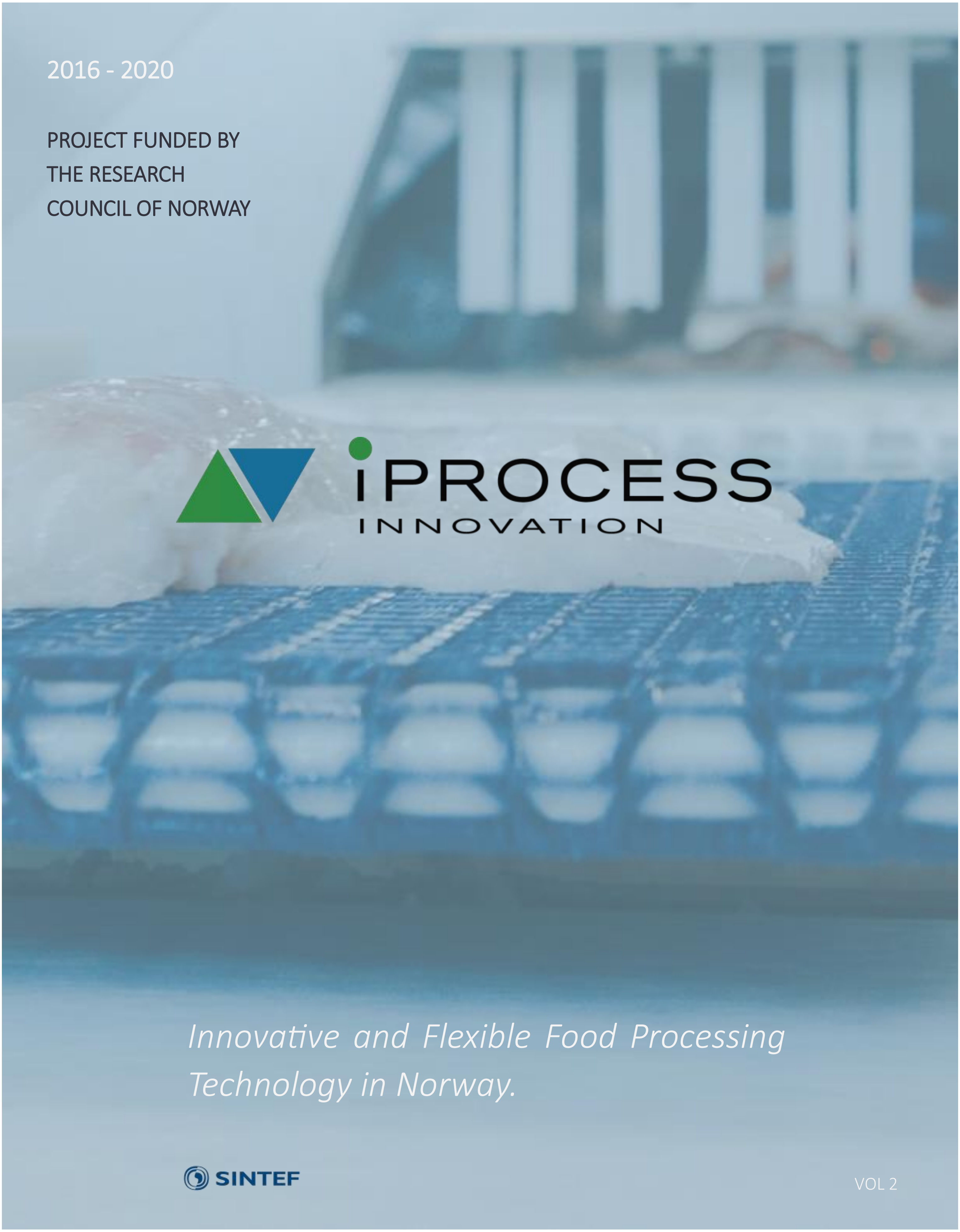


2016 - 2020

PROJECT FUNDED BY
THE RESEARCH
COUNCIL OF NORWAY

iPROCESS INNOVATION

Innovative and Flexible Food Processing Technology in Norway.

SINTEF

VOL 2

Editors:

Guro Møen Tveit

Cecilie Salomonsen

Ekrem Misimi

Aleksander Lillienskiold

Kirsti Greiff

Marit Aursand

Magali Courtade

Marianne Fon

Photos: Unni Skoglund (page 14), Guro Møen Tveit, SINTEF Ocean (page 6, 11, 32, 34, 36) Shutterstock (page 12, 39, 48, 58), TYD (page 1, 40, 64), Norilia (page 25), SINTEF (page 7), Nofima (page 7).

Project

iProcess 2016-2020

Innovative and Flexible Food Processing Technology in Norway.

Coordinated by SINTEF Ocean.

www.iprocessproject.com

Funded by:

The Research Council of Norway (255596)

Report no: 2020:00981

ISBN: 978-82-14-06560-2

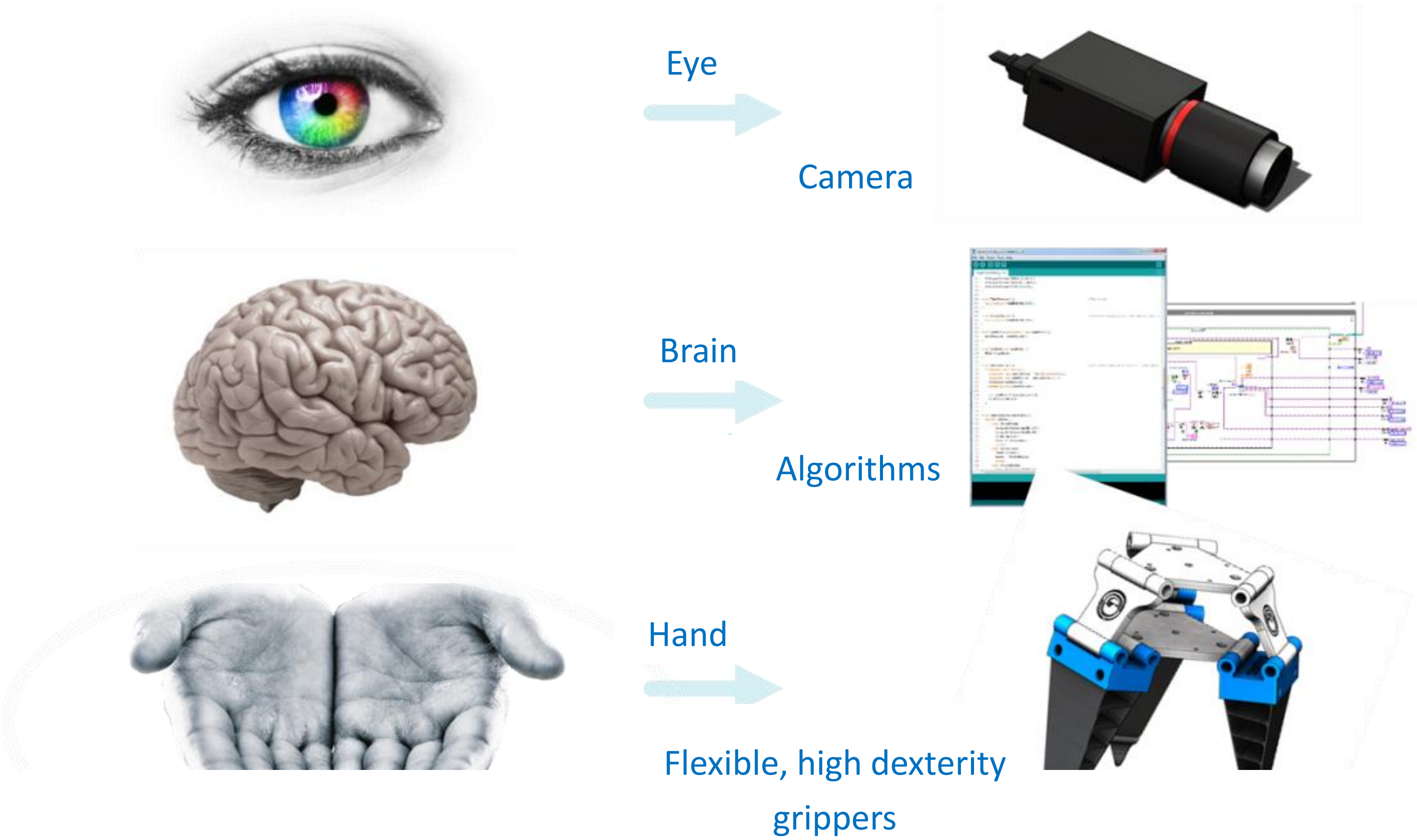
Preface

Currently, 17% of the total greenhouse gas emissions in the EU are derived from the food processing sector. Globally, 1.3 billion tons of food are wasted every year. In the Norwegian food processing industry alone, at least 320,000 tons of food go to waste annually.

In order to address the challenges faced by the Norwegian food processing sector, researchers and industry have been working together as part of a project called iProcess.

iProcess is an interdisciplinary project that aims to achieve “Innovative and Flexible Food Processing Technology in Norway”. The project aims to develop novel concepts and innovative methods adapted to the small production volumes that characterise the Norwegian food production industry, and to address the processing of raw materials that exhibit high levels of biological variation. The ultimate goal is to optimize raw material utilization and boost the sector´s profitability.

iProcess intends to develop highly innovative food processing technologies by conducting research into components such as 3D machine vision, spectroscopic sensors, X-ray imaging, machine learning, Big Data and flexible robot-based automation. Such components are based on machine and robotic ‘eyes’,



'brains' and 'hands' that are capable of performing some complex food processing operations, most of which are currently performed manually.

Too great a volume of raw materials is lost during modern food processing due to the inability of technology to adapt to variations in the individual fish, chicken, and red meat carcasses, fruits and vegetables, or dairy products being processed. In order to manage such small production volumes, combined with high levels of biological variation inherent in the raw materials, there is a need to develop novel concepts for flexible processing automation, process analytical technology, and information flow management.

The acquisition of large data sets derived from 3D-vision, spectroscopic sensors and X-ray imaging from online measurements, combined with exploitation of the Big Data concept, has enabled the iProcess project to develop innovative methodologies for the external and internal characterization of raw materials that extend beyond state-of-the-art. Utilization of these methodologies will ensure that the raw materials are handled and processed safely, efficiently and individually, thus optimizing the quality and utilization of the final product.

iProcess has used its acquired data both to exploit new machine learning paradigms, including deep learning, and to specifically tailor and optimize these algorithms for food processing applications. This has resulted in a form of computerized 'brain' that is capable of analysing and interpreting large volumes of visual and other types of sensing data as a means of improving the recognition and 3D localization of raw materials components.

Inspired by the ways in which humans combine visual and force/tactile sensing, and their ability to learn new and complex tasks, we have developed a number of approaches that enable the 3D deformation tracking of objects during manipulation using a robot. Such tracking is based on colour image (RGB) and depth (D) data, visual servoing-based grasping tasks for compliant food objects, 3D reconstruction of an object model, active vision, shape completion of the objects from a limited number of viewpoints. The project has also developed the use of a combination of visual (RGB-D) information for pose estimation and tactile sensing for force prediction during the grasping of compliant objects by a robot, as well as force feedback control of the robot during manipulation of compliant food objects.

In relation to information flow, the techniques and methodologies that comprise the 'computerized brain' can also be used to optimize communication between food suppliers and processors in order to better synchronize market demand and production. This will help to conserve resources, and the of information in its entirety will enhance the transparency of the value chain and promote the development of innovative ways of utilizing raw materials and reducing food waste. However, societal and bio-economic change will not be brought about by technology advances alone. For this reason, iProcess has dedicated a substantial amount of research to the field of value chain strategies and business models with the aim of maximizing the positive societal, economic and environmental benefits of its flexible processing technology concepts.

When machine and robotic 'eyes', 'brain', and 'hands' are combined and work together, we expect levels of productivity to increase as a result of greater automation. Volumes of food loss and waste are anticipated to decline and sector profitability will increase, thus safeguarding continued value generation from the Norwegian food processing sector. The results presented in this report represent iProcess's contribution to a green transition in the Norwegian food processing industry, and to a more profitable and sustainable bio-based sector.

Ekrem Misimi,

Project Manager, SINTEF Ocean

SINTEF

Innovative and Flexible Food Processing Technology in Norway

Main objectives

To develop novel concepts and methods for flexible and sustainable food processing in Norway with the aim of coping with small volume series and high biological variation in existing raw materials, to enable increased raw materials exploitation for use in food products, and to increase profitability. This will enable the Norwegian food industry to meet its key long-term challenges related to the sustainability of raw materials exploitation and reductions in loss (edible)/waste (inedible) in a life-cycle context.

Objective 1

To identify relevant industrial cases and major challenges as a basis for promoting more flexible and sustainable food processing.

Objective 2

To develop advanced process analytical technologies for the measurement and control of raw materials quality to meet end product requirements.

Objective 3

To develop flexible processing concepts that can handle small production volume series and adaptively process raw materials containing high biological variation.

Objective 4

To develop information flow management solutions to support decision-making so that food processors can maximize resource efficiency and profitability.

Objective 5

To develop technologies that are adapted to raw materials with the aim of increasing utilization and minimising waste.

Objective 6

To develop market strategies and models with the aim of increasing profitability, value generation and market-oriented production.

Objective 7

To achieve technology validation by applying developed concepts and methods to a selected number of industry-relevant cases within the sustainable approaches to food processing developed as part of the project.

Collaboration with the food processing industry

Industry involvement is key to ensuring the commercial impact of the research conducted as part of the iProcess project. The food processing industry has been involved in the selection of the relevant case studies around which research activities have been focused. Since these studies have involved a high degree of complexity, and in order to open the door to radical and innovative approaches, iProcess has focused on fundamental technology-oriented research with the aim of bridging the gap between current state-of-the-art and future industry needs. The nature of this approach has required regular and close collaboration with the food and vendor industry.

The iProcess project has been designed to address relevant Norwegian food industry needs in the fields of robotic automation, process analytical technology, information flow management and new business models. In order to map industry needs and to identify relevant case studies for use in developing the methodologies being researched by iProcess, the researchers have visited the industrial partners and their facilities. Discussions that took place during these visits, combined with annual project meetings, have ensured that the industry's needs are deeply rooted in the project's research activities. As a result of this close collaboration, it has been possible for many of the methods developed in the laboratories to be demonstrated in relevant industrial settings. Both the industry and the researchers have appreciated this approach, which has promoted the generation of new knowledge that will be used to address some of the challenges currently faced by the industry.

