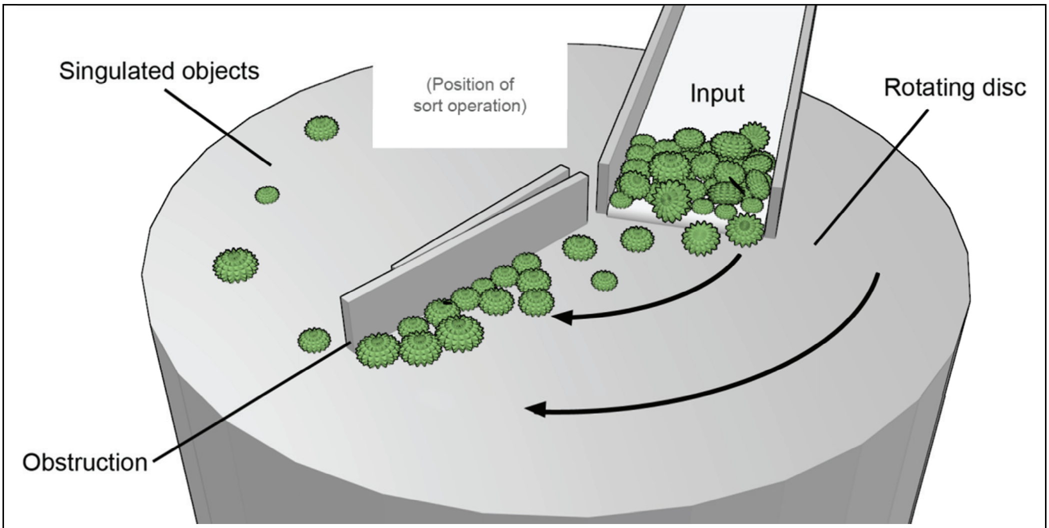


Figure 11-16. Singularization by obstructing objects that are transported on a rotating disc.

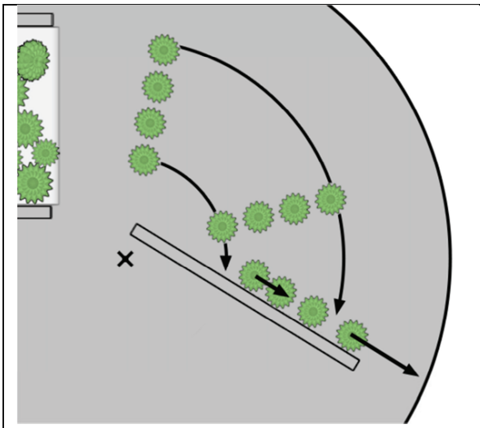
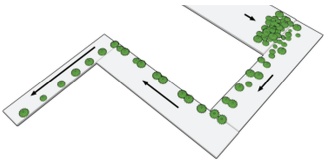
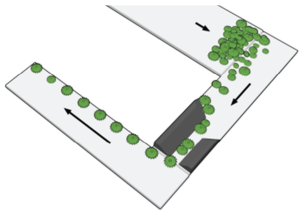
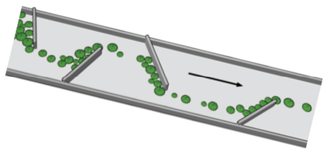


Figure 11-17. Illustrating the effect of higher velocity further from the center of the disc. Also, indicating that newly introduced objects will catch up with the objects that are sliding along the obstruction.

11.4 Singularization ranking

Table 11-1 summarizes the advantages and disadvantages for the three most interesting solutions for singularization. A complete table, including additional solutions and detailed scores, can be found in the appendix.

Table 11-1. Summary of solutions for singularization by change of transport velocity

4 belt increased velocity	3 belt increased velocity	Decreased velocity
		
+ Gentleness + Confidence - Amount of conveyors	+ Medium gentleness + (1 less conveyor) - Middle-ground with no real advantages.	+ Simplicity + Low cost - Gentleness (?) - Confidence (?) - Belt wear - Lack buffer
Conclusion: This is the best choice considering performance. But the cost, maintenance, and area use, all expand in correlation with the amount of conveyors.	Conclusion: The solution represents a middle-ground between both the advantages and disadvantages, of the other two solutions.	Conclusion: Chosen for further testing and development.

Even though the 'Decrease velocity'-solution did not score as the best solution, it is the best choice to select it. The advantages of the solution are great and distinct, while the disadvantages are uncertain. It is therefore recommended to test the solution and find out whether the performance is acceptable. There is no need to go for the more complicated solutions if the simplest one is good 'enough'. Experiments and simulations that have been performed during this master thesis, described in Chapter 15, have increased the confidence in success for this solution. The solution is therefore selected for the prototype, and future large scale testing.

Another argument for selecting the simplest solution is that it can, if it proves to perform inadequate, be upgraded to the other proposed solutions by the addition of additional conveyors.

11.5 The principle of decreased velocity

The objects are transported on a conveyor belt. The obstructions will change the direction of travel for the object, and at the same time decrease the objects velocity in the transporters direction of travel (Figure 11-18–LEFT: showing that v,2 < v,1). When decreasing the angle of openness on the obstruction, the velocity in the transport direction will be decreased even more (Figure 11-19). By looking at the geometry (Figure 11-19), and using vector mathematics, one can estimate the correlation between angle and velocity.

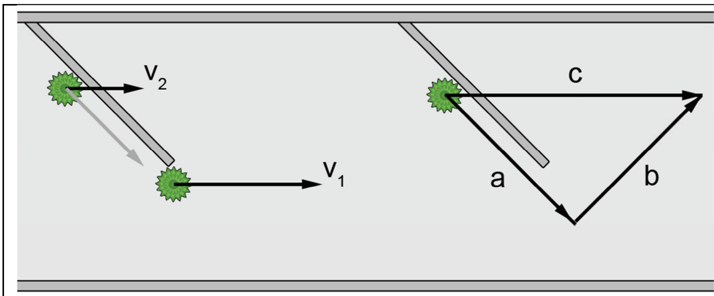


Figure 11-18. Change in velocity caused by obstructions on the conveyor.

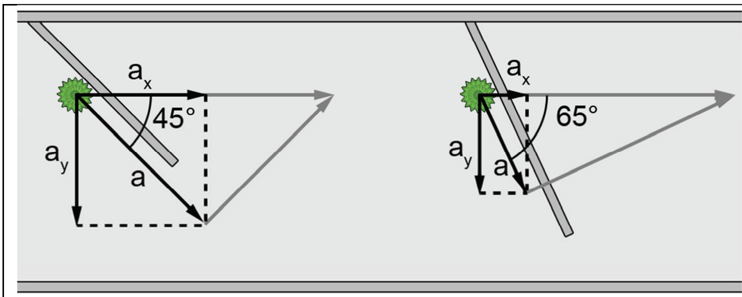


Figure 11-19. Velocity vectors illustrating that the velocity, in both the conveyed (a,x) and travel (a) –direction, is decreased when the openness of the obstruction is reduced.

The preconditions for the calculations are; no friction between the object and the obstruction, and a perfect transfer of speed from the conveyor to the object. Experiments (Chapter 15) show that these calculations are good approximations for large angles.. The increasing dissimilarity, between the calculations and the observed results, when decreasing the angle of openness is not surprising, considering that the normal force (that governs the friction force) will increase with decreasing angles of openness.

The last obstruction in the line will be the one that governs the separation between the objects. If the distance between the objects is to be the same as the object size, the velocity must be halved. The calculations and experiments show that to achieve this, the angle of the last obstruction should be around 45 degree, in a low friction scenario.

For the angle on the first obstruction one must take into consideration that the objects may, because of the small angle of openness, be forced to a complete stop by this obstruction. The results from the experiments were not consistent on the first obstruction. The effect of friction, as mentioned, will play a bigger role on obstructions with a more closed angle. The friction forces could vary with object type, wetness, and obstruction material, which could explain the difficulty in establishing an optimal angle of openness on the first obstruction. It is therefore recommended that the machine is designed in a way that enables easy adjustment of the obstructions angles, for optimization purposes.

The amount of obstructions that is needed will depend heavily on the amount and distribution of objects introduced into the system. Computer simulations and experiments showed that three or four obstructions should be sufficient. They also showed that further increasing the number of obstructions gave little effect on the separation quality, only increasing the operations ability to internally buffer a larger amount of objects.

11.6 Fixing/Detailing

11.6.1 How to avoid jam in the singularization operation

Results from the experiments have shown a rotating behavior, where the objects sliding along the obstructions then to rotate around their own axis. These rotational forces are the probable cause of the effect illustrated in Figure 15-6, where a column of objects rotate around the edge of the obstruction. This behavior can cause 'jamming', where the objects get locked in place by the fence and the obstruction.

As for many of the challenges for the singularization operation, the problem with jamming can also be mitigated by limiting the amount of objects in the input. With less objects there is less chance for build-up of a column of objects, thus prohibiting jam caused by rotating a column of objects.

It is also recommended to have enough space for at least three objects between the end of the obstruction and the surrounding structures (Figure 11-20). The next obstruction should be at least four objects away. Objects may still be able to form a column and rotate outwards in the same manner, but the likelihood for the column to jam is decreased with the number of objects needed to 'build the bridge' to the surrounding structures.

