DESIGN, TESTING AND OPERATION OF FISH PROCESSING LINES – CAN STATE-OF-THE-ART SIMULATION TOOLS BE A GAMECHANGER?

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KEYWORDS

Fish processing, automation, simulation, design.

ABSTRACT

The oceans play an important role in the world's food supply, so it is very important that we can develop sustainable, safe, and cost-effective production and processing of fish that also safeguards fish welfare. The aim of this research is to explore whether state-of-the-art simulation tools can improve the design, manufacturing, commissioning, and operation of fish processing lines. The research team has set up three early-stage trials of a simulation; i) the flow of fish on a transport roller, ii) the design and testing of a singulation machine that organizes fish in a queue for processing in a simulation environment, iii) more precise and intelligent processing of the fish. The research shows that state of the art simulation tools can help solve challenges within design, testing and operation of fish processing lines.

INTRODUCTION

Three billion people currently rely on seafood as an important source of nutrition (Oberio et al., 2019). This means that a significant part of our food comes from the sea. Fish and other seafood provide the livelihoods of coastal communities worldwide. The oceans will become an increasingly important source of food as the world's population increases. This includes not only fish and shellfish, but also edible seaweed. Norway has set the goal of further developing its aquaculture and fisheries industries to reach an export value of fish and seafood of NOK 500 billion in 2050 (Olafsen et al., 2012). It is therefore crucial that Norway can develop technological and biological knowledge and grow innovative and competitive industrial supply networks for advanced automatic and intelligent processing lines and machinery. The fishing industry has made quantum leaps in terms of scaling and automation of production over the past 30 years. However, when we compare fish production with, for example, the manufacturing of cars or computers, we believe there are still possibilities for technology development and innovation in the fish industry.

The aim of this research is to do an early-stage evaluation of if and how state of the art simulation tools can be used to support efficient design, manufacturing, installation, testing and operation of fish processing lines (FPL). The work elaborates overall challenges related to fish processing, introduces fish types and varieties, describes typical fish processing lines and the overall process for design, manufacturing, and testing and verification of fish processing lines. To dig deeper into simulation as a possible tool, this study presents three fish processing cases which are implemented, developed, and tested in NVIDIA Isaac Sim. The three cases are developed in close cooperation with the university and industrial companies (Hansen, I. E. et al., 2022), and the final test and verification is done with a full-scale prototype in an operational environment, Technology Readiness Level 7 (Olechowski, A. L. et al., 2020). In the conclusion we summarize our findings and make recommendations for further research.

STATE-OF-THE-ART SIMULATION FOR FISH PROCESSING

Research on the automation of fish processing has focused on automatic transport systems, robotic bleeding with machine vision (Bondø et al., 2011), intelligent cutting systems with machine vision for optimization of fish (Fu J., 2023) and automated and robotic washing of fish processing lines, using simulation as a development tool (Giske, L. A., 2019). Robotic grasping of soft bodies can be used in fish processing, and simulation is a support tool (Narang, Y., 2021). Digital fish have been developed in the game engine Unity (Giske, L. A. et al., 2023). Machine vision and machine learning are technologies that have a variety of applications in fish processing, such as the classification of fish, automatic detection and counting, fish cutting point predication, as well as other monitoring functions (Gladju, J., et al., 2022). Synthetic data is currently used in connection with artificial intelligence and machine learning. Synthetic data is used to train deep learning models for species recognition. Synthetic data are also used to train models that detect fish diseases and injuries, definition of fish size, and quality control. (Allken, V., et al., 2021).

RESEARCH METHODOLOGY

The research methodology is based on four workshops with participants from the fish industry and research

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institutions. Additionally, it included a comprehensive literature study. Participants included designers of fish processing lines, project managers, sales managers, fish processing line workers and managers, as well as researchers within technology, food quality, and biology. These workshops were linked to several research projects within automatic production of fish, and they were conducted in research and innovation labs for design and automatic production, land-based production lines, and production lines on board trawlers.

In conjunction with the workshops, physical prototypes, virtual models, and simulation scenarios were developed to externalize, combine, and integrate tacit and explicit knowledge related to the automatic production of fish, simulation, and use of artificial intelligence (Nonaka et al., 2000). Moreover, the university, in collaboration with the industry, conducted innovation bootcamps to allow students with fresh perspectives to delve into fish processing challenges and opportunities.