> *The number of animal hides we deal with has increased by 50%, thus boosting our requirement for better traceability. Tufan Yurt (Norilia)*

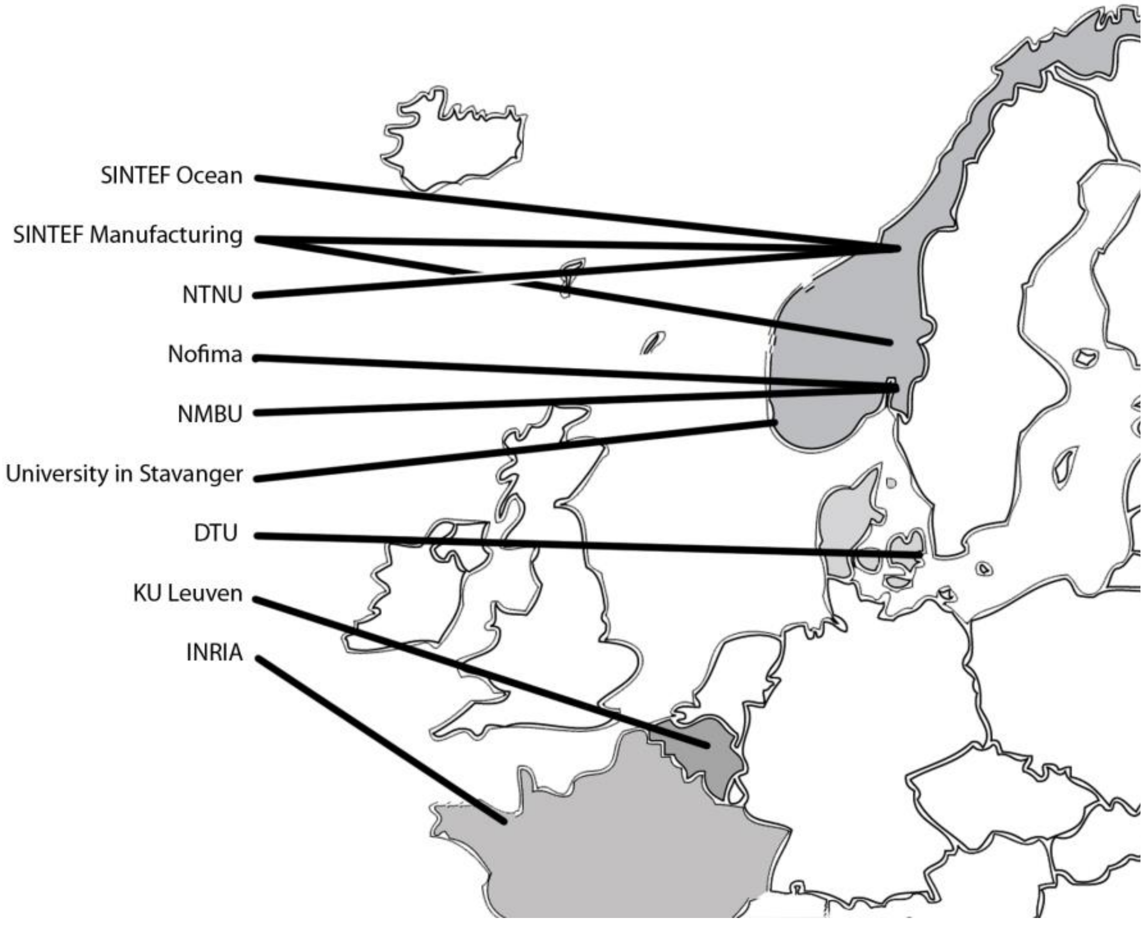
> *Modern industry has an increasing need for systems that can generate data which can provide knowledge and a deeper understanding of production as a basis for achieving optimization and improvement. Geir Tøgersen (Prediktor)*

TECHFOOD CONFERENCE

TechFood is a newly-established conference focusing on automation, sensor technology and machine learning in the Norwegian food industry, and represents a culmination of the collaboration and communication strategy adopted during the iProcess project. The inaugural TechFood conference was held in February 2020 and was the first of what will be an annual event bringing together the food industry, technology vendors, researchers, and public bodies to discuss challenges and new opportunities.

The main reasons for introducing robotisation are HSE considerations, increased efficiency and quality, and reduced costs and food loss. Per Berg (Nortura)

Research partners



Industry partners

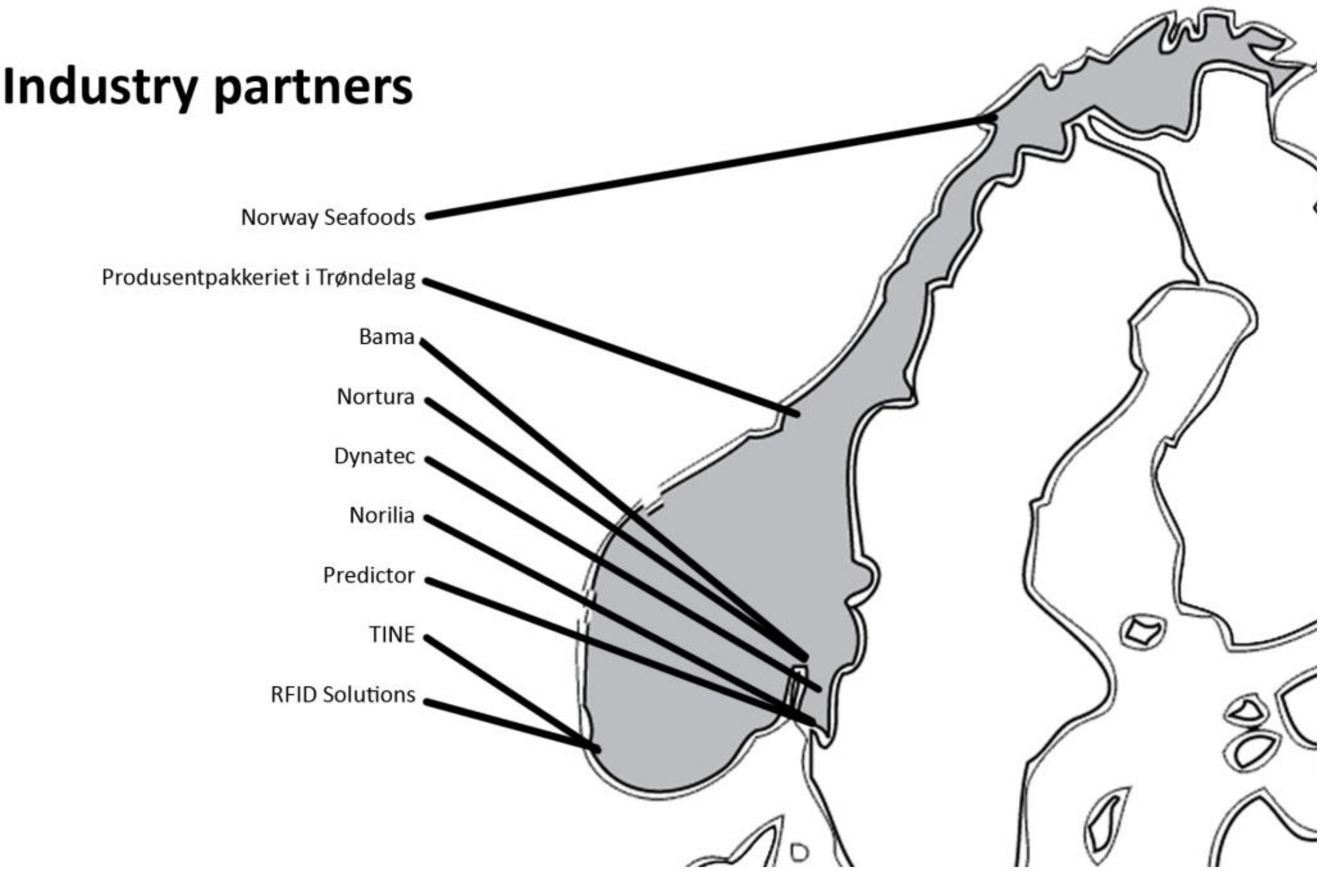


Table of Contents

Agriculture-related research

EKREM MISIMI

Robotic handling of compliant food objects following robust learning from demonstration

Contemporary robots lack the visual, tactile and cognitive intelligence employed by humans to perform complex handling and processing tasks. We will show how robots can be equipped with these abilities and taught how to handle complaint food objects by means of learning from demonstration.

The robotic handling of compliant and deformable food raw materials, characterized by high biological variation, complex geometric 3D shapes, and mechanical structures and texture, is currently in huge demand in the ocean space, agricultural, and food industries.

Many tasks carried out in these industries are performed manually by human operators who, due to the laborious and tedious nature of their tasks, exhibit high variability in execution, with variable outcomes. The introduction of robotic automation for most complex processing tasks has been challenging due to current robot learning policies which are either based on learning from demonstration (LfD) or self-exploration.

Figure 1. Close-up image of an autonomous robot grasping a lettuce based on application of our multi-modal (visual-tactile) robot LfD learning policy.

LEARNING HOW TO GRASP

Most modern robotic systems are based on visual information alone and focus on the handling of rigid objects. Compliant objects pose a major challenge due to their tendency to deform when handled by a robot. For example, humans coordinate the visual and tactile information they receive when they grasp or handle a compliant food object. The merging of visual and tactile information is thus essential if robots are to handle food objects without quality degradation and, at the same time, track and adjust to any deformation that arises. The development of new learning strategies that make use of both visual and force/tactile information in a single control scheme is crucial to enabling robots to learn new and complex tasks and perform them autonomously.

When we reach out to grasp an apple, we use visual sensing to make the necessary adjustments to our hand movements and trajectory in order to assume the "correct" grasping pose immediately before we touch the fruit.

On contact with the apple, we use our tactile sensing, transmitted through our fingers, to regulate the forces we exert on the apple that allow us to grasp, lift and move it. If we were handling a strawberry, we would exert a different set of forces. In robotics, our aim is to endow the machine with the same sensing capability so that it can use both visual and tactile sensing to learn new and complex tasks.

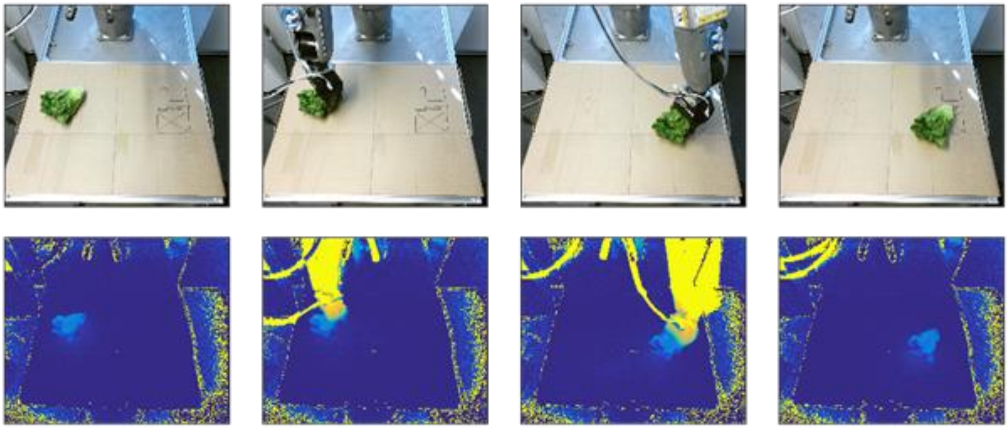


Figure 2: The gripping sequence shown in RGB (top) and depth (bottom) images based on our trained LfD learning policy, where a) an initial image is acquired and the visual state of the lettuce is computed; b) the robot grasps the lettuce according to an action derived from the visual state; c) the robot moves and releases the lettuce to a predefined target point and d) the robot moves out of the way, enabling visual confirmation of the success or otherwise of the grasping sequence.

We present a robust robot Learning from Demonstration approach and methodology in the presence of inconsistent demonstrations from human teachers.

The resulting approach enables the robot accurately to combine visual and tactile sensing to estimate the grasping pose, the correct finger configuration of the gripper, and exactly the forces needed to achieve successful grasping of the compliant object without deforming it.

TEACHING A ROBOT TO LEARN

The learning, or 'brain' development, of the robot is based on supervised learning from demonstration (LfD). In other words, humans demonstrate the task to the robot and then, based on an algorithmic learning policy, the robot is able to infer how to reproduce the task for a variety of compliant objects. Since the robot may be taught by different human operators, who may demonstrate inconsistently, we also developed an approach that enables the robot to learn only from consistent demonstrations. In this approach, the robot automatically rejects inconsistencies in demonstrations by human teachers.

This approach to human-inspired robotic grasping and robot learning enables the learner (robot) to behave more consistently and with less variance than the teacher (human). This approach facilitates the automation using robots of a vast range of tasks carried out in the ocean space, agricultural and food sectors, where current manual methods result in high levels of variation due to the inconsistent approaches of skilled human operators in performing complex processing and handling tasks.

This is human-inspired robotic autonomous grasping of compliant food objects based on a fusion of RGB-D images (for grasping pose estimation) and tactile hand finger sensing (for a stable but gentle grasping of fragile food objects).

GOING FORWARD

Advances in the field of LfD will be achieved by focusing on more complex and challenging tasks in which greater demands will be placed on the human teachers to provide accurate demonstrations. We will also see the use of self-exploration and intermittent learning with the aim of refining learning based on visual and force/tactile sensing.

Ekrem Misimi
Ekrem.Misimi@sintef.no

EKREM MISIMI

Grasping unknown compliant food objects by coupling deep reinforcement learning, generative adversarial networks (GAN) and visual servoing

This learning framework enables the robot to be trained entirely in a simulation setting and, without fine-tuning, to be put to work in the real-world to grasp new and unknown objects. The reality gap from the simulator to the real world is closed using GAN, which effectively tricks the agent into thinking that it is still in the simulator when in fact it is operating in the real world.

In order for a robot to perform complex manipulation tasks on solid objects, on a par with human operators, it is necessary to develop methods that enable robots to learn such skills. Training robots to perform simple tasks such as grasping is important in order to generate a robust learning framework that integrates state-of-the-art concepts taken from Artificial Intelligence (AI) and robot learning. Although the advent of Deep Learning and its application to robot learning has become popular, the requirement for large volumes of training data has become expensive and impractical. To avoid this, in the recent years, we have witnessed increased use of the concept of Deep Reinforcement Learning (DRL) and training in a simulation environment. The drawback of this approach is the reality gap that exists between the simulator and the real world. We close this gap using GAN and visual servoing (VS) to correct for potential failures by the agent to correctly position the gripper in the final target grasping pose.

Figure 1. Grasping of a salmon filet portion. The VS-assisted grasping agent was not presented with any instances of the salmon during training in simulation or the real world, demonstrating that the agent generalizes well to previously unseen objects.

ROBOTS NEED TO BE TAUGHT

Robots are unintelligent and need to be taught to perform simple manipulation tasks. A current, popular robot learning strategy is based on the concept of deep learning. However, agent learning via deep learning involves the acquisition and use of large data sets, which may be costly and impractical.

For this reason, we propose the use of self-exploration and self-learning via deep reinforcement learning as a means of alleviating the need for large data sets. However, the need for such approaches makes it impractical to train a robot agent on a real robot due to the potential for erratic behaviour in early stage training, which can result in damage to the robot and its environment. This consideration has promoted the use of simulated data and simulation environments for use in robot training.