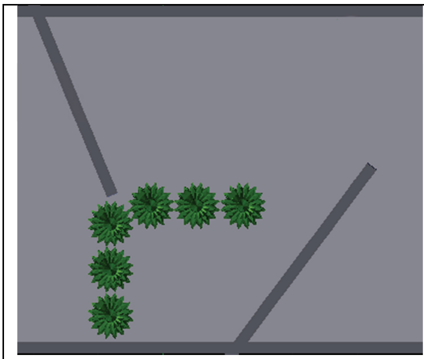


Figure 11-20. Suggested space around obstructions

A curved fence placed on the sides of the conveyor has yielded good results in the computer simulations. The curved fence will make it possible for objects to get pushed up against the fence, instead of getting locked and jammed against a flat wall. The objects in the slope gives returning forces caused by gravity, but the ability to push the object both upwards and sideways will keep the object away from being locked in place. (Figure 11-21, Figure 11-22 and Figure 11-23)

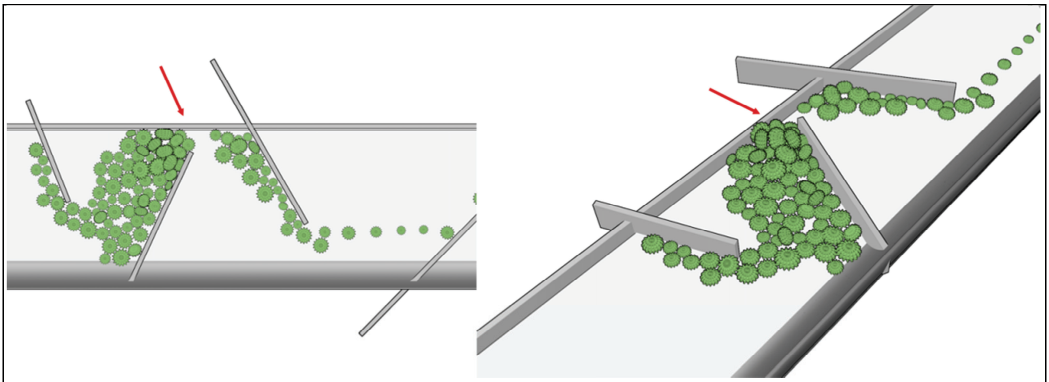


Figure 11-21. A simulation where jam is caused by two sea urchins that are locked in between the obstruction and a flat fence.

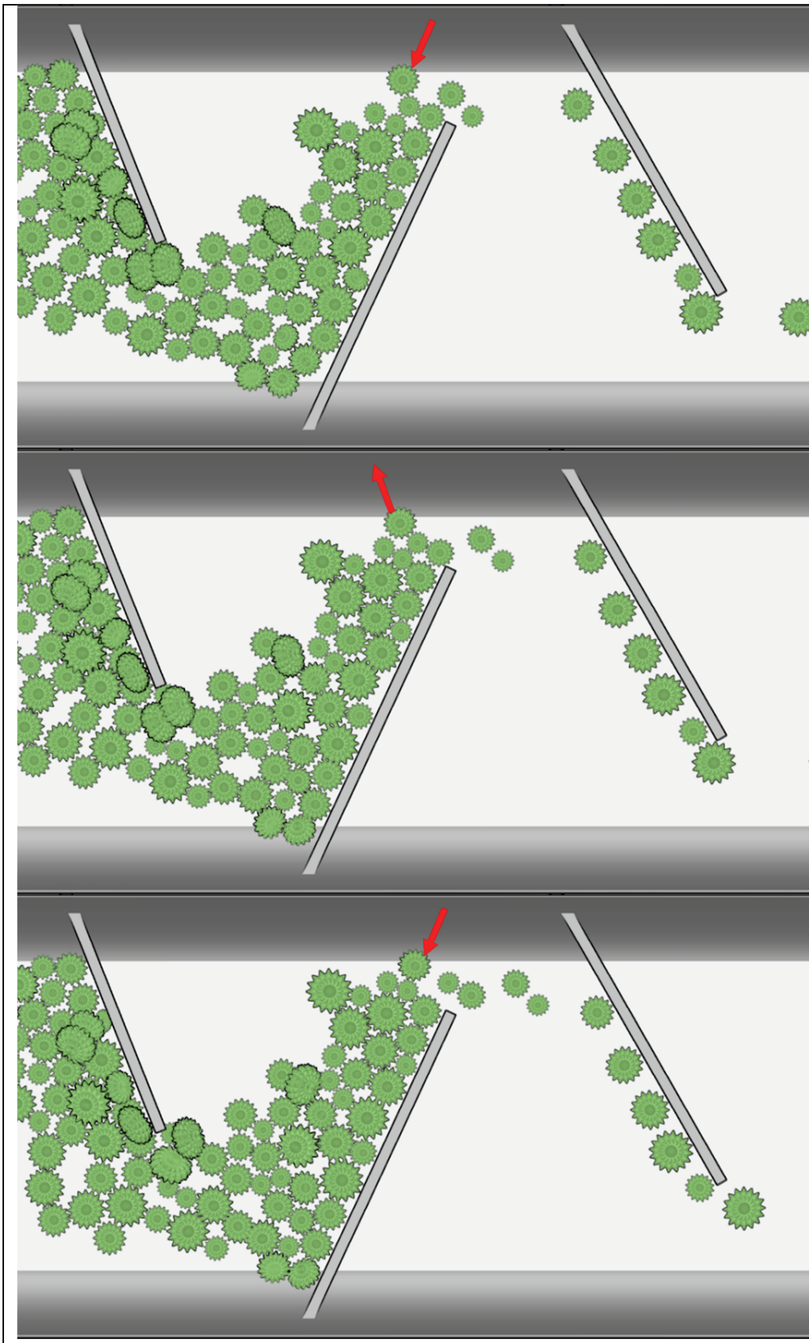


Figure 11-22. A simulation where a curved fence is used. Shows that the sea urchin that is up against the fence (red arrow) gets pushed away just enough to let the two other sea urchins in the 'lock' to pass

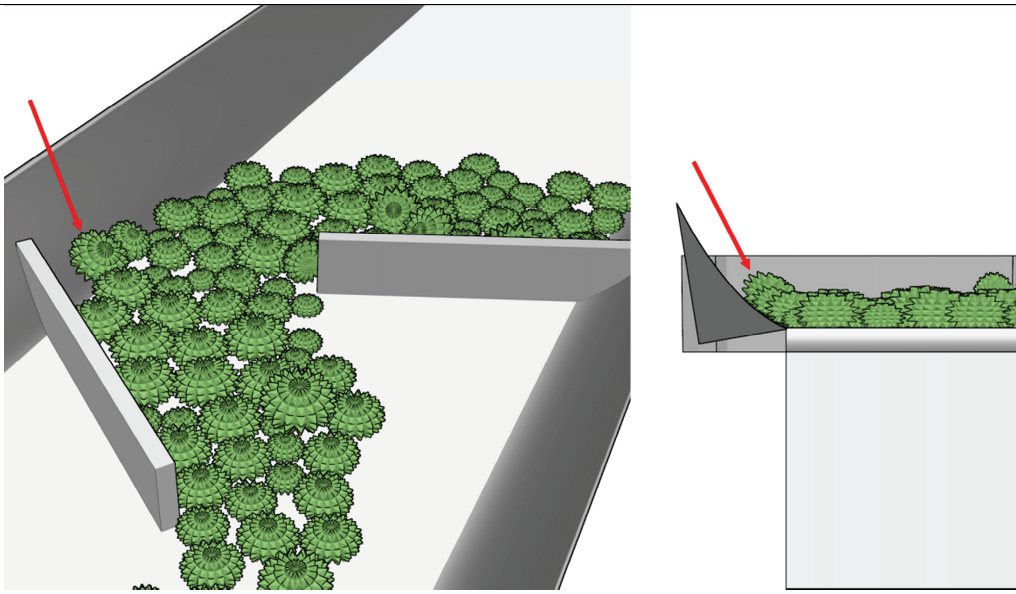


Figure 11-23. A 3D view, and side view, displaying the effect and design of a curved fence.

11.6.2 Mini-obstruction

As observed in the experiments, bad singularization could occur when two objects rotate at the last obstruction. The rotation of the leading sea urchin may encourage the sea urchin close behind to follow, given that there is some coherence between the two. This causes the two sea urchins to lay side by side, and not in a straight line.

Experiments proved that this can be mitigated by adding an extra obstruction. This obstruction should be much shorter, and have a very large angle of openness. The large angle will render the friction forces low enough to prevent rotation at the end. And the short contact time with the objects will prevent the objects upstream to catch up with the objects on the new obstruction. If the objects upstream were to catch up, then the new obstruction would be the cause of decreased separation distance between the objects. The initial problem, and the resulting effect of the new obstruction is illustrated in Figure 11-24.