The workshops and literature review provided valuable data that guided our subsequent findings within each topic:

a) Identifying the main challenges in fish processing lines: The methodology involved a thorough literature review and hosting workshops to pinpoint the key challenges associated with fish processing lines.

b) Characterizing fish types and varieties: Through the workshops and literature review, the most relevant fish types and varieties pertinent to the whitefish fleet were identified.

c) Examining typical fish processing lines: Workshops and on-site studies were conducted to closely examine the operational dynamics of typical fish processing lines.

d) Mapping the Process for HG trawler fish processing lines: Extending the investigation, workshops, on-site studies, and a literature review were conducted to map out the process specifically for HG trawler fish processing lines.

e) Designing fish processing lines: Engagement in workshops, on-site discussions, and a study of the literature with designers, manufacturers, and installation commissioning staff provided insights into the design aspects of fish processing lines.

f) Exploring NVIDIA's Isaac Sim for Fish Processing Operations: To assess the suitability of NVIDIA's Isaac Sim as a simulation tool for fish processing operations, experiments were conducted in simulation environments, laboratory settings, and industrial contexts.

The data collected from these workshops and literature review laid the groundwork for subsequent findings within the same topics, facilitating a comprehensive analysis of each aspect of the fish processing industry.

FINDINGS

In this section, we present the findings derived from our comprehensive methodology, which involved workshops, literature review, and on-site studies. Each subsection corresponds to a specific aspect, reflecting the insights gained from the research. These findings shed light on key challenges, fish types and varieties, operational dynamics, process mapping, design considerations, and the suitability of simulation tools. Through these findings, a deeper understanding of the intricacies of fish processing operations and their implications for industry practices is provided.

a) Main research challenges related to fish processing lines

The review shows that there are three major challenges, where research and innovation may be key to overcoming these.

- Sustainable production. It is important to ensure sustainable production with a low environmental footprint. This requires research to develop and use new sustainable feed raw materials.
- Product quality. Norwegian salmon is known for its high quality and food safety, but there is still a need for research to solve biological challenges in production that affect product quality.
- Automation of fish processing. The fish processing is labor-intensive, and a significant proportion of the fish are sent to low-cost countries for production and preparation.

A close cooperation between authorities, academia and industry is a way to overcoming the challenges.

b) Fish types and varieties

There are more than 30,000 fish species globally, and it is estimated that there are 329 fish species in Norwegian waters. The most common fish species produced in Norway are salmon, trout, cod, halibut, char, mackerel, herring, saithe, and haddock. Salmon, trout, cod, and halibut exist both as wild fish and farmed fish. There is also variation within each fish species related to size, shape and color, and quality according to the season. The fish are also affected by their ocean habitat and the type of food they eat. Another issue is that especially in aquaculture, several fish may experience damage or have quality issues, which must be kept under control in fish selection and processing.

c) Typical fish processing lines

Figure 1 depicts the primary configurations of fish processing lines commonly used in aquaculture, trawler fishing, and ring knot boat operations.

The aquaculture industry has a continuous year- around operation. This industry is the driver for the development of automation of fish processing, since they have high volume. Trawlers and ring knot boats have a season-based operation of fish processing lines.

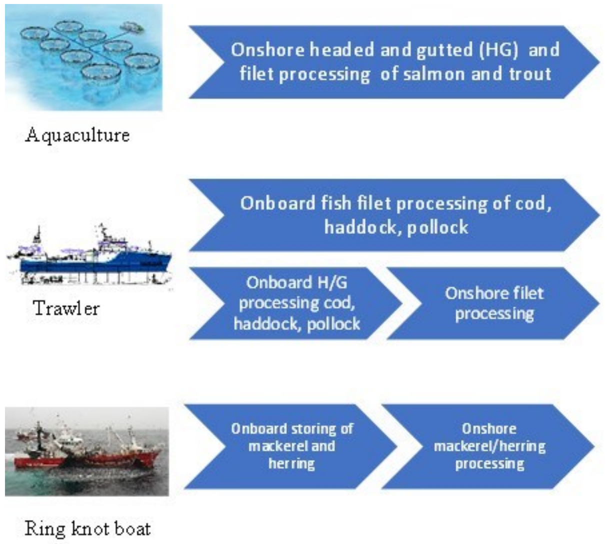

Figure 1: Typical Fish Processing Lines

There are significant differences between onboard and onshore processing. Onboard fish processing lines are exposed to rolling from the waves, the operators are living on board, service of machinery is limited, and available space for the fish processing lines and machinery are limited. The development of fish processing lines is incremental and based upon the single ship owner's or fish processing factory owner's knowledge and experiences. Almost every fish processing line is custom-made related to available space, layout, machinery and how the operators operate the fish processing line.

d) Process map of a Head and Gutted fish processing line on a trawler

Figure 2 shows the detailed process of onboard fish filet processing of cod, haddock and pollock.