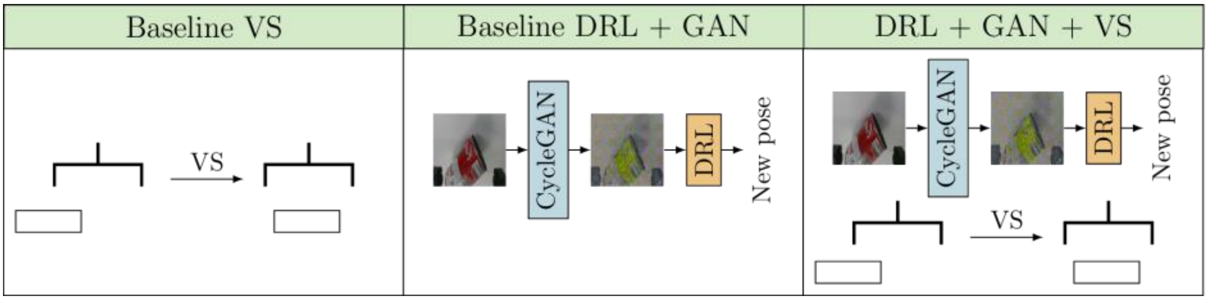


Figure 2. Schematic depiction of our novel approach compared with two alternative baselines, Visual Servoing (VS) and DRL+GAN.

TRANSFER LEARNING

Training in simulation environments with simulated data is very popular, but problems arise when we want to use the agent in the real-world as part of a process called transfer learning. No matter how good the simulator is, there remains a reality gap between real world images and those perceived in the simulation where the agent is trained. As a result, the agent often fails to perform the task in the real world.

Traditionally, this failure is mitigated by task-specific supplementary training of the agent in the real world, a technique known as domain adaptation.

Another recent areas of focus in transfer learning involves making the input images from two different domains appear similar to the system. Such approaches enable an agent to operate in a completely new environment, without the need for fine-tuning. This strategy forms the basis of our novel approach that combines DRL, GAN and VS, where the main function of GAN is to close the reality gap between the simulation and the real world. Our method focuses on the reverse real-to-sim approach, and the trained agent is used without any fine-tuning in the real world.

> *This novel learning framework enables the robot to grasp new, previously unseen, compliant food and other solid objects, demonstrating the effective generalization characteristics of the agent. This framework can serve as a foundation for teaching robots more complex manipulation tasks in the future.*

LEARNING FRAMEWORK

Our novel framework was compared with two baselines, VS and DRL+GAN. The baselines worked well but presented different challenges. For example, VS was successful during the linear servoing process, but problems emerged while attempting to compensate for angular errors during gripper positioning. As we predicted, DRL+GAN worked well overall but frequently failed at the last step due to errors in positioning of the final gripper pose prior to grasping, something which VS effectively compensates for. Our combined method demonstrated that the agent managed to generalize well in the real world. The robot succeeded in grasping the novel, previously unseen, objects with a grasping accuracy of 83%. We have thus demonstrated a robust learning framework that can be used as a foundation for the learning of more complex manipulation skills.

This learning framework can be used for the grasping of novel solid-compliant or non-compliant objects without additional training or fine-tuning in the real world.

THE FUTURE

We envisage the application of our robot learning framework for more complex manipulation skills such as dexterous manipulation, or more challenging tasks such as cutting. The combination of learning from demonstration and self-exploration will be applied to achieve success in connection with more complex manipulation tasks.

SINTEF

Ekrem Misimi
Ekrem.Misimi@sintef.no

ALEKSANDER LILLIENSKIOLD

Grasping at nature's fragile fruit

We propose a dexterous and gentle manipulation tool for the handling of sensitive and fragile food products for use in tasks ranging from harvesting to processing. The tool interacts with products similarly to humans, opening opportunities for simple and intuitive machine training.

Currently, interaction with industrial food products is performed primarily by human hands. Even where purpose-built machines are used, humans retain a vital role due to their innate ability to handle such objects with ‘tender loving care’, using their senses and feelings, and an awareness that food should not be the object of insensitive handling.

This doctoral research project explores aspects of new gripper designs in the domain between specialized tooling and high-level complexity and generality. Our focus is directed at developing human-inspired robotic grasping tools by merging state-of-the-art tactile sensing and space-exploration methods with a set of manageable degrees of freedom, with the aim of developing a tool for use in the harvesting and manipulation of a variety of pliable, fragile, soft-tissue food products.

“An understanding of the implications of interaction processes will yield higher value products and reduce food waste.

CURRENT TECHNOLOGY

The combination of AI and human-mimicking ’hands’ is easy for us to visualize, but the development of such complex technologies remains a task for the future. At present, grasping tools for food item manipulation consist mainly of open-close clutches that are underactuated. This means that they exhibit low dexterity and are this limited in their interactive capability. Current tools (grippers) are designed primarily for specialized tasks, frequently to meet the needs of instant gratification. Some of these grippers can be used for a multitude of tasks but, in general, their highly specialized and tailored designs fail to cope well with the high levels of variance exhibited by individual food items. Such tools are thus poorly adapted to interacting with products for which they are not designed.

The key to useful and efficient robotic interaction with a food item, and the minimization of food waste, is the inherent quality of the product. The handling of an item such as an apple appears to be a simple task. However, if an apple becomes bruised after an impact or squeezing, it will immediately start to decompose. Gentle and sensitive robot interaction maintains the quality of the product and reduces waste.

Figure 1. The robotic handling of food items using current technology. A gripper mounted with sensors along each finger that sense interaction forces and facilitate gentler touch.

Figure 2. Mapping human interactions with objects to establish an understanding of sensor importance during handling actions. This enables a better understanding of contact importance for an AI., creating a key that can be used to weight sensor input when grasping is AI-controlled.

PREHENSILE DEXTERITY BY HUMAN-INNATE APPERCEPTION

This doctoral project has involved a series of experiments focusing on an attempt to understand *'how to transfer human aptitude and instinct to robotic grasping actions'*. We have made the first steps in developing a simple method for weighting the importance of contact between individual robotic fingers and food items. The main research effort utilizes a haptic training and mapping of real human contacts with food objects. Combining these data enables the development of a robotic (AI) 'brain', resulting in a framework within which the 'brain' guides the robot to perform sensitive and gentle handling actions. This approach exhibits clear advantages compared with other recently published methods and baselines.

The haptic mapping of human-like interactions into an AI system enables the 'robotic brain' to contribute with innate, subconscious actions that are difficult to model and predict prior to their discovery.

These results will pave the way for what we will come to expect from robotic grasping tools in the future. Our future research will focus on the development of new grippers and new ways of grasping food items, taking into account sensor needs and placements. Innovative sensory tools will have a major impact on enabling the transfer of human skills and perception to an otherwise highly mechanized world.

By mapping innate human tactile perception and dexterity, and developing an AI 'brain', we can achieve a 'tender loving care' approach to robot interaction with food items, ensuring that robots perceive such items as fragile objects requiring sensitive handling.

In the future, robotic interaction with food objects will be performed by sensitive and gentle grippers that can 'feel' the objects with which they interact. The development of dexterous tools with manageable degrees of freedom and trained by humans, will create opportunities for a generic tool bed that will enable non-specialists to train robots to perform tasks autonomously. About such robots we will truly be able to say that 'handling with care is natural and innate'.

Figure 3. The flexible and dexterous robotic hand of the future, built around sensors and human-inspired robotic interaction trials.

NMBU SINTEF
Aleksander Lillienskiold
Aleksander.Lillienskiold@sintef.no

ALEXANDRE KRUPA

Tracking non-rigid objects using a depth camera

The surfaces of non-rigid objects, such as leafy vegetables and meat and fish pieces, can be completely and accurately tracked using a depth camera and the approach described in this article. Such tracking is very useful during robot interaction.

The automation of the handling of meat, vegetables, seafood and other fragile and irregularly-shaped consumables continues to present challenges to the food processing industry. However, the application of recent advances in robotic gripper technology may make it possible to use robots to sort fruit, vegetables and fresh produce, and for the cutting and slicing of meat and seafood products.

However, this will only be possible if the robotic system succeeds in observing and localizing the shape and surface of the object it intends to manipulate. This can be achieved using state-of-the-art computer vision techniques in combination with recently developed depth sensors. One such approach, described in the following, enables the surface tracking of compliant objects using an approximate CAD model.

SURFACE TRACKING

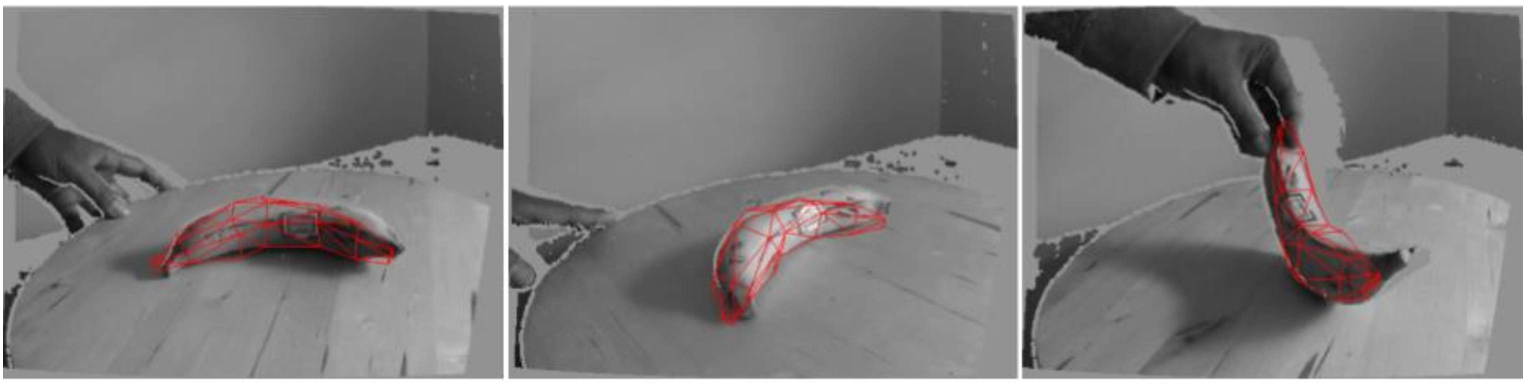
The term ‘tracking’ in this context refers to the continuous identification of the spatio-temporal position of the visible surface of an object, in our case an item of consumable food. The approximate CAD model of the object being tracked is assumed to be known. During processing, the object is observed using a RGB-D camera, which provides colour and depth information about the object in front of it. The depth data are used to fit the deformed CAD model, enabling the entire observable surface of the object to remain traceable.

The robotic manipulation of food objects is an application of major interest to the food processing industry. If robots are to succeed in the efficient cutting, slicing, chopping and deboning of food items, it is important that they can track the surface of the objects they are manipulating. Tracking information enables the robot autonomously to plan where and how it can grasp or cut the object in order to bring about the desired result.

APPLICATIONS

Our research of this method has produced two different outputs, demonstrated in the following using a banana and a pizza. The banana (Figure 1) was tracked using the rigid object tracking mechanism. The model used for tracking was obtained from manual measurements. Despite this, the tracking was quite accurate. The pizza, a non-rigid object, was subjected to significant defor-

Figure 1. A banana being tracked while being moved around.



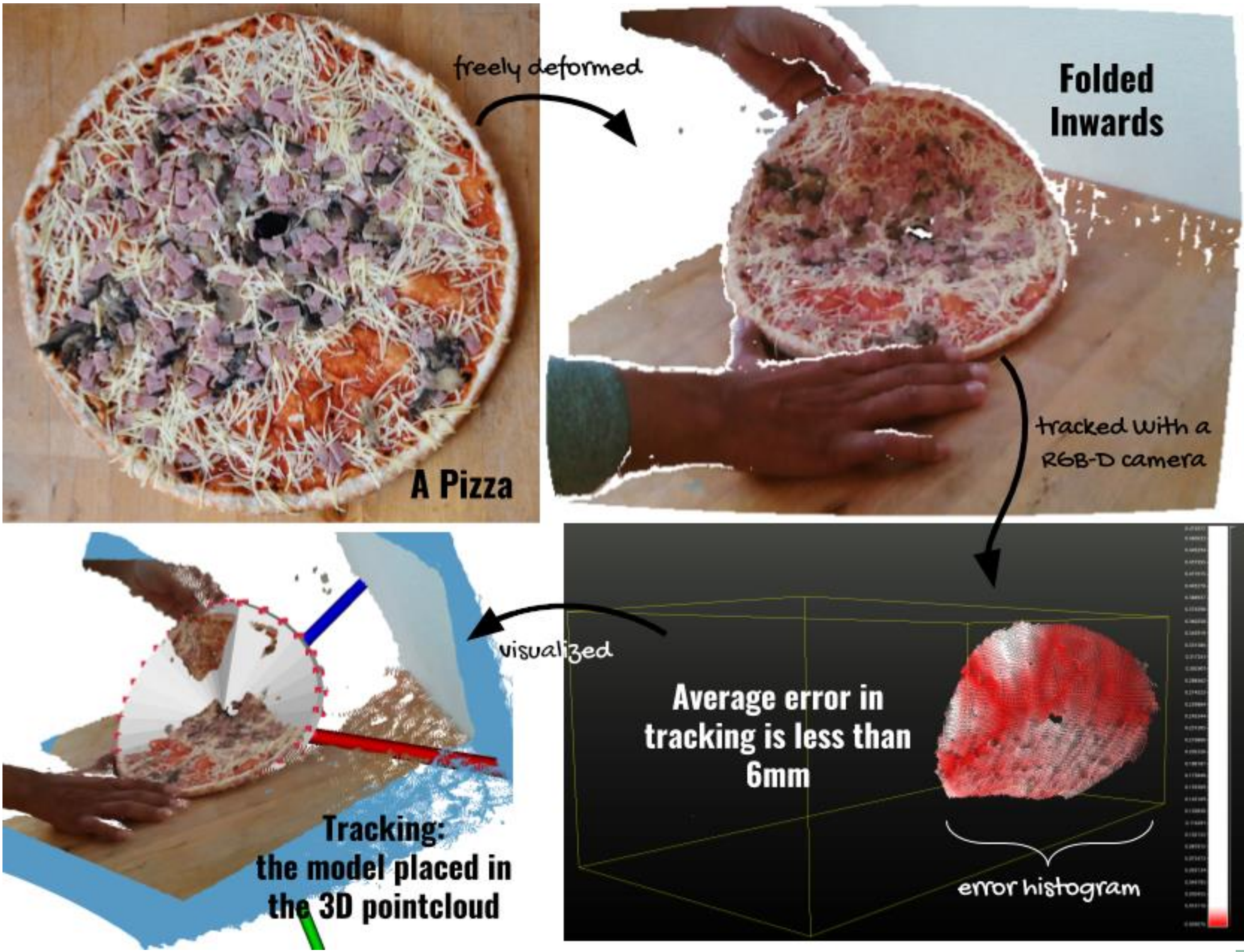


Figure 2. Tracking of a pizza during deformation.