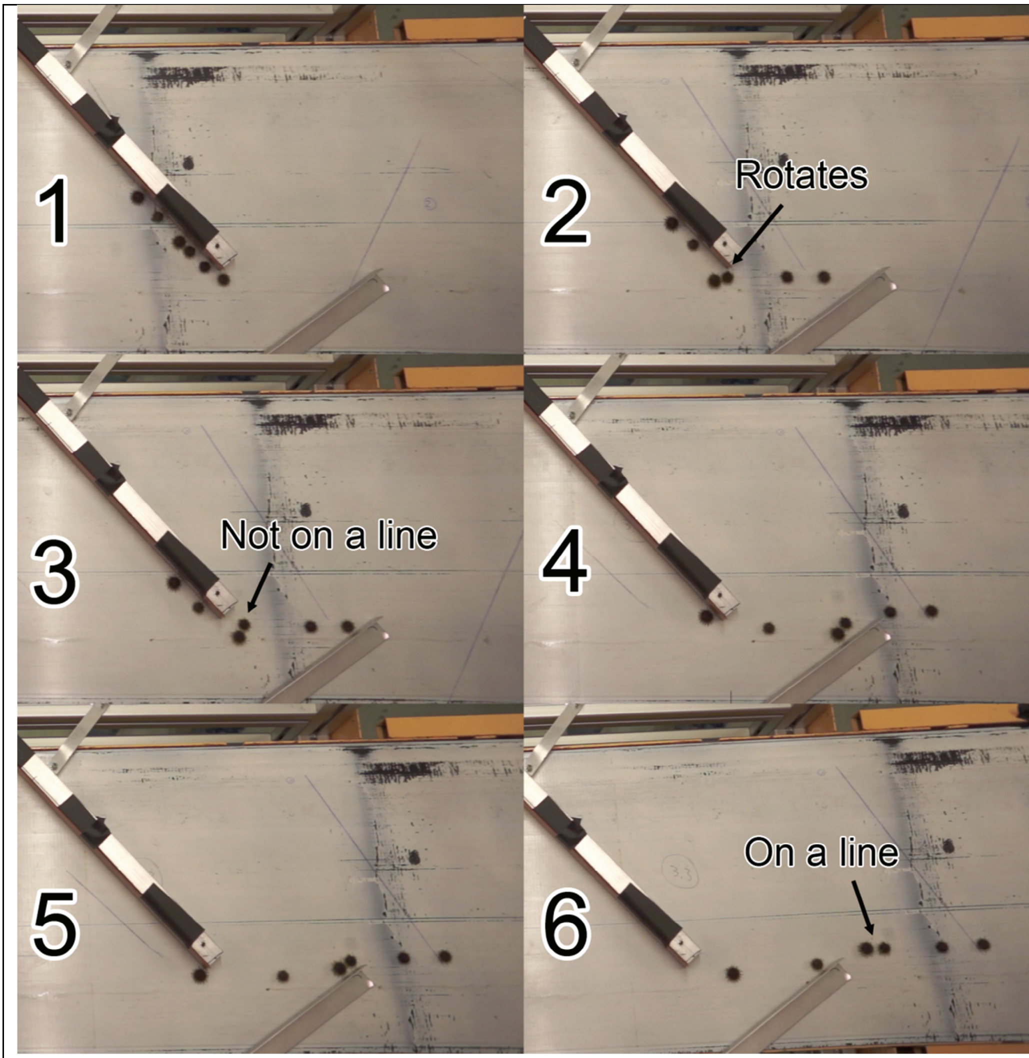


Figure 11-24. The use of a short and open-angled obstruction to correct errors in singularization.

11.6.3 Improve performance – input amount

Results from simulations restate the importance of controlling and limiting the amount of inputted objects. Figure 11-25 show bad singularization as a result of a too high amount of objects in the input. Figure 11-26 proposes that the reason for bad singularization is because the objects start to flow on the outside of the first obstruction, thus no decrease in speed is applied to those objects.

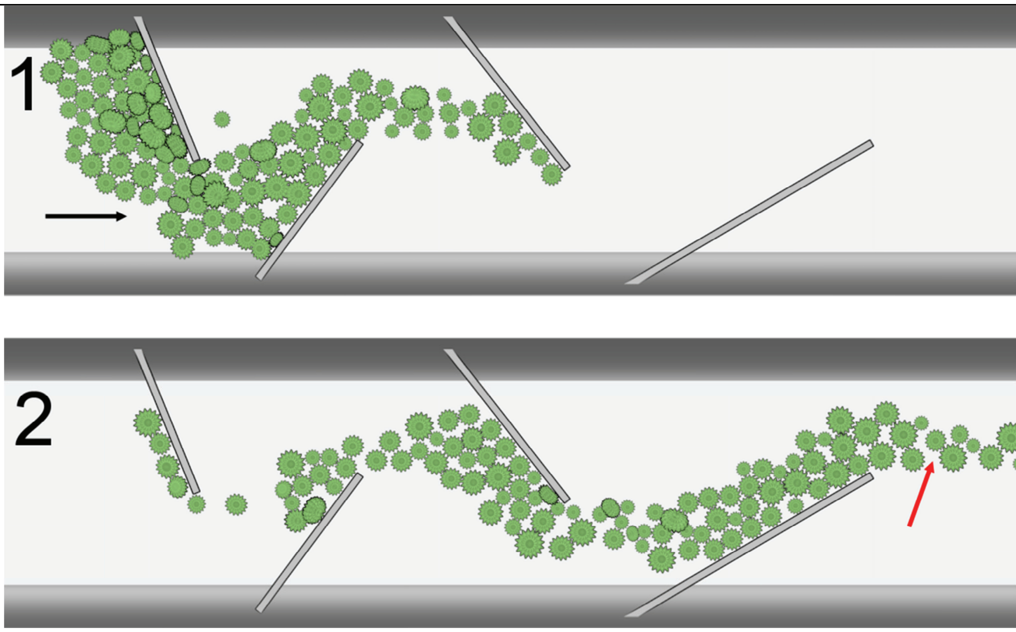


Figure 11-25. Simulation that shows that to large amount of inputted objects (1) leads to bad singularization (2 - red arrow).

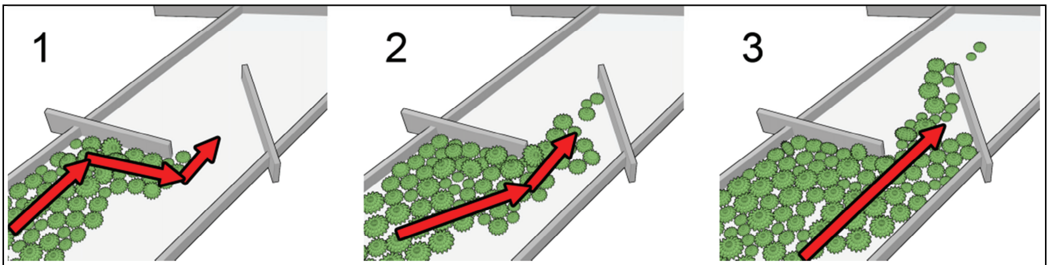


Figure 11-26. Illustration from a simulation where a large and continuous input of objects was applied. The arrows try to point out the reason for bad performance when the input is to large. In 1, all the objects get slowed down by the obstruction. In 3, some objects start flowing past without being slowed down by the first obstruction.

Chapter 12. Cam/sensor

12.1 Software and algorithm

As explained in Chapter 7 the camera sensor was a preliminary starting point for this master thesis. The software for inspection of sea urchin have been developed in a student project [1] and by Searis AS. A brief introduction of the principals of the system will be given here, more details on the software and algorithm can be found in [1].

Any standard optical camera can be used to supply the software with 2-dimensional RGB (Red Green Blue) pictures.

The system uses a classification algorithm to decide if an object is a sea urchin or any other type of object. If the object is classified as a sea urchin, the system will estimate the shell diameter of the sea urchin. After a batch has been processed the system stores all data in a database.

The classification algorithm is realized through supervised learning. The algorithm is trained by letting it process a large number of pre-classified example pictures. The classification is based on OpenCV (Open Computer Vision), whilst the image processing is self-developed. The basis for the object recognition algorithm is ORB (Oriented FAST (Features from Accelerated Segment Tests) and Rotated BRIEF (Binary Robust Independent Elementary Features).

Object recognition consists of two main elements, detection of key points, and the description of key points.

The detection of key points is done by looking at the variation of grayscale in the pixels surrounding a potential key point, and combining this with detection of corners and edges. This is done with oFAST, combining FAST key point detection and Harris corner detection, and will in addition add information about the orientation of the corners. The number of key points is then reduced by removing the less interesting key points if they are neighbors to more interesting key points.

Description of key points is done by looking at the surroundings of a key point and generating a value. The value can then be compared to values generated from previous pictures. The description method is based on Steered BRIEF, and comparing is realized trhough FANN (Fast Approximate Nearest Neighbors.)

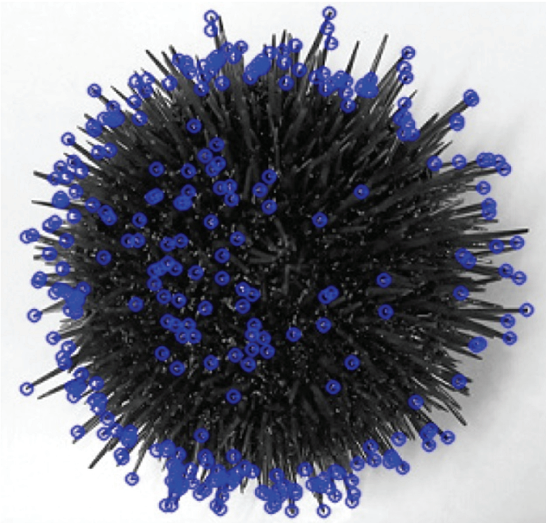


Figure 12-1. Picture of a sea urchin, and the detection of spikes.

The diameter that is to be measured is of the sea urchin shell, not with spikes. To achieve this, a number of steps are taken. First the object is segmented from the background. Otsus method is used to find the optimal threshold for segmentation. Then the spikes are digitally removed by a combination of Erosion and Dilitation. The area of the reaming pixels is calculated and the diameter is estimated based on the laws for a perfect circle. This means that the diameter is only correctly found if the sea urchins are laying on their front or back, displaying a near perfect circle of the largest diameter. This should not be a problem, considering that the sea urchins elliptical shape causes them to naturally fall down on their front or back.