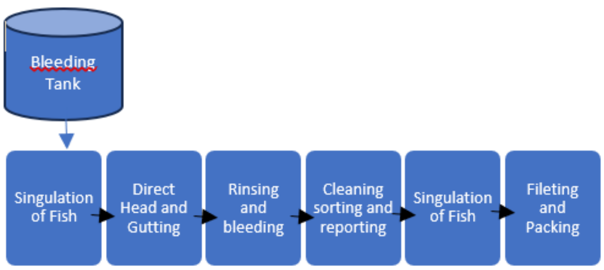

Figure 2: Onboard Fish Filet Processing of Cod, Haddock and Pollock

Initially, the fish are harvested, either through commercial fishing or aquaculture practices. Upon landing, they undergo sorting based on species, size, and quality criteria. Subsequently, the fish are slaughtered, a process that may involve manual techniques or the use of machinery, followed by thorough cleaning to eliminate intestines and other undesirable parts. This standard is called heading and gutting (HG) meaning fish have had their head and viscera (gut) removed. Some trawlers are equipped with filet-making machinery onboard, facilitating automated or semi-automated bone and skin removal processes. Following this, the filets or HG fish are promptly chilled or frozen to maintain their freshness, before being carefully packaged and stored at optimal temperatures for distribution to the market.
The processing line for headed and gutted fish on a trawler is shown in Figure 3.

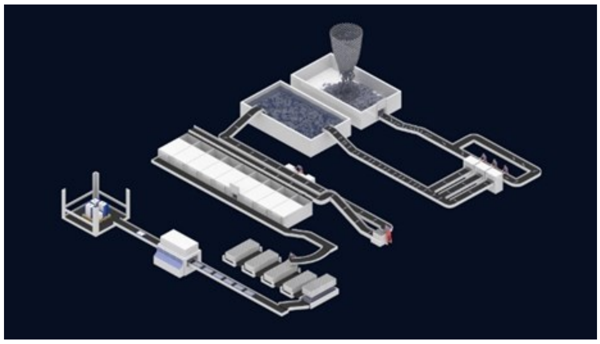

Figure 3: 3D Drawing of Processing Line for Headed and Gutted Fish on a Trawler

For pre-rigor fish, low stress levels are required for effective filleting. In unstressed fish, the pH of white muscle is high, normally in the range of pH 7.5. When stored on ice, it can take up to a day before rigor sets in to fish that have low stress levels. The processes can vary depending on the species of fish, and the specific market the fish is intended for. This emphasizes the importance of adapting the processes to both the species of fish and the requirements of the specific market.

e) Design of fish processing lines

Design of production lines for fish is a complex process that requires a combination of knowledge, insights and working methods, such as a) how to create an industrial design on a production line to ensure efficiency and productivity, b) product development of new products and technical solutions to meet the specific needs of the fishing industry, c) how to loosen a human-machine interaction on the production line, d) hygienic design is essential to ensure that the production line meets all necessary health and safety standards, and e) design of fish production lines includes the development of robotic solutions for full trimming of salmon filets, automatic singulation, orientation and quality sorting in production lines for whole salmon, and technology development for increased profitability in the shrimp industry. The design of a production line depends on many factors, including the type of fish to be processed, the production capacity of the business, and the specific requirements for the final product.

Figure 4 shows the progression of processing line development, from customer specification to operational implementation.

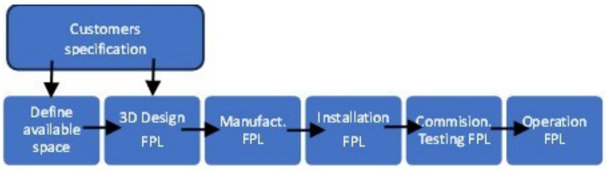

Figure 4: Design, Manufacturing, and Installation Process for a Fish Processing Line

The characteristics for the process are i) the degree of customization, both in terms of availability of space and the customers specification related to machinery and automation, ii) the fish processing line can partly be tested in the workshop after the manufacturing process, but it is only an early stage test, iii) it is not possible to test and verify the fish processing line completely, before it is installed and commissioned in the factory or onboard in the trawler. The fish processing line must be tested in an early-stage operation, which is costly, time-consuming and requires a considerable number of dead fish. Due to the variables - type of fish, custom made fish processing lines, and the rolling movement of the sea - failure will occur with fish processing during the line's lifetime.