> *If robots are to succeed in the efficient cutting, slicing, chopping or deboning of food items, it is important that they can track the surface of the objects they are manipulating. Tracking information enables the robot autonomously to plan where and how it can grasp or cut the object in order to bring about the desired result.*

mation (Figure 2). The tracking was accurate and consistent. The model deformation closely follows the surface of the pizza as it is deformed. Once the deformed surface is tracked, the output of the tracking algorithm can be applied to robotic applications such as cutting, grasping and squeezing, or the picking up of any type of generic deformable object. Most food objects, including leafy vegetables and meat and fish pieces, are inherently and extremely deformable. Other practical applications of deformable surface tracking include use augmented reality (AR) and robotic surgery.

The effectiveness of this approach has been tested on real and simulated objects, and tracking accuracy is consistently adequate. However, further work should be focused on making the system more robust. It can also be optimized to achieve faster performance.

Alexandre Krupa
alexandre.krupa@inria.fr
Francois Chaumette
Francois.Chaumette@inria.fr

PETTER VEJLE ANDERSEN

Raman spectroscopy for the quality differentiation of pork

Raman spectroscopy can be used for the analysis of key quality indicators in meat, possibly leading to future on-line applications.

The overall quality of consumable meat products is key to consumer confidence, and the consumer's willingness to pay and repeat purchases of fresh meat. Intramuscular fat (IMF) content, pH, water-holding capacity (WHC) and colour are the best indicators of the eating quality of fresh pork. However, these indicators are difficult to measure before the meat is dispatched from the processor. Raman spectroscopy is a vibrational spectroscopic technique with the potential to analyse IMF content, pH and WHC, all as part of a single analysis. The following describes a study that aimed to use Raman spectroscopy to estimate the IMF content in pork loins by recording spectra using intact samples at the abattoir.

QUALITY

In general, the qualities consumers prefer in pork are characterized by moderate IMF content, an ultimate pH of 5.6-6.0, high WHC and a reddish-pink colour. However, most pigs reared in Norway are lean, resulting in low levels of IMF, which in turn are often associated with undesirable deviations in desired pH and WHC values. As a result, a significant proportion of the pork being sold is of unknown and inconsistent quality, leaving consumers to rely on their own knowledge of meat quality when deciding what to buy.

CONSUMER SURVEYS

International surveys have shown that consumers are willing to pay more than twice as much for meat of 'premium' as opposed to 'passable' quality. The pric-

Figure 1. Pork loins.

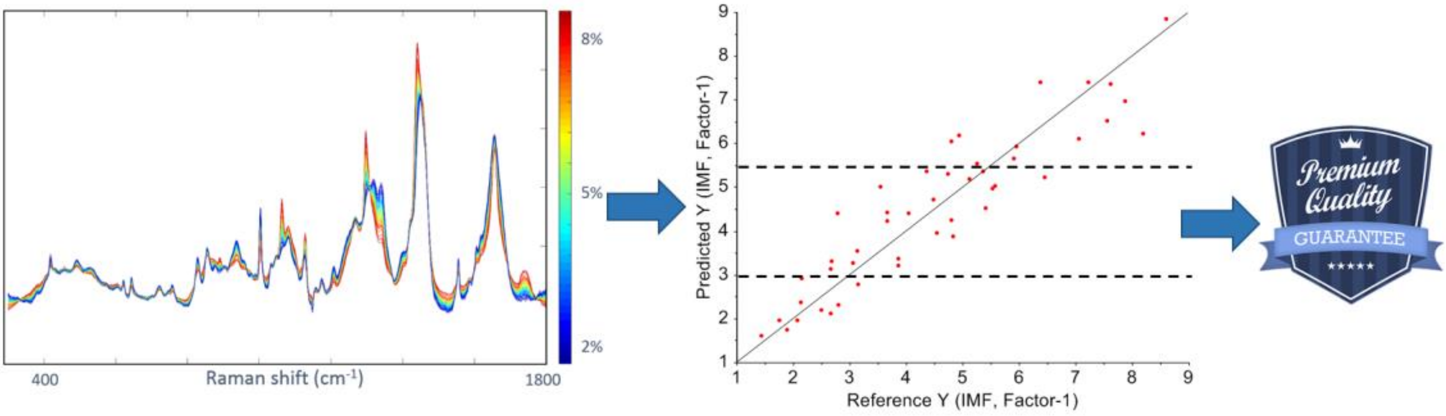


Figure 2. Raman spectra used to estimate intramuscular fat content may contribute to the quality classification of pork loins.

ing of meat according to quality is as yet an untapped instrument available to the Norwegian meat industry, but which has the potential to boost revenues for the sector substantially if systems were put in place to enable quality differentiation. The introduction of objective meat quality assessment methods should provide the cornerstone of such work.

> *Raman spectroscopy may represent the future of objective and non-contact meat quality analysis for commercial applications.*

INTRAMUSCULAR FAT ANALYSIS

IMF content can be estimated successfully both for intact and homogenized pork loins using a Raman instrument equipped with a wide area illumination probe. In this study, the IMF content of the samples ranged from 1.4 to 8.6%, which was considered representative for Norwegian pigs. The PLSR model for intact samples had a cross-validated r^2 value of 0.84 and an error of 0.78%, while the model for homogenized samples had an r^2 value of 0.94 and an error of 0.47%, using only one factor. These results demonstrate that the method is clearly adequate for the classification of meat into different quality grades.

MEAT QUALITY

The results from this study, involving the introduction of a new application for Raman spectroscopy in meat quality analysis, should encourage further research and development into expanding the application of this useful technique in other aspects of the food industry.

INDUSTRY APPLICATIONS

Before Raman spectroscopy can be implemented in the meat industry, more research is needed to refine our calibration models both for IMF content and other quality indicators such as WHC and pH. There is also a need to develop robust instruments that can meet the specific requirements and tolerate the working conditions prevalent in the meat industry.

Nofima

Petter Vejle Andersen
Petter.andersen@nofima.no

JENS PETTER WOLD

On-line estimation of dry matter and fat content in production blocks of cheese by NIR spectroscopy

Modern dairy factories produce thousands of cheese blocks each day. In order to achieve true time control of the production process, we evaluated the use of NIR spectroscopy for the on-line determination of fat and dry matter in such cheese blocks.

Dairy production involves a range of complex processes in which the quality of the end-product depends on raw material variation as well as process settings. Achieving desired end product quality is key to both profitability and the prevention of waste and low-grade products. To control such processes it is vital to measure relevant quality indicators in real-time during processing so that discrepancies can be identified and the process adjusted.

A modern dairy factory can produce thousands of cheese blocks every day, but to date no tools exist for the on-line determination of the chemical composition of such blocks.

> *On-line NIR spectroscopy enables the determination of fat and dry matter content in blocks of cheese during processing.*

ON-LINE ANALYSES

In this study we evaluated the use of NIR spectroscopy as a tool for the on-line determination of fat and dry matter content in cheese blocks measuring approximately 40×30×12 cm. Three different sampling modes were tested, involving scanning reflection, scanning interaction and imaging interaction measurements. NIR measurements were made in a pilot plant at three different production stages: 1) on fresh cheese blocks before pressing, 2) after pressing and 3) after salting.

A total of 160 cheeses from ten different production batches were measured. Fat and dry matter content were determined at a local laboratory. Partial least squares regression (PLSR) was used to obtain calibrations between NIR values and chemical composition.

QUALITY INDICATORS

Large blocks of cheese constitute one of the most important products of dairy production, and fat and dry matter content are among the most important end-product quality indicators. During cheese-making, both the raw material (milk) and the various processing steps will influence the final chemical composition. The amount of dry matter also determines the cost-efficiency of the process, so it is important to steer the process towards achieving the desired end-product quality.

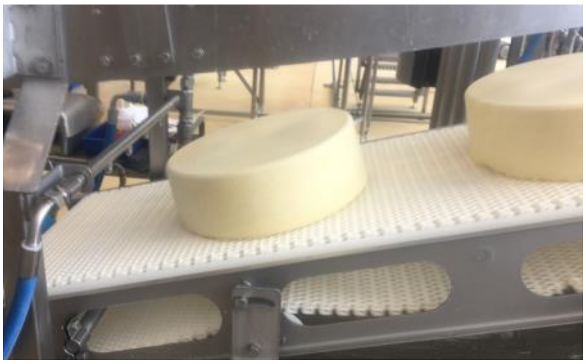


Figure 1. Cheese blocks in production.

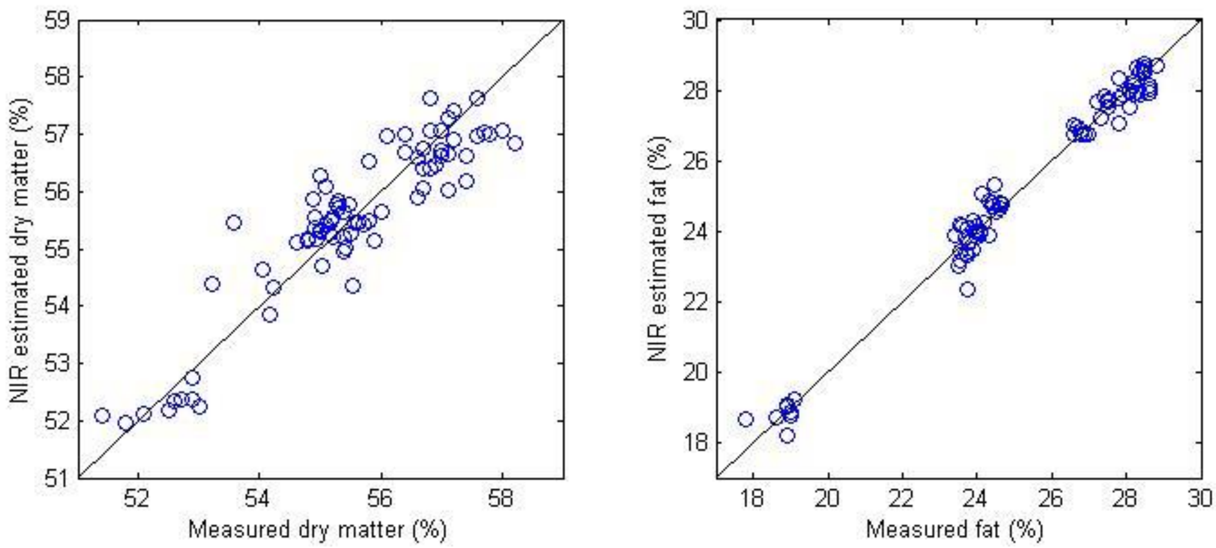


Figure 2. On-line NIR predicted plot versus measured values for dry matter (left) and fat content (right) in cheese blocks.

OBSERVATIONS

NIR scanning reflection and interaction instruments enable the determination of fat and dry matter content in cheese blocks with an accuracy of about ± 0.53% and ±0.63%, respectively. This is comparable to what can be achieved using a laboratory instrument on homogenized cheese. This means that the surface chemistry of the blocks is representative for the average chemical composition of the blocks as a whole.

We also observed that it is possible to use NIR measurements to predict fat and dry matter content in pressed and salted cheeses at an earlier stage in the process, provided that the pressing and salting processes are consistent from day to day.

IMPROVED CONTROL

The fact that NIR spectroscopy can determine fat and dry matter in cheese blocks at an early stage in the cheese-making process enables improved control of the process as a whole. Quality discrepancies can be detected and the process adjusted accordingly. Cheeses exhibiting values outside quality specifications can be used for other products.

INDUSTRY 4.0

Since standard industrial NIR instruments can be used for this application, it is possible for dairy companies to implement this approach today. The use of such process analytical technology is expected to increase as food companies move towards adopting the Industry 4.0 standards.

> *Measurements using on-line NIR spectroscopy enable improved control of the cheese-making process, making it possible to detect deviations from desired end-product quality early in the process.*

Nofima

Jens Petter Wold
Jens.petter.wold@nofima.no

JENS PETTER WOLD

Raman spectroscopy for the estimation bone mineral residues in mechanically-deboned chicken meat

Bone residue, measured as %calcium or %ash, is a strictly controlled quality parameter of mechanically -deboned chicken meat (MDCM). Raman spectroscopy was developed for use as a tool for the rapid estimation of this key parameter.

Mechanical deboning is the optimal process for the recovery of protein-rich mince from animal carcasses. It typically involves the grinding of carcasses to create a meat-bone slurry, which is then passed through a separation system that separates the meat from the bone residues. According to the European food safety authorities, one of the quality control parameters for mechanically separated meat is its calcium (or ash) content, which is effectively an indicator of residual bone. Currently, no analytical tool is available for the rapid measurement of calcium or ash levels in meat and bone mixtures in commercial production settings.

BONE GRANULES

Depending on the process settings and carcass composition, fine granules of bone may find their way into the MDCM. For this reason, the bone content of such meat is commonly controlled by setting calcium or ash limits. Current analytical procedures used to determine calcium and ash contents in mechanically separated meat are based on methods such as titration and combustion, respectively. However, these methods are time consuming and are normally carried out off-line on a few grams of sample that are assumed to represent an entire production batch. As such, they cannot be used directly to measure calcium and ash contents in a large-scale industrial production setting.

RAMAN SPECTROSCOPY

In the present study we have developed the Raman spectroscopy method into a tool for the rapid estimation of residual bone content (ash and calcium) in MDCM. In contrast to existing methods such as titration, our approach is rapid and requires only minimal or no sample pre-treatments. The tool can be further developed and adapted for use on production lines to enable the optimal recovery of MDCM, while at the same time maintaining permissible calcium or ash levels.

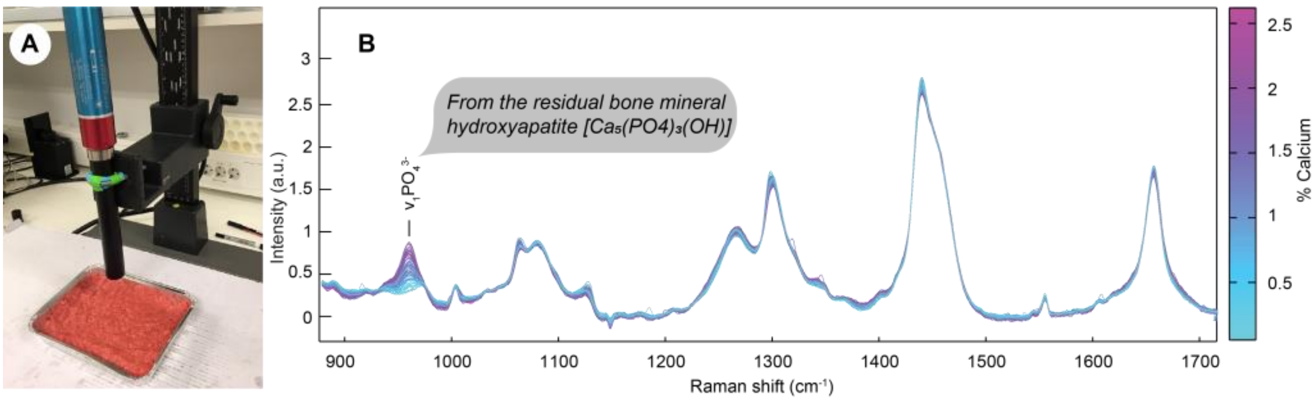


Figure 1. EMSC-corrected Raman spectra of the 79 samples taken after the mechanical deboning of chicken. All spectra are colour-weighted according the % calcium.