The test from [1] estimated the shell diameter of sea urchins, of diameter 40 mm to 58 mm, with an average error of 2,3mm. At this point the software and algorithms were still not optimized. Also, the camera used had low image resolution; an increase in resolution would increase the accuracy. [1]

The camera software shows promising results. The error, which is expected to improve with optimization, of 2.3 mm is 5.75% of the total diameter for a 40 mm urchin. The absolute value of the error is expected to drop considerably when measuring small sea urchins. As shown on Figure 4-3, the small sea urchins have less spikes and it is easier to directly view the inner shell.

12.2 Background and light

To present a contrasted background for the pictures, a white conveyor belt is to be used. Constant light conditions should be ensured so that the comparability of the pictures is good. A closed box with built in lights can be used to achieve this. I addition the box can have flexible flaps or curtains where the objects enter and exit, to further minimalize the influence of external light..

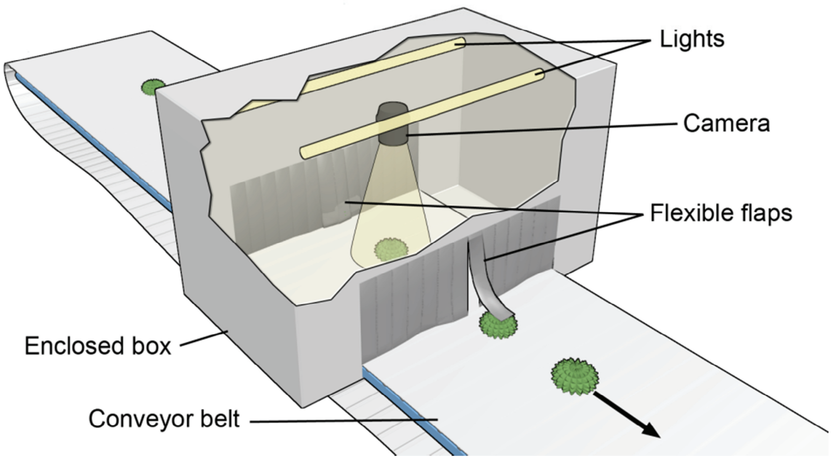


Figure 12-2. The camera cell. Consisting of internal lamps and an enclosed box with curtains that ensure stable light conditions.

Chapter 13. Sort operation

Any mechanical solution for sorting has been ruled out because of the general low gentleness, and a number of disadvantages that comes with using actuated components.

The choice for using air rejection instead of water rejection is based on that it is the easiest to implement at this stage. Whether the sorting is done by water or air does not play a big role in how the machine is to be designed. Other than that air nozzles will have to be placed closer to the objects to ensure minimum co-deflections.

More thorough examination and analysis of the sort operation should be executed to ensure that the best solutions have been found. Also, a proof of concept prototype for sorting by air should be tested before the large scale customer test.

Water	Air
+ Easier to apply a concentrated rejection beam - Pre-pressurized water supply may not be available for all customers - Infrastructure costs -	+ Cheap and low tech compressor can be used* + Easier to test - Noise - May contaminate the water with oil

*A standard compressor for home use can be utilized if a simple oil filtration box is added on the output.

Chapter 14. Prototype

14.1 Design considerations

Goals for the prototype:

1. Form a basis, and serve as a platform for further resarch
2. Verify the working principals in large scale
3. Investigate the mortality effect on sea urchins

Since the prototype is to serve as a platform for further resarch it is subject to modifications. It is therefore decided to build the prototype with ….

The prototype should also be possible to disassemble, transport, and reassemble relatively easily.

Building materials for a machine for the use in salt water environments are a critical choice. The industry standard is to use stainless steel almost everywhere. In addition plastics can be used. The cost of building in stainless steel is so high that it is not … to use this in the prototype.

The aluminum frame system of Aluflex –Item have been choosen for the frame of the prototype. It is chosen because it will be easy to change and modify the machine during the development phase. Realizing that when the machine is placed in the customers environment it will not last very long. Considering the difference in cost between stainless steel and the aluminum frames, it is possible to build several prototypes and let them be destroyed before reaching the same level of cost.

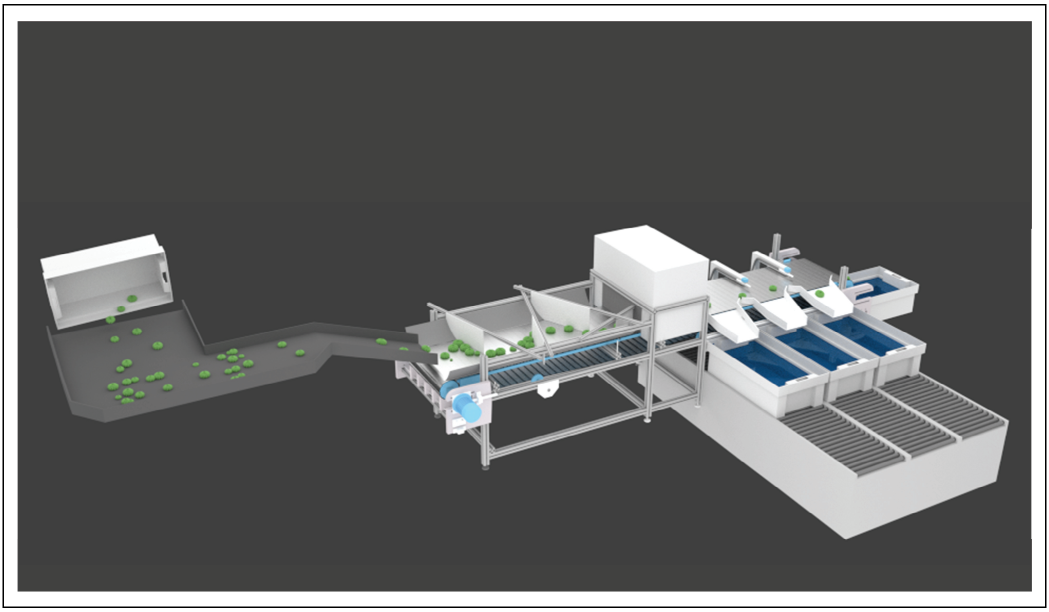
It is also a goal to use as much plastic as possible in the prototype.

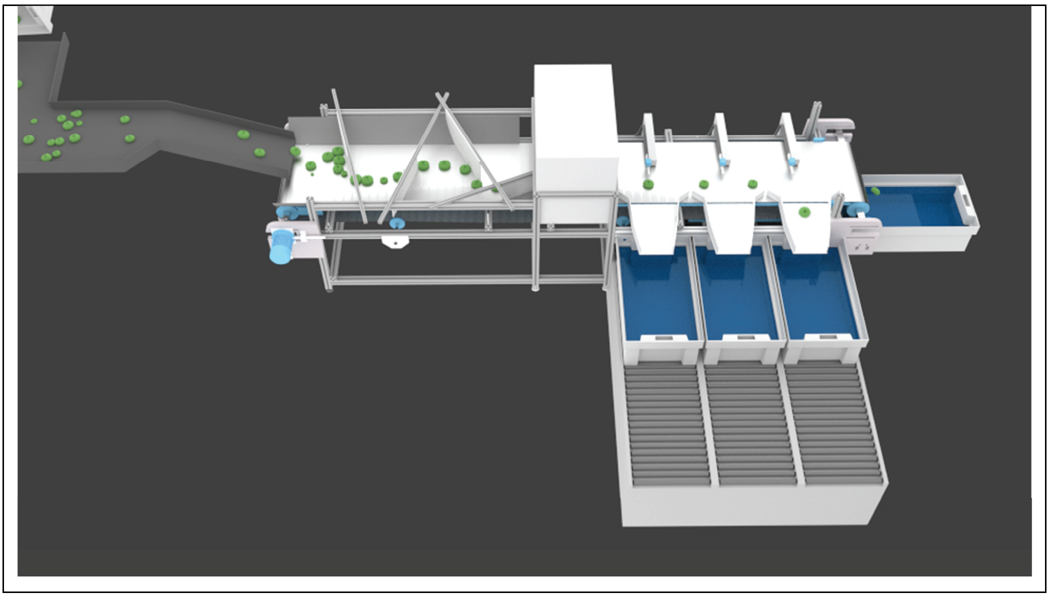
14.2 Frame

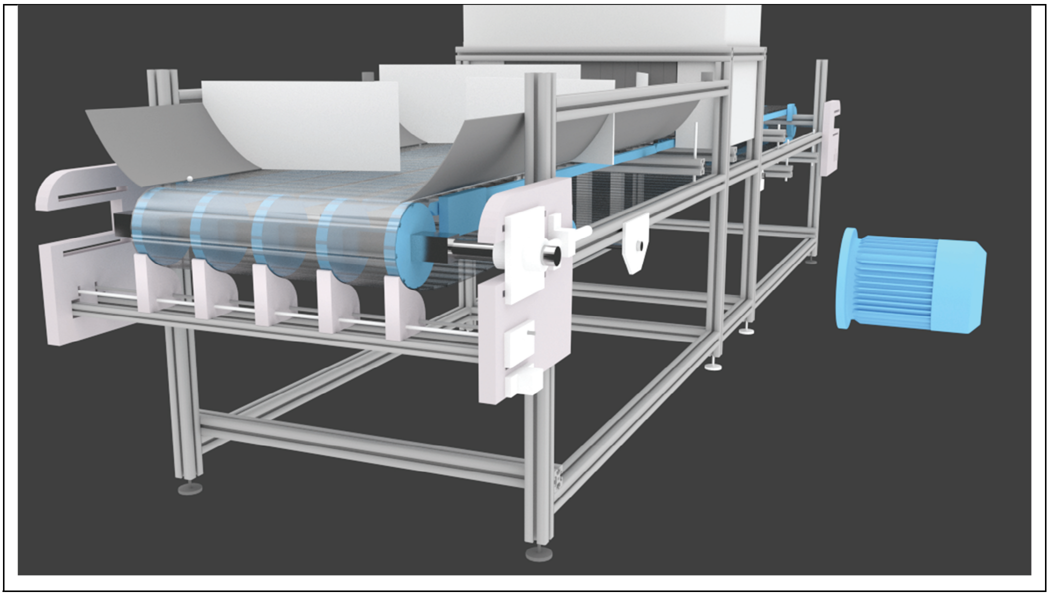
The purpose of the frame is:

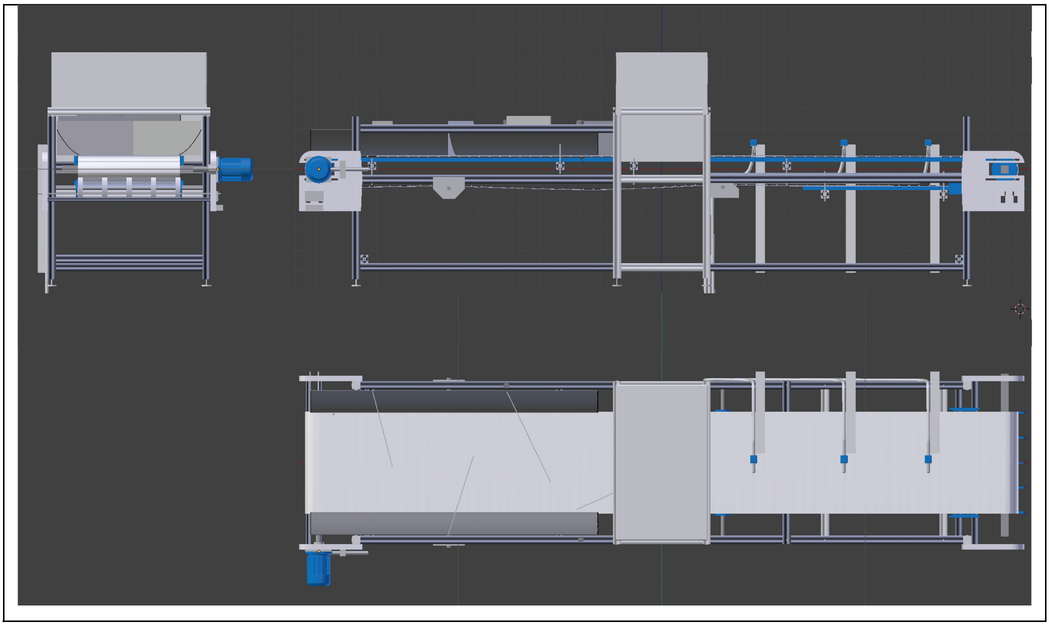
1. Support the axels, motor
2. Support strips for continuous conveyor support
3. Support the sort actuators
4. Support the conveyor “walls/fences”.
5. Support camera (and make sure there is no shaking)
6. Support camera light box.

14.2.1 Pictures of the prototype









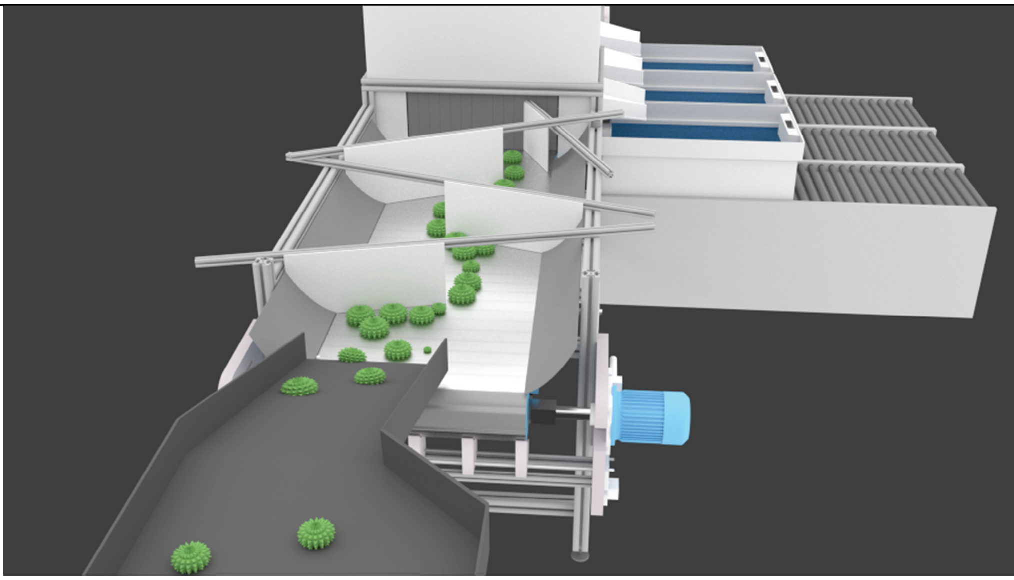


Figure 14-1. The singularization operation.

14.3 Choosing the type of transporter.

A conveyor belt from Intralox called ThermoDrive have been chosen for the prototype. This belt have ben chosen because of it's wide use of plastic parts. And because of its non-tensioned drive, which makes it durable and less susceptible of mistracking. Also because of the sprocket drive there is no need to worry about water making the drive slide.

14.3.1 Bearings

It has been decided to use slide bearing for the support of the conveyor belts axels. This is because normal bearing are prone to wear and rust, especially in the corrosive environment where the machine is to be used.

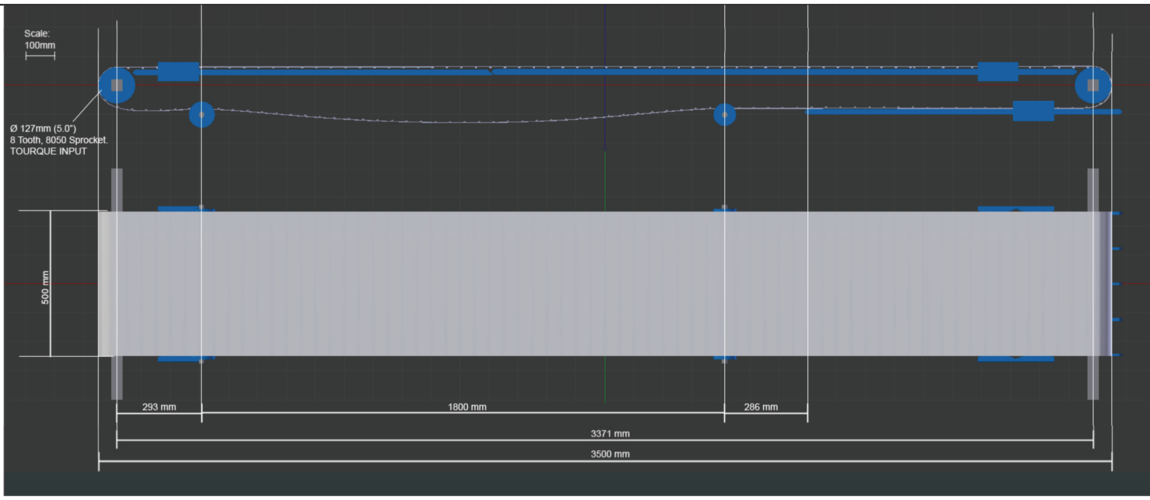
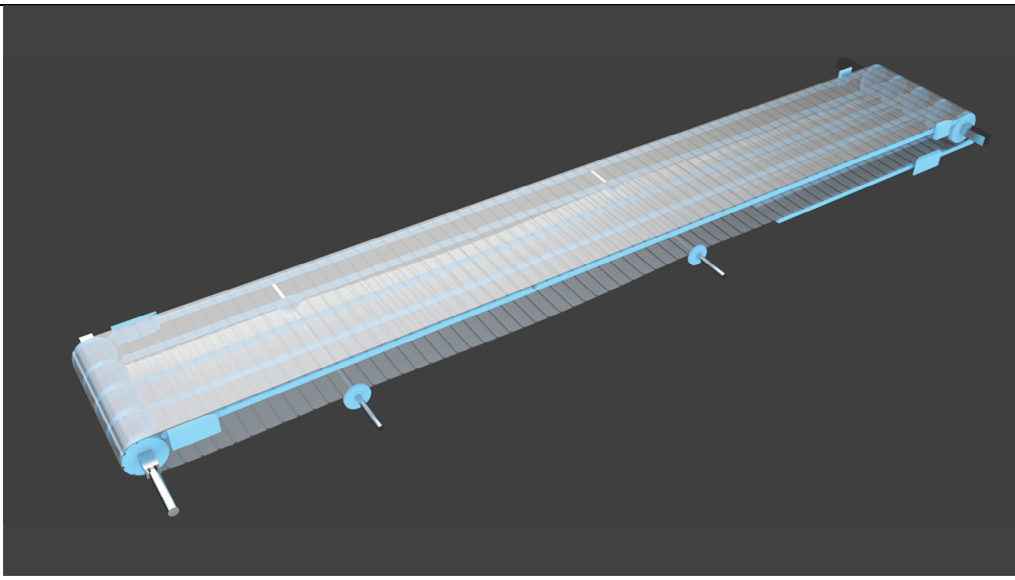


Figure 14-2. Dimensions on the conveyor belt



Chapter 15. Experiments and simulations

15.1 Questions and expectations.

The reasons for conducting the experiments were to answer the following questions:

1. Will the principal for singularization and separation work as suggested?
2. Will the spikes on the sea urchins cause them to attach to each other? To what extent will the sea urchins attach to each other when they are pushed into each other on the conveyor belt? Will the sea urchins clog together and form one giant ball of connected sea urchins?
3. Will there be any visible damage or injuries on the sea urchins? Will they lose or break spikes, or will there be any behavior changes subsequent to the handling (ie. hanging their spikes, or less active behavior)?
4. Friction: How well will the sea urchins slide against the obstructions? How much will the sea urchins stick to the conveyor belt, will the belt suffer any wear caused by the sharp spikes?
5. Finding the velocity decrease caused by blockers. (For deciding optimal angles on the obstructions, and for input and verifications of the computer simulations.)
6. (Camera: Will the camera take good pictures?) (Result: several objects..will have to make blob functionality)

15.2 Setup

Two test rigs were built; one for testing singularization FIG, and one for testing the camera cell FIG.