f) Exploring NVIDIA – Isaac Sim – simulation tool for three fish processing operations

Exploring simulation of fish flow on the processing line. Every fish processing line is unique, and the flow of fish on the processing line can currently only be tested by filling the conveyors with fish. This can be done by building a prototype version or by testing the fish processing line when it is installed and ready for use. The operational and financial consequences of a non-functioning fish processing line are quite high. Specific factors like movements from the waves and the variety of fish, will increase the risk of problems occurring. How can simulation help solve the flow of fish on the processing line?
First, fish data for the creation of virtual fish with similar behavior to dead fish was collected. Figure 5 shows the digital fish made in the simulation environment of the Issac Sim-program.

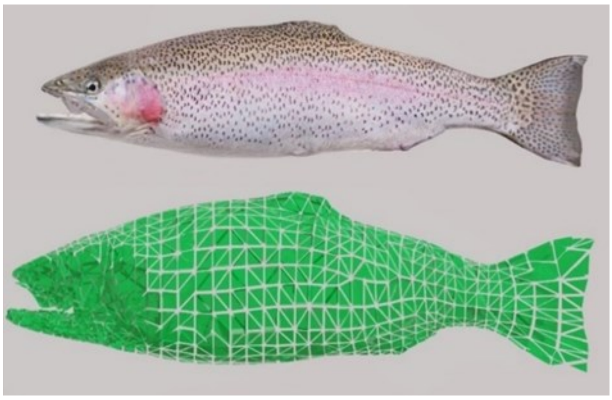

Figure 5: Design and Modelling of Digital Fishes in Isaac Sim

Real fish processing line transports were imported into Isaac Sim. A comparison of the physical demonstrator and the virtual demonstrator is shown in Figure 6. It shows that it is possible to test fish processing lines already in the design stage with this specific equipment. If these experiments prove to be transferable to more comprehensive fish processing lines, the use of simulation tools can reduce risk and cost for the fish industry.

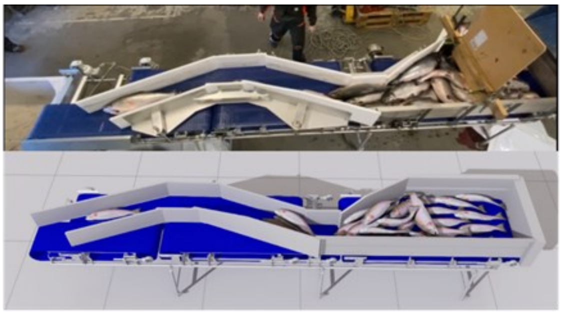

Figure 6: Fish Flow - Comparing flow of Real Fishes on a Transporter with Digital Fishes in Isaac Sim

Exploring automatic singulation of fish. So far, neither industrial companies nor research institutions have been able to create singulation methodology for fish processing. Traditional development methodologies have been used while searching for a singulation solution, that is, designing solutions, and building physical models for testing concepts. This requires resources and, not least, uncertainty, as it is challenging to test with a significant number of fish. First, the challenge is the number of species, sizes, shapes, colors etcetera. Second, the uniqueness of the fish processing lines. Third, the moving waves which rolls the processing lines at sea.

The design proposals for a singulation machine were installed in Isaac Sim. A population of digital fishes were put into the simulation environment and dropped into the singulation machine for testing. The experiment shows that simulation can be used for testing and verification of new and innovative machinery. The next stage will be a verification of the automatic singulation concepts with physical models of the most promising concepts tested in the simulation environment. Isaac Sim is a powerful simulation platform, which allows parallel simulation of several design concepts. Artificial intelligence can be used to evaluate and select the most promising concept.