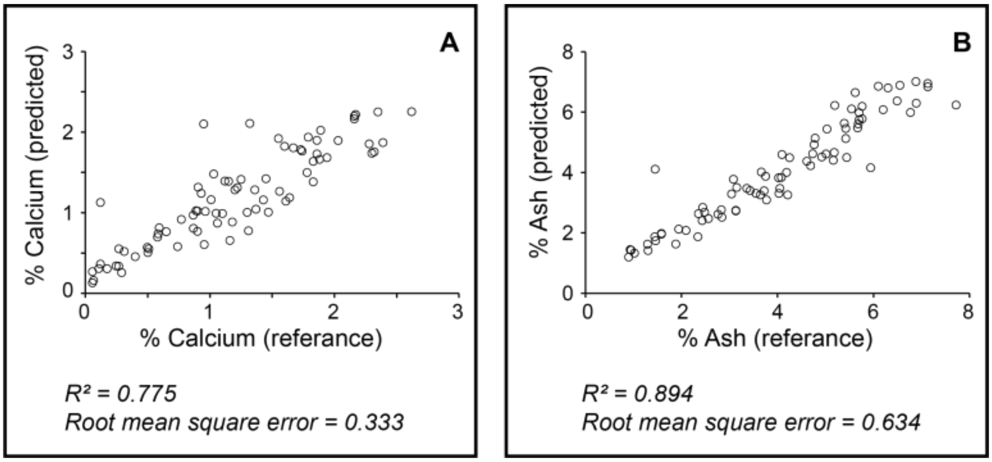


Figure 2.
PLSR correlation plot of calibration for the determination of % calcium (A) and % ash (B) using EMSC-corrected Raman spectra.

SAMPLE ANALYSIS

Raman spectra were acquired for 79 meat-bone mixture samples from four different production days involving industrial mechanical chicken deboning (Figure 1). Principal component analysis (PCA) of the spectra revealed qualitative variations between the samples (Figure 2), which are attributed, in addition to differences in calcium (or ash) content, to variations in fatty acid composition.

> *In EU member states, mechanical deboning is normally carried out by setting separation pressures below 100 bar for the production of low-pressure, mechanically-separated, meat. However, in the absence of a process control tool, such arbitrary separation force settings will not always guarantee either a permissible level of calcium or optimal yield. The approach presented here, based on Raman spectroscopy, enables rapid estimations of the levels of calcium residues in deboned chicken meat.*

Raman-based partial least squares (PLS) regression models were developed, based on pre-processed spectra, in order to estimate ash and calcium content. The prediction model based on EMSC (Extended Multiplicative Scattering Correction) corrected Raman spectra afforded the lowest root mean square error of cross-validation and the highest coefficient of determination (Figure 3).

A PROMISING TECHNIQUE

This study represents the first application of Raman spectroscopy for the estimation of calcium and ash content in bone and meat mixtures taken from THE mechanical deboning of chicken. The technique offers potential as a commercially feasible on- or at-line tool for the quality management of mechanically deboned chicken meat and similar food matrices.

THE FUTURE

Further work is required to expand the calibration data set and optimize the data acquisition set-up with the aim of developing robust prediction models for application in industrial process management.

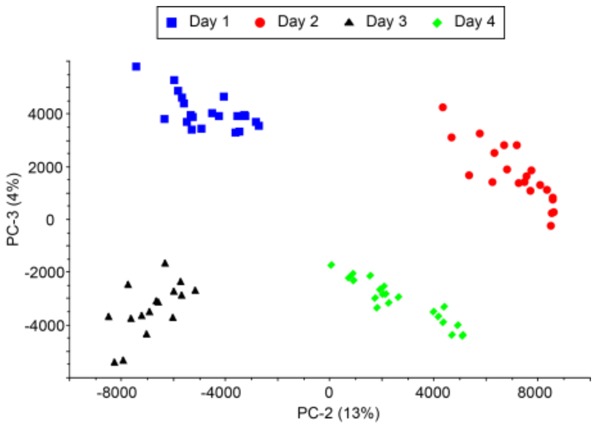


Figure 3. Score plots from principal component analysis of the Raman data obtained for 79 samples collected from four production days of mechanical chicken deboning.

Jens Petter Wold
Jens.petter.wold@nofima.no

MAITRI THAKUR

Supply chain traceability of animal hides

The processing of animal hides to make leather products makes them one of the most important rest raw materials (plus-products) derived from the meat industry.

The animal hide supply chain is made up of producers (farms), slaughterhouses, hide processors and tanneries. A study carried out in cooperation with Norilia Skjeberg found that large volumes of data are generated in this supply chain, but that an information gap exists due to the lack of comprehensive product.

Information gaps can be bridged using a traceability systems that will also contribute to better quality products and more environmentally-sound production processes. Such systems could also benefit the monitoring of animal health.

ANIMAL HIDE PRODUCTION IN NORWAY

Norwegian farmers spend a great deal of time safeguarding the welfare of their animals. Farms are small, and farmers are highly knowledgeable about animal husbandry and welfare. Norwegian cattle hides are world-class and are used in the manufacture of luxury handbags, belts, shoes, and upholstery. In 2015, Norwegian hide production amounted to about 10,000 tons, and a total of 293,371 cattle hides were produced in Norway in 2017. Norwegian hides are renowned for their high quality, and farmers can earn as much as EUR 30 per animal in the global tannery market. Luxury handbags that may typically cost about USD 470 from factory outlets may cost consumers up to USD 4,000.

TRACEABILITY

Many global and Norwegian brands such as Gucci, Bolia and Dressmann are concerned about the impacts of leather production and ethical sourcing, and are demanding higher levels of traceability. The multistep and globalized nature of leather supply chains makes it difficult to define sustainability criteria. Traceability systems for animal hides are proposed as a tool that can drive leather sustainability, and their development is being driven by consumer demands for sustainable and ethically-sourced leather.

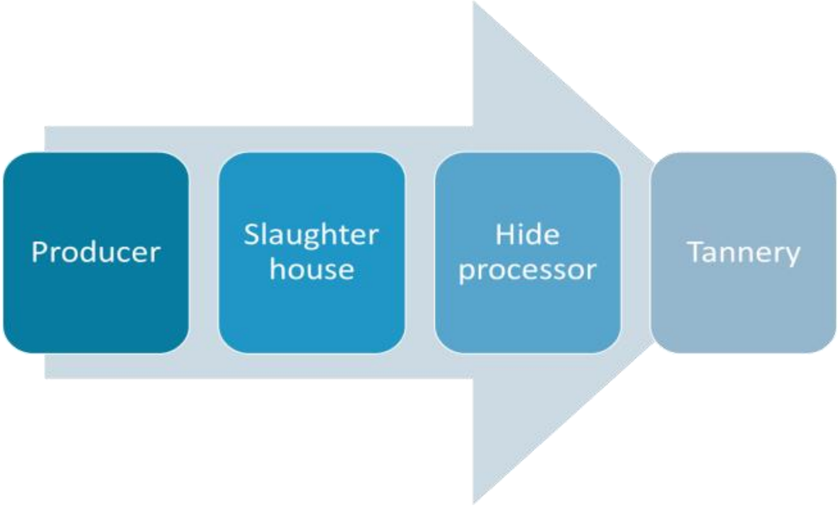


Figure 1. Schematic of a typical cattle hide supply chain.

Figure 2. An example of a laser-tagged hide taken from tests carried out in collaboration with Norilia.

> *A traceability system is useful for keeping track of hides on their way from the farm to the tannery. It also enables its users to authenticate hides by linking them to specific farms.*

A study was carried out to map the hide supply chain using process mapping methodology, and a traceability system proposed to track the hides from the farm to the tannery. Data capture points were identified, and a variety of tagging methods such as RFID, dot peening and laser tagging were evaluated.

FINDING THE RIGHT TECHNOLOGY

Animal hides encounter a number of challenging environments on their journey from the farm to the tannery, and it has been a difficult task to identify the right tracking technology. Many of the tags were lost during the process or became illegible after tanning. Tracking using RFID technology provided the best results, and is currently probably the best tracking approach up to arrival at the tannery. However, the only tagging technology that remained legible after the tanning process was laser markings.

The tracking of animal hides is useful because it enables users to authenticate hides by linking them to specific farms. Data generated during supply chain quality inspections can be used as feedback to the producer and used to improve farm handling, transport and slaughter practices.

SINTEF

Maitri Thakur
maitri.thakur@sintef.no

PIETER VERBOVEN

Porosity maps provide an 'airy' image of fruit and vegetables

3D X-ray based porosity mapping reveals the internal structure of your product.

The porosity of a fruit or vegetable is a measure of the air contained inside the product. It determines how, and to what extent, it dries out, and also influences responses to changing or controlled atmospheric conditions.

Horticultural products transport the oxygen they require and waste materials, such as carbon dioxide and water, through their pores. Porosity thus also exerts an influence on a number of changes that result from oxygen lack or the inadequate disposal of waste materials. Examples of such changes include the internal brown discolouration observed in apples or celeriac.

UNDERSTANDING POROSITY

Porosity in fruit and vegetables is very heterogeneous. Pore development may be very open or almost entirely absent. Gas transport is more difficult in those parts

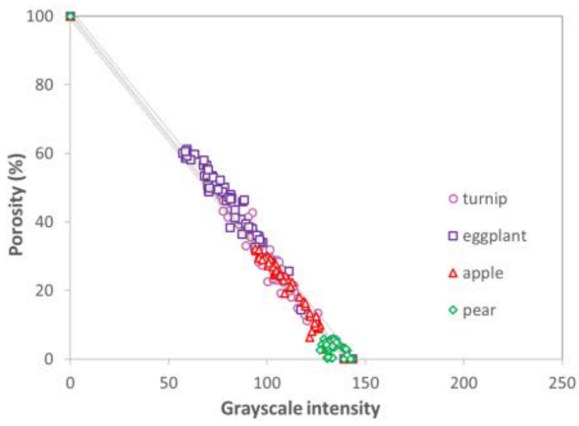


Figure 1. Correlation between the grayscale intensity of CT images and actual porosity (%) of eggplants, turnips, apples and pears.

of the product that contain small pores. It is thus very important to obtain a quantitative visualization of porosity throughout the product in order to obtain a better understanding of respiratory gas transport.

KU Leuven has demonstrated that X-ray CT (Computed Tomography) is an effective method for the accurate and non-destructive mapping of whole fruit porosity based on a simple model using the correlation between CT images (grey shades) and porosity. The correlation is proven to be valid for a wide variety of products, demonstrating its broad application potential.

Localisation of a product’s dense tissues enables a better understanding of why certain patterns of abnormalities or symptoms occur in particular products or cultivars. This will help us to better understand and

The new porosity measurement technique is convenient and easily applicable for a variety of other products. “

optimize storage conditions and shelf life, and design appropriate MA packaging.

A non-destructive method of porosity mapping is a first step towards the development of sensors for in-line quality assessments of porosity on sorting lines with a view to storability. Porosity maps of Jonagold apples, Purple-globe eggplants, Purple-top turnips and Conference pears (Figure 1) demonstrate that fruits and vegetables exhibit very different internal structures. Differences in porosity in specific tissues can be accurately predicted and visualized. On average, eggplants are the most porous (41.8 ± 1.0% porosity),

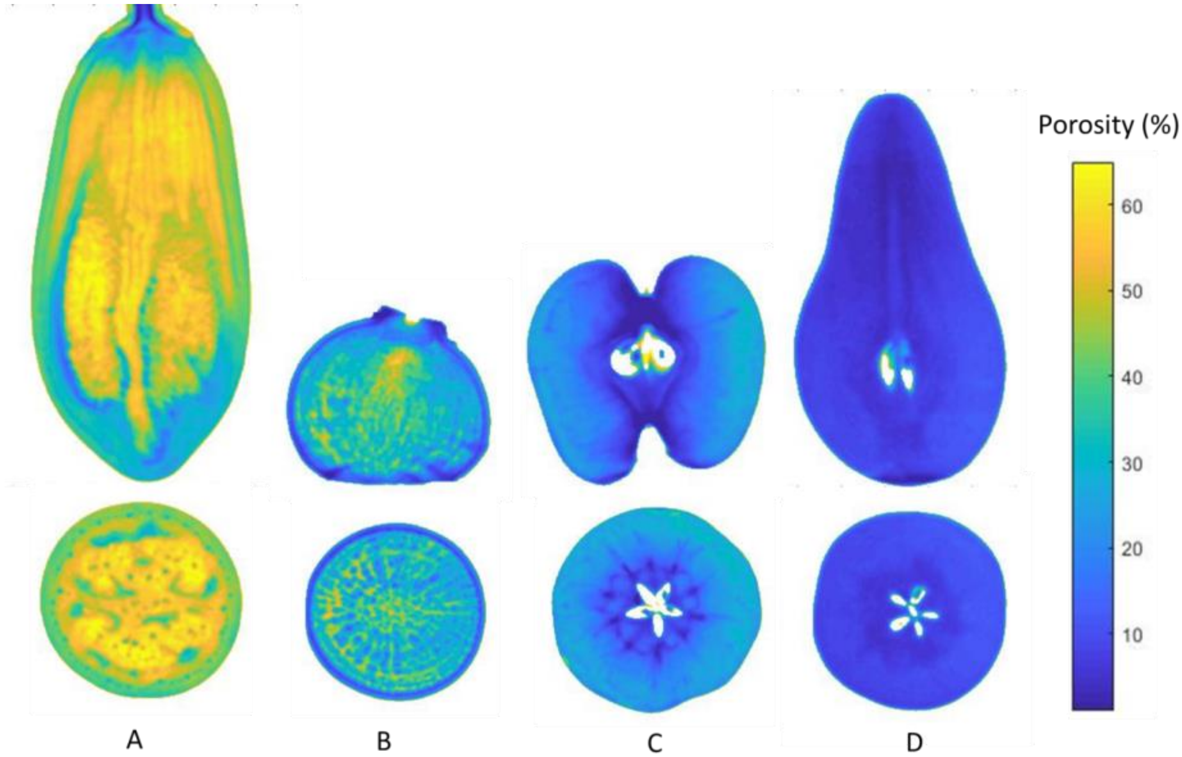


Figure 2. Transaxial (X-Y, top) and coronal (X-Z, bottom) slices of eggplant (a), turnip (b), apple (c), and pear (c) porosity maps translated from grayscale CT images.

> *The technique will help us to better understand and optimise storage conditions and shelf life, design appropriate MA packaging, and will form the basis for on-line internal quality inspections.*

followed by turnips (23.3 ± 3.4%), apples(19.7 ± 1.1%) and pears (4.0 ± 1.6%).