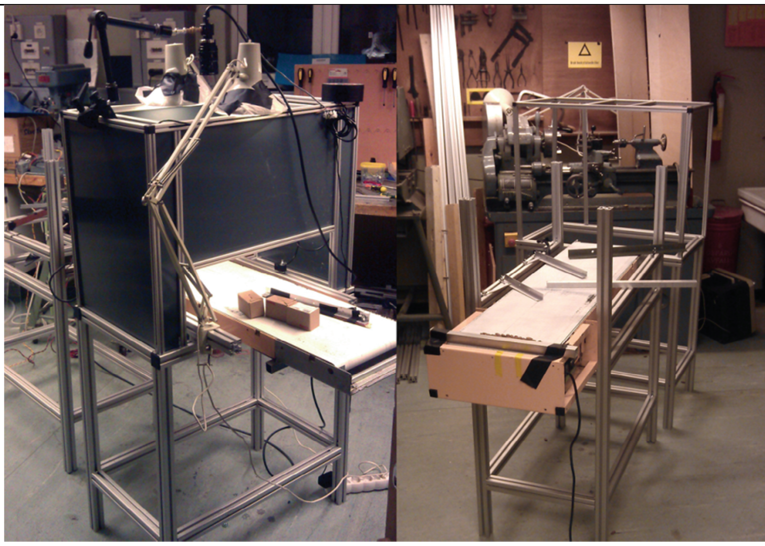


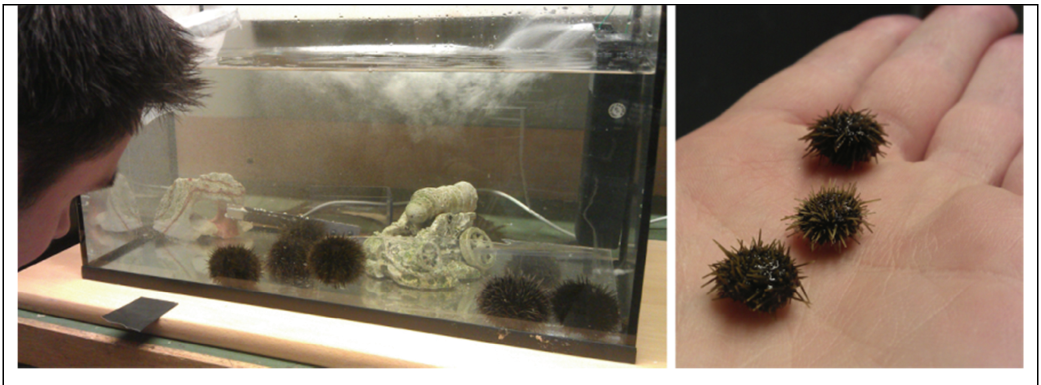
Figure 15-1. Test rigs. Left: camera cell. Right: Singularization

An old conveyor from the counter of a supermarket pay desk was used. The conveyor had a conveyed transport speed of 0,2 m/s. White paint was applied to the upper surface of the conveyor belt, for the reason of giving the camera a white background surface. A frame was assembled with the use of a modular aluminium profile system from Aluflex - Item. Adjustable obstructions were mounted on the frame, and extended out over the conveyor belt. The distance between the obstructions and the conveyor belt was minimalized to the extent that some of the obstructions had continuous contact with the belt.

The camera cell was built with the same type of components, with the addition of lamps, a camera, and a motion detector. A semi-closed box was also constructed around the camera.

Sea urchins was transported in a polystyrene box, and flown by plane from Troms Kråkebolle to NTNU. The sea urchins were kept in relatively small aquariums (FIG), but fresh salt water was added regularly. The oxygenizers, which mix air into the water, seemed to perform well in both mixing in air, and stirring the water. Two size classes of sea urchins was tested. The large sized class ranging from 50 – 63 mm diameter in shell size, with a max. diameter ranging from 62 – 82 mm. The small sized class, with around 17 mm diameter shell size, and a max. diameter of around 26 mm.

In early tests, before sea urchins were available, tests were performed on other objects, like screws and nuts, almonds, and exotic fruits like rambutans.



Several tests was conducted with variations on the inputted amount of objects, angles on the obstructions, the amount of obstructions, the material on the surface of the obstructions. Pictures and video was recorded to document the results.

15.3 Results

Singularization and good separation is generally achieved with this principle. The magnitude of the separation depend largely on the angle of the last obstruction. Also different types of objects achieve different separation for the same angles on the obstructions, this is suspected to be the cause of difference in friction. Figure 15-2 show almonds with a large separation distance. Even with a large amount of inputted objects, good singularization is achieved when using at least four obstructions.(Figure 15-3). Note that the angle of openness on the last obstruction is larger, thus causing the difference in separation distance seen in Figure 15-2 and Figure 15-3.

Some objects have been forced to a (almost) complete stop by the first obstruction. Especially objects with large friction will be stopped by the low angle of openness on the first obstruction.

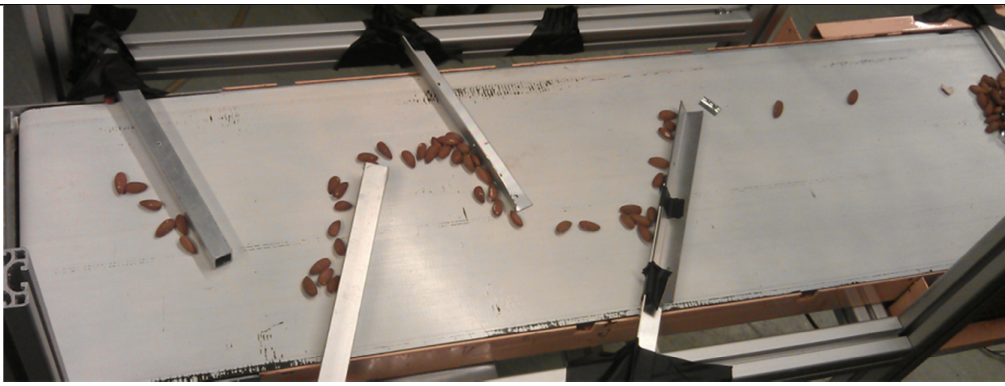


Figure 15-2. Large separation distance between the singularized objects (almonds).

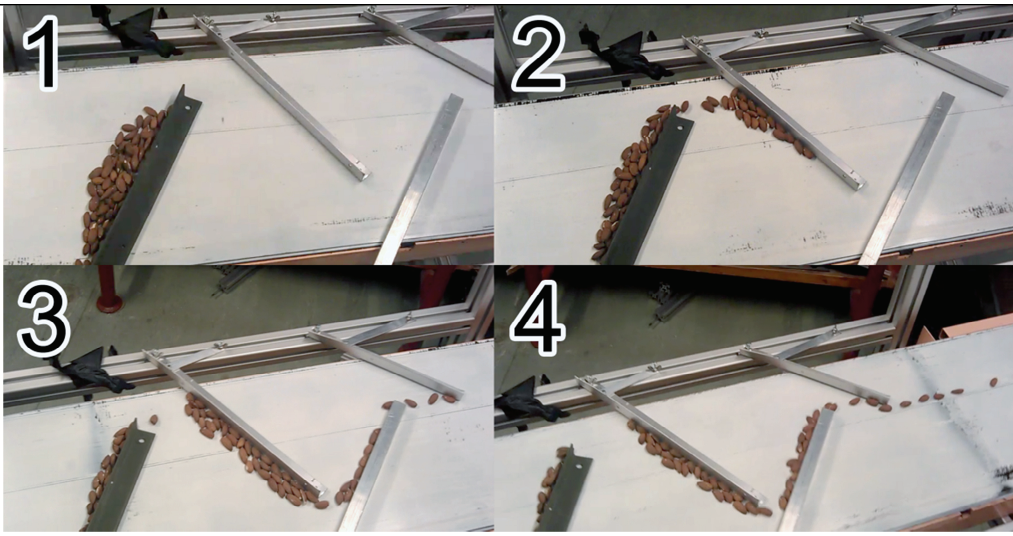


Figure 15-3. A large amount of objects (almonds) inputted, still achieves good separation and singularization.

Live sea urchins seem to also achieve good separation. Although, the test rig was a little bit too small and caused the sea urchins to jam more easily.

Even though the sea urchins were packed together they did not lock into each other. (This was an occasional problem with the fruit; rambutan). Figure 15-4 show sea urchins that get pushed together by the conveyor, and even so they have not locked into each other. In fact they are already on a line at the second obstruction.