Figure 7: Fish Cutting Machine in Real Operation

Exploring new cutting and carving methodologies for fish processing. Today, the processing of fish is done using standardized machines that have existed for more than 50 years. Figure 7 shows one of the standardized cutting machines in operation. Such machines have undergone incremental developments, but there have been no revolutionary improvements on these machines. The machines perform standardized operations, where the tools are knives or saws that perform the same cut on all fish. The machine can manually be adapted to the size of the fish. In the fileting process, for example, there are six fileting machines in combination with burrs, which then sort the fish according to the setting on the machines. No two fish are alike so an adaptive processing methodology that can adapt to fish species, fish size, fish shape, as well as shape the fish pieces according to the specific customer's wishes, would be an important step forward for the industry. Such a processing method would increase the amount of fish meat, increase the value of the fish to the consumer, and perhaps also lead to a better and more stable quality of fish. Icelandic Valka has developed processing machines for fish filets that are based on water cutting and that can operate, for example, according to graphic drawings of a filet. However, so far, the state's framework conditions for the fisheries industry have not facilitated a breakthrough in this technology.
In our case study fish processing machines were implemented in NVIDA Isaac Sim together with robotics and machine vision in simulation environments as is shown in Figure 8. Different types of camera technologies and machine learning software were tested. New innovative cutting processes were implemented in close cooperation with physical machine designers and machine builders. The experiments so far show that simulation as a development methodology is a useful tool in combination with traditional design and physical prototype building. The research also includes the generation of smaller populations of fish types. Software created in the simulator can be used directly in the physical machine setup.

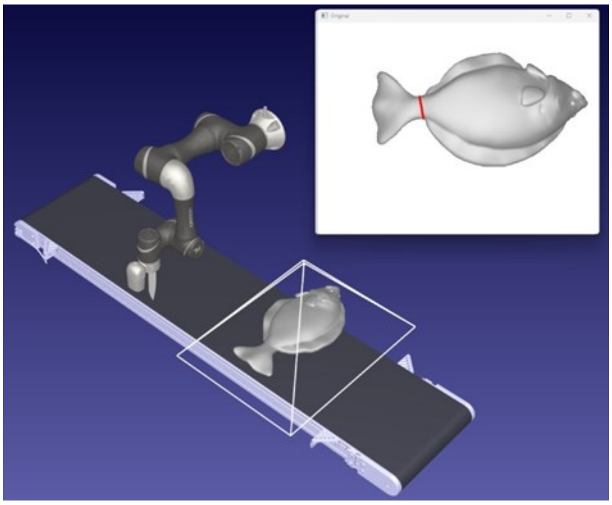

Figure 8: Simulation in Isaac Sim of a Robotic Arm with Knife for Cutting of Fish Tails

CONCLUSION AND FURTHER WORK

The findings shows that the fish and sea food industry have considerable challenges related to sustainable production, food safety and automation of fish processing. It is difficult to see how simulation can contribute to solve all challenges. Therefore, this research work digs deeper into automatic and sustainable fish processing. The product itself – the fish – exists in millions of types and varieties. The fish processing lines are adapted and customized upon experiences and needs. It is likely that simulation and automation in general can be a powerful tool to improve fish processing. Advanced automation using machine vision, machine learning and artificial intelligence can enable identification, tracking and adapted processing to each unique fish on an industrial fish processing line.
Isaac Sim has photorealistic simulation, addresses many common use cases in robotics, including manipulation, navigation, and synthetic data generation for training data. Isaac Sim allows easy connection of the robot's brain to a virtual world through the Isaac ROS/ROS 2 interface, full-featured Python scripting, and plug-ins for importing robot and environment models. Isaac Sim provides the tools and workflows needed to create robust, physically accurate simulations and synthetic datasets, and is widely adopted by industry. Altogether, Isaac Sim supports the idea of using simulation as a tool for solving complex and comprehensive fish processing.
This research describes three cases, where Isaac Sim is explored as a tool for simulation tool for fish processing. The application of Isaac Sim on three fish processing line cases, shows that simulation can be useful for design, manufacturing, testing and installation. The successful development of a digital fish with almost equal physical properties and behavior as a real fish, was a breakthrough in the research and development. Physical verification of the fish flow confirmed compliance with the Isaac Sim simulation. Set up and integration of a physical fish processing line in Isaac Sim was manageable.

The industrial impact from the use of simulation and artificial intelligence can a be more cost-efficient design, manufacturing, and installation process of fish processing lines. The time to market can be reduced. The risk for problems in commissioning and in the full operation will be reduced, especially if the simulation can include the rolling of the ship on onboard lines and trials with a wide range of digital fish species, sizes, and shapes. Even season varieties can be integrated if a robust data set can be provided. Sustainability will also improve since the use of dead fish for testing will be reduced significantly. The use of artificial intelligence and simulation to generate and develop completely new technological solutions could be the next step.
Further work can focus on the development of a population of dedicated species, for example, salmon and cod. It should explore the general possibilities within Isaac Sim and build a simulation foundation for fish processing. Research should be done in close collaboration with industrial companies, to ensure that the simulation can be used in real industrial applications.

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