The highest porosity values are found in the cores of eggplants and turnips (45 to 65%). Towards the surface of these vegetables, flesh porosity decreases to between 30 and 45%. Some zones exhibit a porosity of less than 10%. In apples, porosity increases from the core to the surface, varying between 10 and 30%. The porosity of a pear is very low and consistently less than 10%. The most dense tissue is found in the core.

> *Localisation of a product's dense tissues enables a better understanding of why certain patterns of abnormalities or symptoms occur in particular products or cultivars.*

The new porosity measurement technique is more convenient than many existing methods because it now requires only a juice reference scan and a homogeneous water sample to create porosity maps of other horticultural products. Based on the simple linear correlation, it is relatively quick and easy to extrapolate measurements to other products.

THE FUTURE

The porosity maps will be of considerable value in achieving a detailed understanding of the transport of metabolic gases and water during post-harvest handling and storage. This in turn may promote the development of non-destructive on-line porosity measurement techniques for use during internal quality inspections.

KU LEUVEN

Pieter Verboven
pieter.verboven@kuleuven.be

MORTEN LIND

Intermediary Real-Time Trajectory Interpolation using Cubic Hermite Splines

Real-time trajectory interpolation enables a Python-based sensor-integrating application to control a Franka Emika robot in real time. Application development in Python is much faster and easier than in C++.

When robot motion generation for a processing task relies on real-time sensor feedback from the processing tool, the motion must, by its very nature, be generated at the temporal micro to meso level in real time. Some open robot controllers allow real-time trajectory feeding at the micro level, and these represent obvious candidates for such real-time sensor-based motion applications.

If a given application only requires real-time trajectory generation at the meso level, interpolation may be used to alleviate the application from the micro real-time requirement of the robot controller. This, in turn, opens for freedom of choice concerning the application platform, framework and programming language.

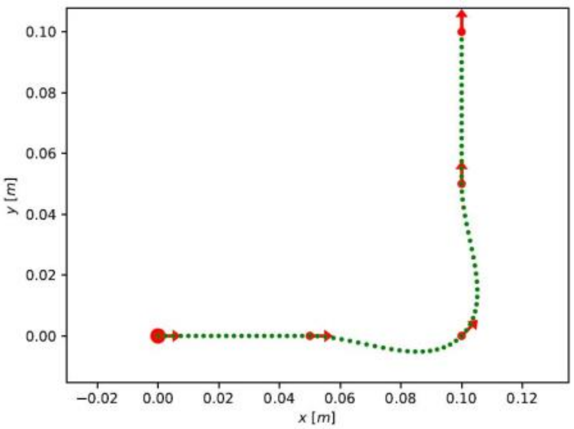


Figure 1. Illustration of mesoscopic interpolation points in red, defining a smooth trajectory. In green are shown the microscopic interpolation points that are sent to the robot controller, obtained by Cubic Hermite Splining of the mesoscopic points.

ROBOT CONTROLLER

The temporal micro level of control in a robot is 1 ms or lower, down to the control of current in the servos of the order of 10 µs or 100 µs. Good contact control under demanding conditions requires 1 ms, or better, in the sensor to servo control loop. However, for tolerant control under compliant conditions and moderate speeds, 10 ms may suffice. We may define the meso level of real-time control from 10 ms to 1 s. Macro level real-time control is at the level of 1 s and above, and may adequately be called real-time task generation.

> *Performing tough robot motion generation stuff with an adequate level of coding effort.*

A smooth real-time trajectory interpolator has been developed based on Cubic Hermite Splines and implemented in C++ to address the direct need of the robot controller. This “trajectory frequency scaler” ensures the micro level requirement of the robot controller, while imposing only a meso level real-time requirement on application-oriented, sensor-based motion generation.

INTERPOLATOR

The interpolator is an independent, network-connected and long-lived process that keeps the robot controller operative in its real-time modus over several application runs.

For example, the cutting of meat is a fairly complex physical process, but the interaction is fairly compliant, involving good real-time tolerance. Sensor integration for motion generation may thus adequately be performed at the meso level.

Thus, in order to develop an entire control application with only a meso level requirement for the sensor to servo control loop, it is possible to switch from the complexity of C++ code to something much more flexible, such as the interpreted language Python. However, the robot controller may still need to be fed 1 ms interpolated trajectory points.

In experimental and development settings, the interpolator plays a key role in maintaining operation of the robot controller modus, because restarting the robot controller system generally requires a certain degree of manual interaction and waiting time.

“This framework enables robots to be taught complex motion trajectories for advanced manipulation tasks such as meat cutting with relatively little coding effort. This is important for fast development cycles during research investigations.

SOFTWARE

A software program has been developed that uses Cubic Hermite Splines to generate smooth trajectories at resolutions of 1 ms, which are fed to the robot controller in real time. At the other end, the program listens for a network connection from a sensor-based application motion generator, which is required to feed a trajectory at the meso level of resolution (10 ms to 100 ms), also in real time. The software performs well for sufficiently smooth application trajectories.

The software is yet to be used outside experimental settings. However, experiments using it in a Python-based motion generation framework indicate that the principle is sound.

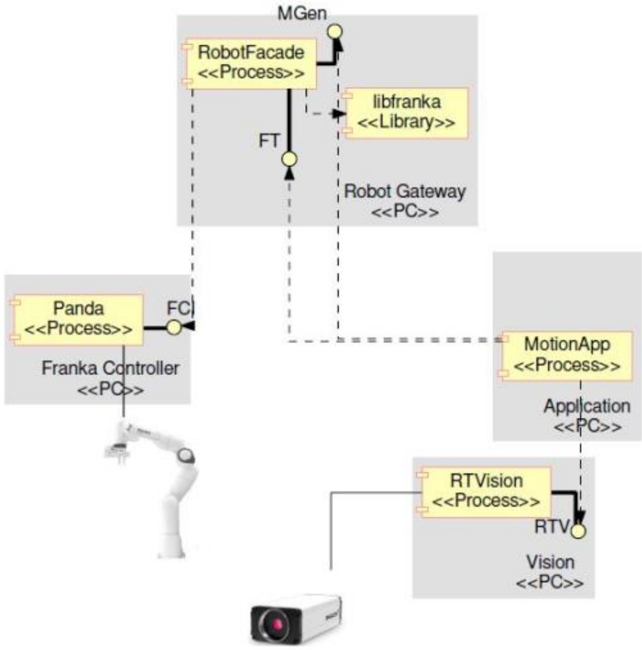


Figure 2. Illustration of the deployment of components surrounding the interpolator (called RobotFacade, top of diagram).

NETWORK COMMUNICATION

It is observed that network communication malfunctions may distort communication with the robot controller, sometimes leading to divergence between the generated trajectory and the actual robot position. This in turn may result in large accelerations in the robot arm, exceeding permitted limits. Current activity is focusing on the prevention and handling of such malfunctions in network communication.

The prevention and mitigation of network malfunctions are achieved using appropriate computing and network hardware, and by optimizing the real-time performance of the software.

Malfunction management involves monitoring the robot in its divergent, post-trajectory, state, and then smoothly transitioning it back to its planned trajectory.

Morten Lind
morten.lind@sintef.no

MAITRI THAKUR

Information sharing strategies in the whitefish supply chain

Information sharing constitutes a key supply chain strategy for reducing uncertainty and is vital to supply chain coordination and efficiency. All actors can benefit from sharing relevant information in a timely manner.

Whitefish supply chains are complex in nature due to seasonal variations, high levels of supply uncertainty, and rapid quality deterioration due to temperature variations and inconsistent handling practices. In Norway, most wild cod catch is exported as lower-value products in salted, dried or frozen form. In-season processors typically buy fresh whitefish from coastal vessels, and in the off-season from sea-going vessels that supply frozen fish. This lack of vertical integration appears to limit information sharing between the vessels and the processors. Limited amounts of data place constraints on decision support at the processing stage, which in turn limits data flow upstream in the value chain.

INFORMATION FLOW

The Event-driven Process Chain (EPC) technique was used to develop an AS-IS model of the whitefish processing chain, describing both current status and information flow practices between fishing vessels and the processors. Case study methodology was used to analyse the entire whitefish supply chain, including fishing and processing operations. Information on data management and planning practices was acquired by means of semi-structured interviews.

The management of food supply chains is particularly complex due to an intrinsic focus on product quality. Various motivating factors for information sharing among supply chain actors are mentioned in the literature, including legislative requirements, efficient product recalls, the optimization of business processes

Figure 1. Fishing for whitefish.

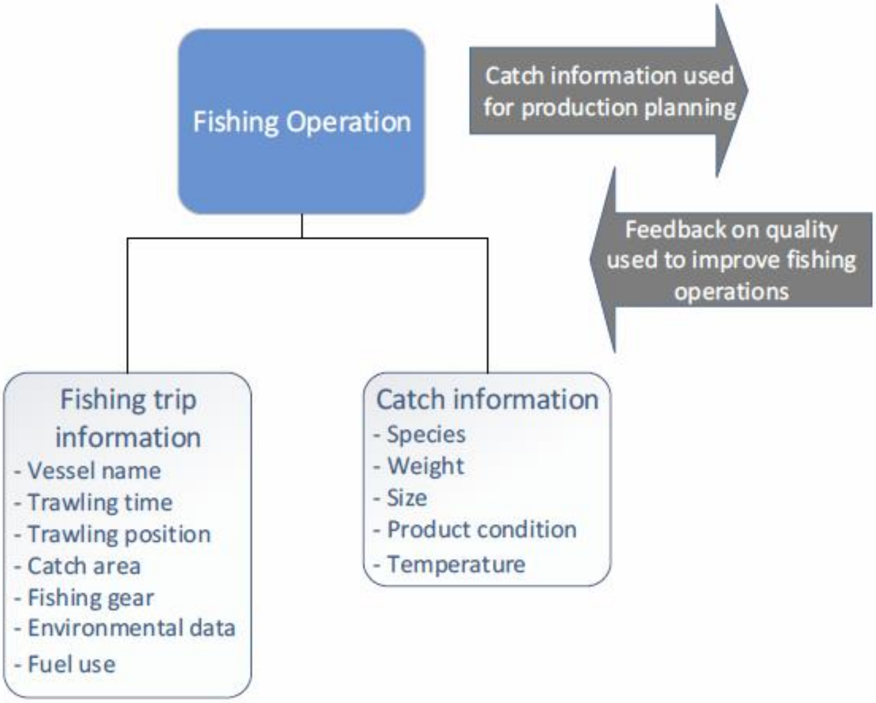


Figure 2. Proposed schematic for information exchange in the whitefish supply chain.

> *The issue is how to share the right information at the right time and in the right format for the mutual benefit of the entire supply chain, as well as individual businesses.*

and product differentiation. In recent years, several studies have investigated the value of information sharing and its impact on supply chain performance.

Information from individual fishing trips could be better exploited to improve fishing operations and production planning, but is not being used optimally. Moreover, detailed information on catches such as temperature conditions and product status, which is available onboard vessels, is not being shared with processors. If such information were available at an early stage, processors could use it to improve production planning decisions.

CONSIDERING QUALITY

Information from individual fishing trips and on product quality can be used to optimize operational decisions such as selection of the best areas to fish. Information linked to individual operations is already available in existing systems such as eCatch and TrackWell. Product quality information is held by the processors in their internal databases.

In terms of production planning, improved information sharing may also contribute to the process of product differentiation in sales planning. Access to real-time catch and fleet information can be used to harmonize the fishing strategies of multiple vessels and to support decisions on vessel location and delivery times. Historical and season-specific information about catch areas and factors affecting catch quality can be used to improve fishing strategies.

Further work is needed to investigate factors such as the willingness among industry actors to share supply chain information, and the barriers that prevent optimal sharing. Such work will also serve to identify new opportunities for both fishermen and the processors. In the absence of vertical integration, new research should explore the concept of vertical coordination, by which in the future, fishermen and processors will willingly share information for their mutual benefit.

Maitri Thakur
Maitri.Thakur@sintef.no

HEIDI DREYER

Integrated planning in whitefish supply chains

Information sharing during integrated supply chain planning promotes reductions in uncertainty, resulting in improved supply chain performance among whitefish processors. Many NTNU research scientists and students have been working on this issue as part of the iProcess project.

Throughout Norwegian history, the fishing industry has provided a foundation for people's livelihoods and culture, and has made a significant contribution to the country's economic growth, export revenues and industrial innovation.

Despite declines in profitability, facility downscaling and job losses, the industry has succeeded in promoting product and process innovation, and expanding its market reach. However, the industry operates in a highly global and competitive market that constantly demands higher levels of performance, efficiency and market responsiveness. In terms of information sharing, performance can be improved by optimal supply chain operations management that guarantees supply and demand alignment by applying novel integration and coordination mechanisms.

MASTER'S STUDENTS

Many students at NTNU have written their Master's theses on research topics linked to the iProcess project. Such topics have included the impact of supply and demand uncertainty on supply chain operations, and the ways in which supply chain planning can improve performance, with a focus on the role of information and technology. This work has resulted in a proposal for a process design for integrated tactical supply chain planning.

SUPPLY UNCERTAINTY

The scientific literature continues to highlight the negative impact of supply uncertainty on supply chain performance, focusing on factors such as inefficient capacity utilisation, the risks and costs associated with over- and understocking, unreliable raw materials availability and inadequate service levels. Supply chain planning (SCP) aims to mitigate uncertainty by coordinating and integrating key business processes throughout the supply chain from raw materials procurement to production, distribution and sales, and by managing supply and demand. This is particularly relevant in the whitefish sector.

The iProcess project has identified and ranked the factors that impact on supply uncertainty and has proposed a method by which whitefish processors can improve their ability to boost capacity utilisation, service levels, product availability and profitability. Furthermore, our analysis demonstrates high demand sensitivity to price mechanisms, and recognises the importance of access to updated information about raw materials quality and market behaviour in both the short and long term.

SUPPLY AND DEMAND

We have proposed integrated tactical planning design strategies based on an analysis of supply and demand uncertainty. Such strategies will contribute towards integrating suppliers and customers in the planning process, and promote the application of updated information and technology in planning support. Moreover, suppliers can involve themselves in development programmes that

> *The volume of information flow, often in disorganised forms via customer contacts, phone calls, WhatsApp chats and suchlike, forces you to filter and extract the information you need to make good decisions. You have to accept this market dynamic and sporadic trends.*

promote collaboration and commitment, and which contribute to the formulation of contractual terms containing collaborative incentives such as price mechanisms and risk sharing. The use of information dashboards in support of market-related decision-making may also improve performance.

Tactical planning at supply chain level is particularly important in environments characterised by long-term uncertainty, in which decision-makers struggle to predict changeable internal and external factors such as seasonality and the imposition of quota systems.

A GLOBAL CHALLENGE

Globalisation, outsourcing, the application of Lean production principles and high levels of competitiveness have made supply uncertainty a key factor, particularly in sectors such as the food industry, which derives its raw materials from natural resources but has only limited storage capacity. With the exception of parameters such as supply quantity, quality, lead time, price and product information (raw materials size and type), less is known in terms of supply uncertainty about inputs such as probabilities, severity and the contextual factors that would make planning more efficient and robust.