The smallest sea urchins were also singularized, but sometimes the separation was not good. The small sea urchins displayed a better ability to lock into each other, than the large sea urchins. They are not really locked into each other strongly, but enough to make some of them stay close to each other, and occasionally flip around the corner of the obstruction. (This is further discussed in chapter **Error! Reference source not found.**)

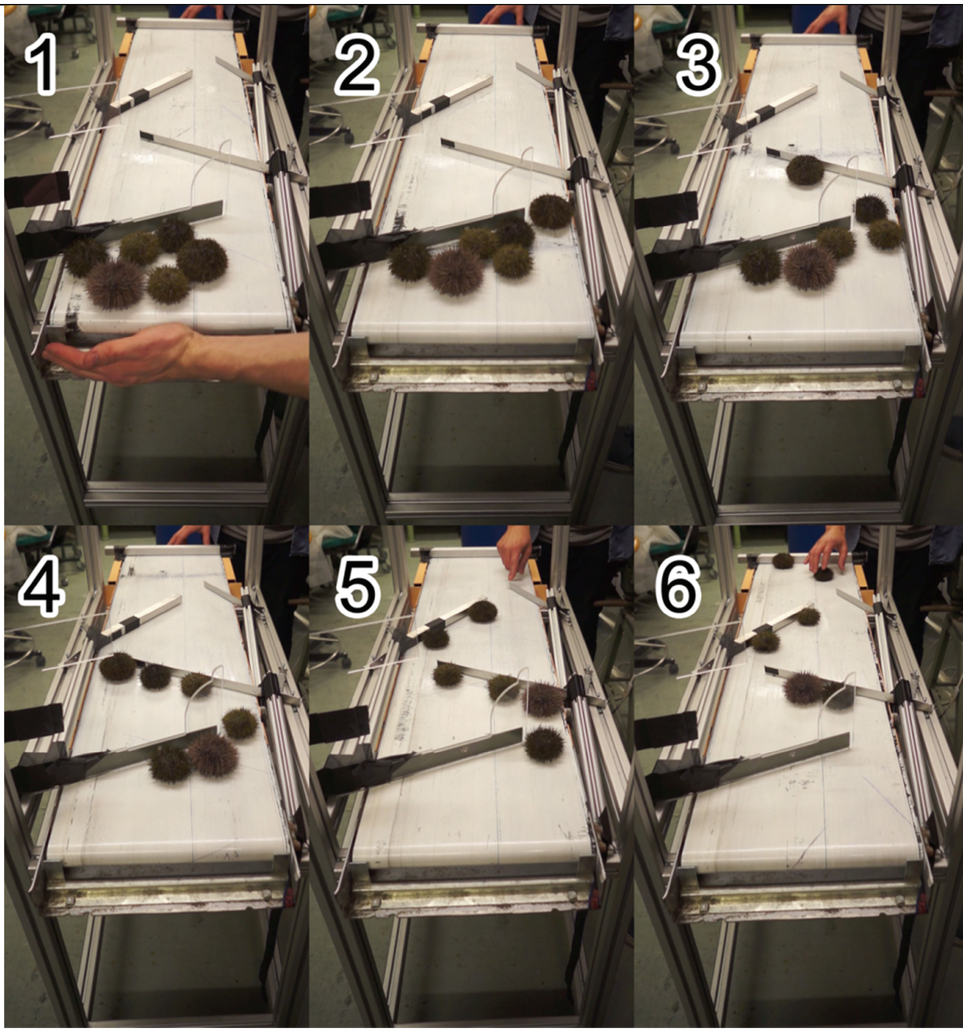


Figure 15-4. Live sea urchins on the test rig. Showing good resistance against clogging.

A distinct behavior can be seen when looking at a single object sliding along one of the obstructions. The objects tend to rotate around their own axis, as illustrated in Figure 15-5.

This may contribute to a jam (Figure 15-5 – Right). When a column of objects reach the end of an obstruction, the rotational forces may cause the entire column of objects to rotate outwards (as seen in Figure 15-6 and Figure 15-7). The column of objects may extend all the way to the edge of the conveyor when rotated, causing a jam, or object fall-off if there is no walls on the side of the conveyor.

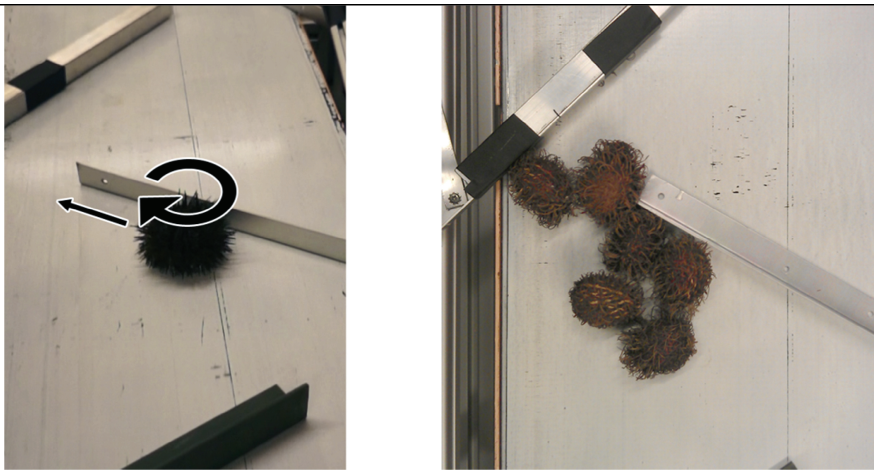


Figure 15-5. Left: A sea urchin that rotates around itself as it slides along an obstruction. Right: 'Jam' causing the objects to come to a complete halt.

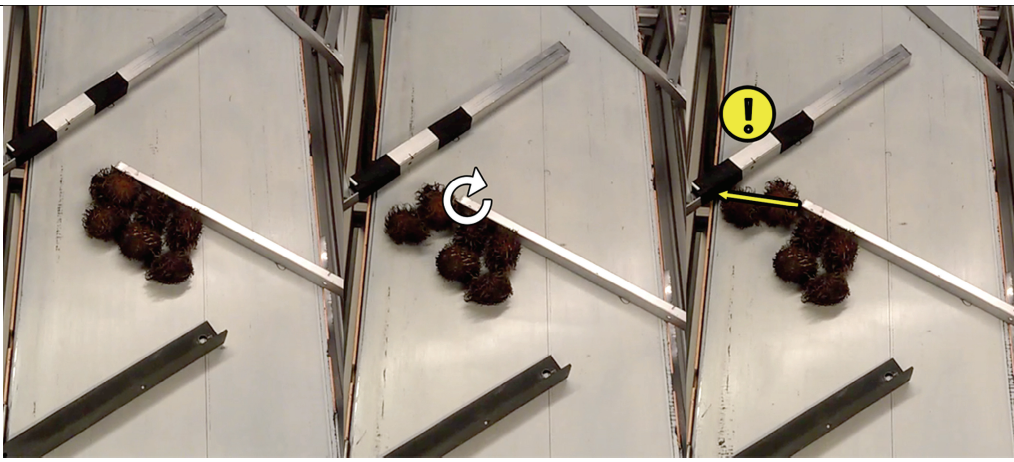


Figure 15-6. Rotational behavior causing a jam.

Figure 15-7. Rotational behavior causes a column of three objects to rotate and extend to the edge of the conveyor.

There were no observed injuries on the sea urchins during or after the experiments. Extremely, there were not a single sea urchin spike to be found anywhere in the test rig. Also, the behavior of the sea urchins were not changed after returning them to their aquarium. Subjectively, the sea urchins survived in the aquarium for a longer period than was expected.

There was not observed any wear on the conveyor belt. No scraping from the sea urchins was visible to the naked eye. This can be said to be surprising, considering that the white paint used on the rubber belt was not optimally cohered.

The camera performed well, giving good pictures. The sensor that triggers the camera needed fine tuning and a ‘quickfix’. The main problem was that the light beam from the sensor could escape under the gap between the sea urchin and the belt, thus not detecting the sea urchin. The ‘quickfix’ was to use a plate with a small hole in front of the sensor light source to narrow the beam. This worked well, but had to be readjusted when changing object size. It is therefore recommended that a solution without using a sensor is developed. (I.e. make the camera constantly take pictures and make the software understand when there is a new object introduced.)

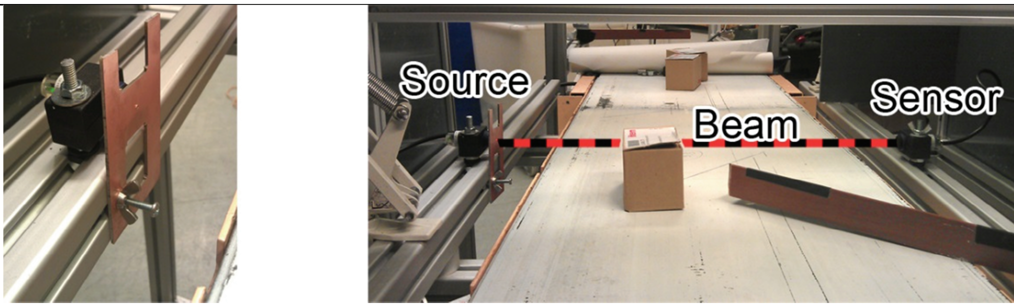


Figure 15-8. Right: Sensor for detecting objects in the camera-box. Left: 'Quickfix' that narrows the beam.