NTNU

Heidi Carin Dreyer
Heidi.C.Dreyer@ntnu.no

JØRN VATN

Managing supply uncertainty in operational production planning – a whitefish case study

Managing fisheries supply uncertainty using formal stochastic programming methods demonstrates how more robust production planning can boost profits.

PRODUCTION PLANNING

The concept of operational production planning focuses on the issue of establishing optimal production plans. A production plan specifies the products in question, the production lines utilised, and the allocation of resources such as personnel and machinery. In the fisheries sector, key factors such as the volumes, quality and distribution of production raw materials, the fish species, are unknown when planning is taking place.

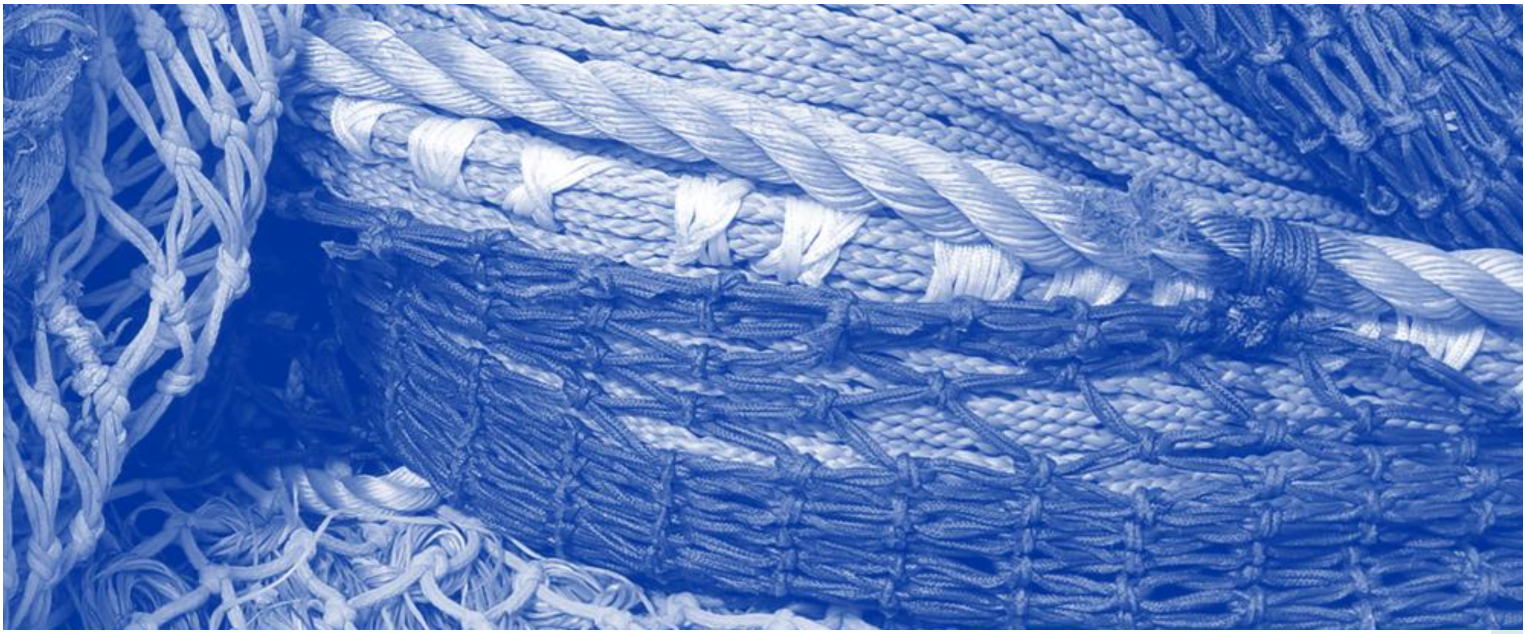
A production plan that is optimal for high catch volumes may be very costly in low catch scenarios. Stochastic programming enables the preparation of robust plans that maximise profits in spite of catch size and other uncertainties.

PROGRAMMING

This research project explores a stochastic programming approach to operational production planning designed to take supply uncertainty into account. Focus during the initial problem structuring phase is directed at identifying decision variables such as the content of the various execution plans, the number of hours spent following each plan, the number of production line workers assigned and whether to pay them overtime. The next phase involves the operationalisation of the various uncertainty factors, for example by assigning probabilities to a variety of possible scenarios. One scenario involves a discretisation of supply with an added probability, such as a high volume catch, a high proportion of high quality raw materials, and a medium proportion within the catch of the species haddock and pollock.

SUPPLY UNCERTAINTY

In order to reduce supply uncertainty, a statistical prediction model has been developed, involving operations planners addressing the optimisation of infor-



> *A systematic approach to uncertainty enables the preparation of robust production plans in which opportunity and risk are balanced to provide optimal long-term performance.*

mation about vessel type, fishing gear, weather etc., in order to improve catch prediction and reduce uncertainty. It is known from the literature that treating uncertainty explicitly during optimization outperforms an approach in which uncertain variables are replaced by their expected values.

To simplify the modelling, we have directed our main focus on key activities such as production line filleting and cutting. Our case study has considered only the processing of cod, and future models will be required for species such as haddock and pollock. Instead of considering the flow of raw materials along the production line, the modelling has addressed a limited number of so-called production plans, using the number of hours per day during which a given production plan is implemented as the main decision variable.

HIGHER PROFITS

Our study shows that the stochastic programming approach yields a 70% increase in expected profits compared with cases in which uncertainty is ignored. Refining the model by the addition of discretisation levels during scenario building yields an even better result, but requires more complex modelling.

The catch prediction model developed in this study is able to explain more than 60% of the variability related to explanatory variables such as weather forecasts and vessel type.

This novel approach has involved a quantification of the value of refining uncertainty models. It will enable production planning tool developers to include only the most significant uncertainty factors in their products, which can be optimized to ensure that anticipated gain is balanced against the complexity of the model. Moreover, the catch prediction model may be used to reduce the supply uncertainty.

Only a limited number of uncertainty factors have been included in the current model, and future work should focus on investigating uncertainties linked to factors such as quality deterioration rate, initial quality distribution of the catch, production resources and demand/market prices. The current model addresses only a 3-day period, and potential exists for expansion towards development of a rolling horizon planning model. The use of a multi-plant production model will demonstrate how production can optimally be distributed across a number of different facilities.

NTNU

Jørn Vatn
jorn.vatn@ntnu.no

Combined agriculture- and marine related research

KIRA SVENDSEN

5 points to consider before setting sails in data science projects

Current food sector digitalisation, which forms part of the Industry 4.0 paradigm, has created a need to handle increasingly large amounts of data. This has required innovative analytical toolboxes and digital infrastructure that have opened up new opportunities for value creation from data.

The emergence of techniques such as Data Science, Big Data, Machine Learning and, more recently, AI, have generated a wealth of opportunities. But they represent no egg of Columbus. One size does not fit all. Full-steam-ahead commitments to advanced data science projects are vulnerable to failure if they are not fully thought through and properly implemented. This article discusses a few issues worthy of consideration before starting out on data science projects in the food production industry.

WHAT IS OUR GOAL?

A direct question deserves a direct answer. We are all aware of data science projects initiated either because “we would like to learn more about what’s going on” or because “we have to apply AI/Big Data on all our data”. Goals in data science are not always easy to formulate, but we also know that vague goals yield vague results.

Before evaluating the use of AI and Big Data, we must have a clear idea of what we hope to achieve. What would bring most value to our company? Do we really need insights from complex algorithms? AI may not be necessary if we can generate value from a simple data display technology.

Figure 1. It is a challenge to sort and collate multi-source data.

ACCESS TO DATA

There is a lot of data around. But where is it stored, and is it accessible?

In paper files. Analysis of data in paper formats may require costly labour-intensive and time-consuming manual handling.

In detached databases without keys. These data cannot be linked, turning our Big Data dreams into a series of small nightmares. If we are fortunate, a joint, if cumbersome and time-consuming, investigation by the data owner and data scientist may be able to elicit the elusive keys.

In detached databases with keys. If keys exist, we may be able to solve the jigsaw puzzle and get our data into shape. And so to our project. Our planning must be realistic, and this part is time-consuming. Analyses estimate that data scientists spend between 51 and 79 percent of their time cleaning and organising their data.

In a database. Even when our data appears to be easily within reach there is still a massaging process to be done in order to obtain full access. Variables often have cryptic names, or may lack descriptions. The project that did not find such skeletons in its data closet is yet to happen.

And finally, there is data protection legislation. Before we can start our project, we must comply with the GDPR, the rules for data sharing, and consider all our stakeholders’ interests.

> *Vague goals yield vague results.*

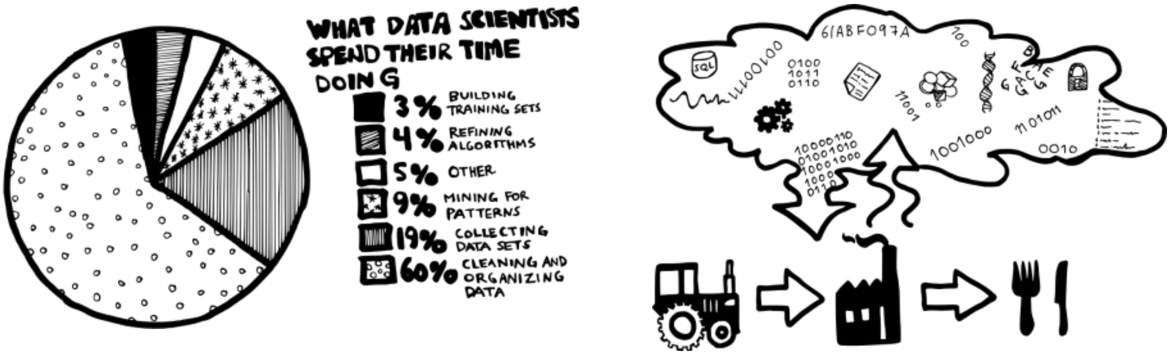


Figure **2. The cleaning and handling data are the most forgotten and time-consuming aspects of data science projects.**

DATA QUALITY

Data quality is a great many things.

Relevance. Our data must be relevant to our project goals. We may be interested in faults or quality variations in our production process, so the data we measure must be relevant and focused on our goals.

Correctness. Rubbish in, rubbish out. No amount of erroneous data will yield the correct result, and there isn't much we can do about that. However, different machine learning methods can to some extent be applied to address missingness, outliers and other artifacts.

Amount. Our project will require an adequate amount of data, but as quality increases, the need for data to identify signals is reduced. Fundamental changes in conditions, such as new equipment, may mean that the data cannot be compared before and after the change, thus limiting the amount of data available for analysis.

Variation. The implementation of a food recipe entails very little data variation. This may be good for production, but if the aim of our project is to learn how the recipe can be expanded beyond standard production frames, then our observation of variation is crucial.

Dirty data. Data dirtiness represents one the biggest barriers to obtaining insights from our data. The data janitor's role is to identify and handle such things as missing data, outliers, labels that have changed over time, dates and timestamps, and suitable feature representation. It is important to note that these tasks usually consume the majority of our project hours, and though often neglected, can be crucial to project outcomes.

COMMITMENT

Data science project participants bring very different, but equally important, knowledge and expertise to the table, and a successful outcome requires commitment from all parties. Data science has been oversold as a "silver bullet" to the challenge of generating groundbreaking new knowledge using comprehensive data analysis projects. But things are not that simple. The knowledge possessed by data owners is crucial.

Data gathering. Equipment and data analysis procedures change over time and data engineers provide key assistance to data scientists in addressing data infrastructure issues and general data dirtiness.

Domain knowledge. This is essential if we are to obtain a full overview of what are investigating and what we can expect; the extent to which existing knowledge can be incorporated into our modelling, and the identification of important factors that have not been measured or registered.

End users. We must consider the expectations and requirements of our project outcome end users. By putting outcomes into context we can achieve project success in terms of ownership, adaptation of results, and value creation.

THE FUTURE

Long-term and sustainable solutions based on data science require model outcomes to be anchored in a business context. Project participants must always be aware of how the results of their analyses can be implemented and, equally important, maintained for the future benefit of the business. Models must be checked and updated in order to remain relevant. An effective hand-over is crucial to the longevity of project success.

Kira Svendsen
kirasvendsen@gmail.com
Line Clemmensen
lkhc@dtu.dk
Ingrid Måge
Ingrid.Mage@nofima.no

RAGNAR TVETERÅS AND HILDE SANDVOLD

Barriers to increased automation and technological development in food processing

The most important barrier to the introduction of AI technology in food processing in Norway is the complexity of the new technology, which is difficult for companies to adopt given their current knowledge bases.

INCREASED AUTOMATION

In recent decades, the increased use of automation involving artificial intelligence has changed production processes in almost every industrial sector. However, food processing has so far stood out as an exception to this trend. There are many reasons for this, although the nature of the product is probably paramount. New and innovative technologies that can better handle fragile raw materials are now readily available, but levels of automation remain low. This situation places obstacles in the way of further technological development and raise questions as to the barriers faced by processing companies in adapting to new technologies. In this study, we aim to analyse why this industry is lagging behind, and why companies appear to be struggling to adopt new and more flexible technologies. Our aim is to examine the specific barriers or bottlenecks that prevent the adoption of technologies involving artificial intelligence.

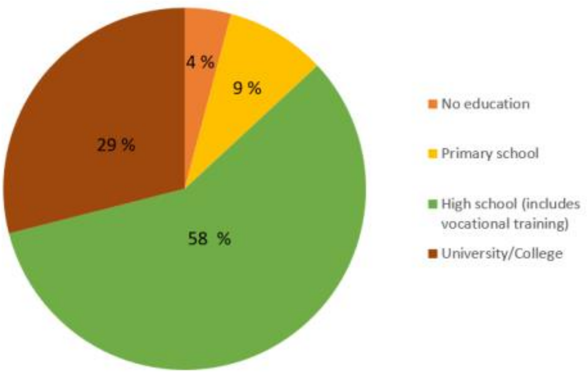


Figure 1. Level of education of most employees in the food processing industry.

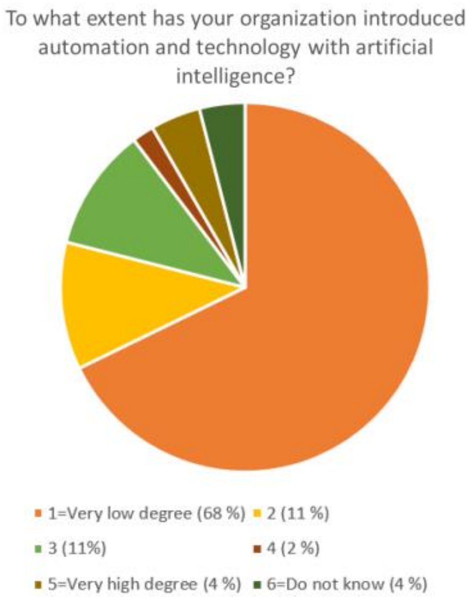
SURVEY

In order to analyse the challenges related to technological development faced by Norwegian food processing companies, we conducted a tailored, innovation survey. A total of 250 companies of different sizes, making up about 10 percent of all processing firms in Norway, participated in the survey. These companies process food raw materials from both agricultural and marine sources. Data gathering entailed telephone interviews with CEOs. The 25 survey questions were related mainly to automation, but the respondents were also asked about their R&D capabilities, and the factors that motivated their attitudes to innovative technology and collaboration with others.