15.4 Analysis

The experiments show that the principal for singularization works. With sufficient tweaking of obstruction angles, good separation can be achieved for a great variety of object sizes. There was not much coherence between the sea urchins, enabling the singularization to perform as wanted.

Ways to avoid jam have to be considered. For example by ensuring plenty of free space around the edges of the obstructions.

There were no observed injuries on the sea urchins. But the principal will have to be tested in large scale to ensure there is no long term effect on mortality.

The size of the conveyor used for the test was not optimal. The width was way too small to enable efficient singularization of large sea urchins. Only one sea urchin had room to pass along the sides of the obstructions. Also, the amount of sea urchins tested was low. Only six sea urchins were placed on the conveyor at the same time. But the use of other, and smaller, objects showed that the principal of the operation works well. Still it was valuable to test with the sea urchins to confirm that there were no visible injuries and no considerable coherence effects.

The tests have greatly increased the understanding of the operation, and have given valuable input to the design process.

15.5 Computer simulations

The computer simulations were executed in Blender 2.67a. Physical simulations incorporating gravity and friction forces was applied. The validity of the simulations was strengthened by tweaking the program parameters until the behavior replicated that of the lab experiments. The simulations successfully replicated the rotating behavior of sliding objects, and the tip around corner mechanics for jamming. Also the velocity decrease along the obstructions was similar to the ones in real life. The sea urchins were modeled with correct dimensions and weight. The spikes was not modeled accurately, but some spikyness was added to prevent the objects from rolling, and to add some inter coherence.

The computer simulations were used mainly as a tool to aid in the creative process of idea generation and selection. But the results have also contributed to the confidence in that the proposed singularization operation will work as wanted.

Chapter 16. Final design

16.1 Description of final solution (total-form)

Description of the finished concept. How does it work. How is the material flow and grading (illustrate? Flowchart with small images).

And document the design in some way,,

Point out the “few” and “small” differences for a finished product…

- Length of transportband? Width?
- Frame, materials and some small changes in design..

Chapter 17. Conclusion

A complete system of principals for a grading machine have been proposed. Critical components have been developed, and a sketch for a prototype have been made.

The main challenge has been developing a singularization operation that ensures good separation, and meet the requirements for low cost, low complexity, and gentle handling. Thus, the other functions of the machine have been given a lower priority in this master thesis.

Computer simulations and real-life experiments have increased the confidence in the working principals of the developed singularization process.

The proposal for a prototype, consist of a manual input, a singularization operation, a camera box, a sort operation, and a conveyor that transports the objects through these operations.

The main conclusion is that the construction of a prototype, that meets the customer demands for the grading of sea urchins, is well within reach.

The singularization operation still needs to be verified by a large scale customer test, where the mortality on the sea urchins can be recorded. Before constructing the prototype it is also recommended that further development and detailing is performed. The input, output and sort operations is yet not fully understood and developed. Based on the suggestions made in this thesis, work on analyzing and testing the reaming functions should be done.

The CAD-modell of the prototype should also be developed in more detail. Also a more descriptive presentation of the existing CAD-model should be presented and documented.

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Chapter 19. Appendix:

Solution:	Function	Low complexity	Low cost	Gentleness	Reliability	Std. Components	Flexibility	Easy to maintain	Probability of sucess	Comments	Conclusion	Clean score	Score weighed by importance
	Importance	5	5	4	4	4	4	3	3				
4-belt increased speed	Heap - Single	2,8	2	3	2	3	3	2	3	No blocking/pushing of the objects. Built in buffer.	-4 conveyors	16,8	83
3-belt increased speed, with 1 blocking	Heap - Single	2,8	2	2,5	2	3	2	2	2			14,3	74
3-belt increased speed, with 1 V-belt	Heap - Single	2	2	2,5	2	2	3	2	2			13,5	70
1-belt blocking	Heap - Single	3	3	2	2	3	3	2	2			16	82
1-belt blocking, and 1-belt increased speed	Heap - Single	3	2,9	2	2	3	3	2	3			16,9	84,5
Rotating transport with blocking	Heap - Single	2	2	2	2	1	3	2	2			12	64
4-belt sideways, increased speed and blocking	Heap - Single	2	2	2	2	3	3	2	3	Compact, less jamming, -both many conveyors and blocking		15	75
Transporter network	Heap - Single	1	1	3	2	2	2	2	2			11	58
Roller-transport, localy increased speed	Heap - Single	1	2	2	1	2	3	1	3			13	59
Water canals localy increased speed, and 1 belt increased spe	Heap - Single	2	2	3	2	3	3	2	2	Only one conveyor, -must use anti-attach serum		15	76
Height limiter block	Heap - Low heap	3	3	2	2	2	1	3	2			13	73
Shaker	Heap - Low heap	1	1	3	2	2	3	1	2			12	59
Manual distrubution	Heap - Low heap	3	2	3	3	3	3	3	3			17	91
Steep transport angle	Heap - Low heap	2	2	2	1	2	3	2	1			12	61

19.1.1 Belt

(Data sheet attached)

The Intralox Thermodrive belt is a belt that is run without tension. Consequently there will be excess belt length that needs to be accommodated. This excessive belt will be accommodated by the unsupported spans in the returnway.

There have to be enough spare belt length and sag to accommodate for potential changes in belt length. The belt length can be changed by thermal expansion/contraction and by strain caused by applied load.

The KILDE MANUAL gives ….directions.. for how much sag….

- Max. longditudal distance between supports: 72" (1829mm) (Plus max. back bending.
- Recommended 2" (51 mm) of catenary sag in each unsupported

span but it can change depending on conditions such as load, temperatures etc.)

- The belt should be installed so that it has a minimum of sag for all unsupported

spans (Fig. 2.5, Dim. B):

Thermal

The OPPGITTE length is … when 21?

Merk kråkebollene tåler ikke temperaturendringer… såå ikke så farlig…. Men når båndet står til lagring eller er i transprt.. må ikke bli tension!..

Thermal expansions calculation -> make sure there is still sufficient slack.

Polyeuretan, coefficient of thermal expansion: e = 0.15 mm/m/*C

Up to 30 grader…

$$\Delta L, thermal = L * (T2 - T1) * e$$

$$\Delta L, thermal, exp = 7{,}2\ m * (35 - 21)C\ * 0.15\ mm/m/C = 15{,}12\ mm$$

For down to -35 …

$$\Delta L, thermal, contract = 7{,}2\ m * (-35 - 21)C\ * 0.15\ mm/m/C = -60{,}5\ mm$$

Strain

Elongation caused by load (strain): The belt manufacturer informs that the maximum elongation a ThermoDrive belt can ever experience is 1.5%. This elongation will only occur between the loaded part of the belt and the drive sprockets.

The part of the transportband that can carry load is (from axle to axle): 3370 mm

$$\Delta L, strain = 3370\ mm \cdot 0.015 = 50{,}55\ mm$$

Note: This is max elongation. …the max load for sea urchins case is: "The case with all stones…)

The total maximum

$$\Delta L, max, increase = \Delta L, strain + \Delta L, thermal, ex = 65{,}7\ mm$$

$$\Delta L, max, decrease = \Delta L, thermal, contract = -60{,}5\ mm$$

The design of the sag: and calculation of lengths::

19.1.2 Support..

In the span between the axles, the belt needs to be supported in order to carry its own weight and the weight of the objects it shall carry. The recommended support method for this type of belt is using support strips, contra a conventional support plate. [KILDE manual]

The carryway of the belt must be continuously supported along the path where load is

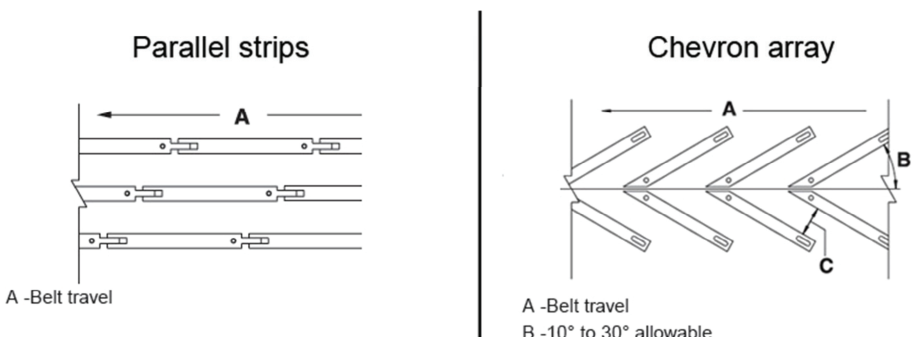

Figure 19-1 - The two options for arranging support strips [KILDE INTRALOX MANUAL] applied, which in this case is along the full length of the carryway. There are two choices of how to position the support strips; parallel longitudinal strips or a chevron array of strips. [FIG]. The parallel strip configuration is the quickest and easiest to assemble, but have a disadvantage in that the belt wear is confined to a narrow area. The chevron array distributes the belt wear, and it may work as a means to scrape of accumulated dirt from the underside of the belt. On the negative side the chevron array is prone to produce catch points that may cause interference between the belt and the strips. To avoid catch points the strips must be correctly chamfered and assembled with diligent accuracy. [KILDE manual]

The prototype will be disassembled and assembled repeatedly [MULIG LNK TIL PROTO SPECS], and it should be possible for non-mechanical personnel to assemble it. Also being a prototype, wear is not crucial. To provide easy assembly, parallel strips are therefore chosen.

In the returnway a combination between longitudinal strips and transversal points of support will be used in order to give the belt room for belt sag. The transversal supports will be made of circular rods, and they will have flanges on the ends to support belt containment.