NEW BUSINESS MODELS

The overall aim of our survey was to investigate if strategies or business models were being applied that are more successful than others when companies are considering adopting a new technology. This is important because the introduction of new and more flexible technologies offers greater efficiency and profitability, which in turn yields greater added value. Thus, to better our understanding of the factors that boost the competitiveness of the Norwegian food processing industry, we considered it important to examine the barriers that prevent the adoption of new technology.

Our econometric analyses identified several barriers to the introduction of new technology, the most important of which are complexity and lack of compre-



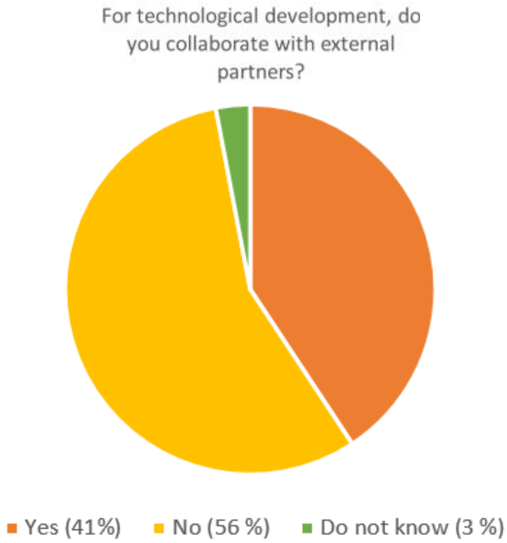


Figure 2.
Left: Diagram illustrating levels of automation and the application of artificial intelligence in the Norwegian food processing industry.
Right: Diagram illustrating the level of innovation-related collaboration with other organisations in the Norwegian food processing in-

> *The most important barrier to the introduction of new technology in food processing is the fact that employees find the technology too complex and too difficult to understand.*

hensibility. We found that low levels of education and collaborative effort within the industry also have a major impact on the adoption of innovative technologies. We found that only 12% of employees had attended higher education, and only 56% of the firms collaborate with other organisations on technology issues. Furthermore, 64% of the firms do employ employees assigned to R&D work, and 75% operate without a dedicated R&D budget.

Our findings lead us to believe that companies intending to increase automation also need to boost their employees' levels of expertise on several fronts.

NEW BUSINESS MODELS

We believe that above all else, food processing companies need to boost their levels of technological expertise if they are to achieve a full appreciation of the value of new technology. They must also develop their collaborative skills, both in Norwegian and global contexts.

There is good reason to believe that business models will change in the years to come. Organisational structures that emphasise technological and collaborative skills must achieve increasing importance if we are to boost the application of artificial intelligence in the Norwegian food processing sector.

Universitetet i Stavanger

Ragnar Tveterås
Ragnar.tveteras@uis.no
Hilde Sandvold
Hilde.sandvold@uis.no

CECILIE SALOMONSEN

Design within the circular economy

How can the food industry and their equipment vendors use design as a tool to gain entry to the circular economy?

Future human activity must become more sustainable by adopting the concept of the circular economy. Designers can show us the way by applying circular design as a tool for use within a holistic, cyclical system.

CIRCULAR DESIGN

Circular design involves product design that influences the entire system around it in a cyclical way. To achieve this, industrial designers must adopt a holistic approach and take a greater step back from the product than usual. There is nothing new about examining different levels of complexity, but a new approach means thinking holistically about the system that a product or service is a part of. Unlike a linearly-designed product, which is simply delivered into the world, circular design assumes that the product will be returned for repairs, upgrades, reuse and recycling. In linear design, our main focus is on the end user, whereas in the circular economy we expand our view to consider all product stakeholders and users throughout the product's life-cycle. This requires designers to build feedback loops into their products and be fully aware of the life-cycles of the materials they use[1].

DESIGN STRATEGIES

Two main design strategies are involved; design for slowing resources loops, and design for closing resource loops[2].

Design for long-life products (slow down loops)

- Design for attachment and trust
- Design for reliability and durability

Design for product-life extension (slow down loops)

- Design for ease of maintenance and repair
- Design for upgradeability and adaptability
- Design for standardisation and combability
- Design for dis- and reassembly

Design strategies to close loops

- Design for a technological cycle
- Design for a biological cycle
- Design for dis- and reassembly

In addition, strategies such as Biomimicry, Life Cycle Analysis and Cradle-to-Cradle design represent alternative sustainable design options.

AREAS OF FOCUS

Two main areas of focus for the food industry involve addressing how rest raw materials can be used to manufacture high-value products, combined with packaging design and associated issues. Vendor companies have different concerns linked to their knowledge of materials, such as design for disassembly, upcycling and hygienic design, as well as design for maintenance, upgrade and repair, and design for professional stakeholders and user groups.

iPROCESS APPLICATIONS

The iProcess project has investigated several instances of how new and flexible technologies can improve current production methods. One example has looked into the measurement of fats and dry matter in cheese. Others have studied robotics and the ways in which robots can be used to cut ham or package fragile, compliant, and shape- and size-variant objects such as fish. All these studies have addressed the issue of introducing these technologies as everyday tools in

[1] IDEO; Ellen MacArthur Foundation. (2017, 1 1). *Circular design guide*. Retrieved 06 07, 2018, from Circular design guide: https://www.circulardesignguide.com/

[2] Bocken, N., Bakker, C., Grinten, B., & Pauw, I. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 33*(5), 308-320.

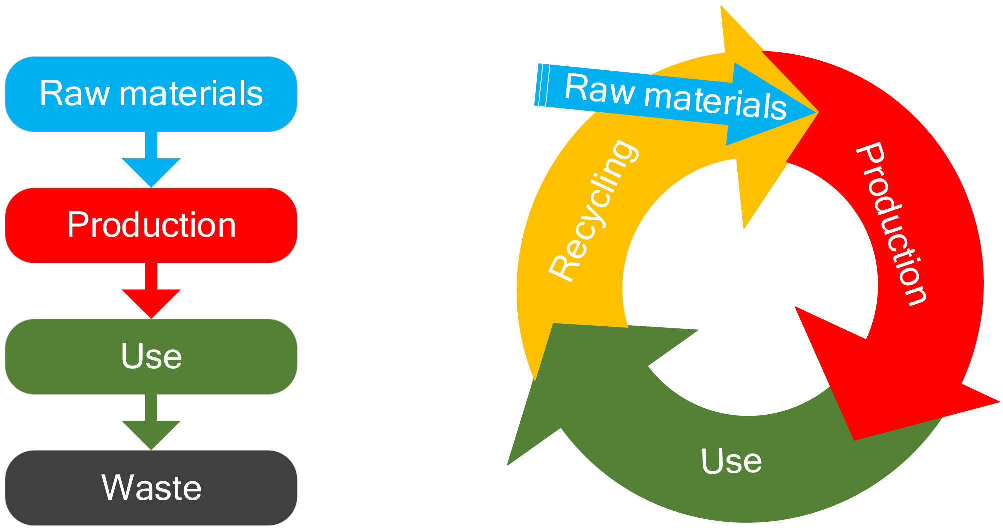


Figure 1. A linear versus a circular economy.

> *Circular design is never finished. It is not like linear design, where you design a product and send it off into the world. In circular design, the product will return for repair, upgrades, reuse or recycling.*

food processing and production facilities. From a circular design perspective, it is vital to be aware of the strategies needed for slowing down resource loops. Design must focus on durability and reliability. It is also important to design with the aim of extending product life so that they remain easy to clean, maintain and repair. It must be possible to replace parts if necessary, and for software to be upgraded. And last, but not least, it is important to design for dis- and reassembly so that a product's constituent materials can be safeguarded within their respective cycles for use in a new cycle, thus contributing to closing the material loops.

The iProcess project has also investigated information flow. For example, the company Norilia uses animal hides from Nortura to manufacture a variety of different products. iProcess has investigated information flow from the farm to the tannery, and the ways in which technology can be used to transfer information and provide feedback to previous process stages. This information can then be used to improve performance at each successive stage and thus optimize hide quality. Optimal hide quality provides manufacturers with greater flexibility in their choice of which product to produce from each hide. This is turn enables the manufacturer to better satisfy consumer demand and thus create products more suited to a circular economy.

The iProcess project has also investigated information logistics and raw materials flow as part of two studies linked to the whitefish sector. The greater the volume of catch information available onboard fishing vessels, the greater the volume of data that can be transferred to the processing plants for use in operations planning. Optimised production planning enables more of the raw material to be used for market-relevant applications and may, from a circular economic perspective, reduce the levels of cascading at the retail and consumer stages, enabling more of the products to be used as intended.

CONCLUSIONS

The introduction of a new approach will always generate challenges. However, circular design is now identified as the means of safeguarding a sustainable future. Industrial designers can show the way by demonstrating how various methods can be applied within different companies. They can be the drivers of a transition towards a circular economy, characterised by products and services that a sustainable future demands.

SINTEF

Cecilie Salomonsen
Cecilie.Salomonsen@sintef.no

Dissemination

iProcess dissemination

Scientific publications

1. Dreyer, H.C., Kiil, K., Dukovska-Popovska, I. and Kaipia, R. (2018). Proposals for enhancing tactical planning in grocery retailing with S&OP. *International Journal of Physical Distribution & Logistics Management*. Vol. 48 No. 2, 2018, pp.114-138

2. Eskildsen, C.E., Sanden, K.W., Wubshet, S.G., Andersen, P.V., Øyaas, J. and Wold, J.P. (2019). Estimating dry matter and fat content in blocks of Swiss cheese during production using on-line near infrared spectroscopy. *Journal of Near Infrared Spectroscopy*, 27 (4), pp. 293-301

3. Isachsen, U., Theoharis, T and Misimi, E. (2020) Fast and accurate GPU accelerated robotic 3D reconstruction of 3D compliant food objects. *Computers and Electronics in Agriculture*.

4. Farstad, P.K., Thomseth, T.N., Dreyer, H.C., and Hedenstierna, C.P. (2018). The impact of supply chain uncertainty on supply chain planning process: reflections from a whitefish case study. 25th Annual EurOMA Conference, Budapest Hungary, 24-26 June.

5. Janssen, S., Verboven, P., Nugraha, B., Wang, Z., Boone, M., Josipovic, I. and Nicolaï, B.M. (2020). 3D pore structure analysis of intact 'Braeburn' apples using X-ray micro-CT. *Postharvest Biology and Technology*, 159, p. 111014.

6. Lind, M. (2020) Real-time quintic Hermite interpolation for robot trajectory execution. PeerJ Computer Science, 6, p.e304, ISSN 2376 -5992.

7. Misimi, E., Olofsson, A., Eilertsen, A., Øye, E.R. and Mathiassen, J.R. (2018). Robotic Handling of Compliant Food Objects by Robust Learning from Demonstration. In: *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).* IEEE: pp. 6972-6979.

8. Nugraha, B., Verboven, P., Janssen, S., Wang, Z. and Nicolaï, B.M. (2019). Non-destructive porosity mapping of fruit and vegetables using X-ray CT. *Postharvest biology and technology*, 150, pp. 80-88.

9. Pedersen. O.M., Misimi, E. and Chaumette, F. (2020) Visual servoing assisted robotic grasping from grasping agent trained in simulation. In: *IEEE International Conference on Robotics and Automation*, pp. 5655 - 5662.

10. Sengupta, A., Krupa, A. and Marchand, E. (2019). Tracking of Non-Rigid Objects using RGB-D Camera. In: *IEEE International Conference on Systems, Man and Cybernetics (SMC).* IEEE: pp. 3310-3317.

11. Sengupta, A., Krupa, A. and Marchand, E. (2019). RGB-D tracking of complex shapes using coarse object models. In: *IEEE International Conference on Image Processing (ICIP).* IEEE: pp. 3980-3984.

12. Sengupta, A., Lagneau, R., Krupa, A., Marchand, E. and Marchal, M. (2020). Simultaneous Tracking and Elasticity Parameter Estimation of Deformable Objects. In: *IEEE International Conference on Robotics and Automation (ICRA).* IEEE: pp. 10038-10044 .

13. Thakur, M. and Gunnlaugsson, V.N. (2018). Information Sharing Strategies in Whitefish Supply Chains in Norway vs. Iceland: Impact on Supply Chain Decision Making. *International Journal on Food System Dynamics*, 9(3), pp. 240-252.

14. Thakur, M., Tveit, G.M., Vevle, G. and Yurt, T. (2020). A framework for traceability of hides for improved supply chain coordination. *Computers and Electronics in Agriculture*, *174*, p.105478.

15. Van De Looverbosch, T., Rahman Bhuiyan, M.H., Verboven, P., Dierick, M., Van Loo, D., De Beenbouwer, J., Sijbers, J. and Nicolaï, B. (2020). Nondestructive internal quality inspection of pear fruit by X-ray CT using machine learning. *Food control*, 113, pp. 107170.

16. Verboven, P., Defraeye, T., Datta, A.K. and Nicolai, B. (2020). Digital twins of food process operations: the next step for food process models? Current *opinion in food science.* 35, pp. 79–87.

17. Van Dael, M., Verboven, P., Zanella, A., Sijbers, J. and Nicolai, B. (2019). Combination of shape and X-ray inspection for apple internal quality control: in silico analysis of the methodology based on X-ray computed tomography. *Postharvest biology and technology*, 148, pp. 218-227.

18. Wubshet, S.G., Wold, J.P., Afseth, N.K., Böcker, U., Lindberg, D., Ihunegbo, F.N. and Måge, I. (2018). Feed-forward prediction of product qualities in enzymatic protein hydrolysis of poultry by-products: A spectroscopic approach. Food *and bioprocess technology,* 11(11), pp. 2032-2043.

19. Wubshet, S.G., Wold, J.P., Böcker, U., Sanden, K.W. and Afseth, N.K. (2019). Raman spectroscopy for quantification of residual calcium and total ash in mechanically deboned chicken meat. *Food control*, 95, pp. 267-273.

Publications in preparation

1. Andersen, P. V., Wold, J. P., Gjerlaug-Enger, E. and Afseth, N. K. Prediction of water holding capacity and pH in porcine longissimus lumborum using Raman spectroscopy. *Meat Science.* (Submitted for publication in 2020).

2. Andersen, P. V., Afseth, N. K. and Wold, J. P. Analysing main components in heterogeneous bio-materials by Raman spectroscopy. *Applied Spectroscopy*. (To be submitted for publication in 2020).

3. Lillienskiold, A., Rahaf, R., Giordano, P. R., Pacchierotti, C. and Misimi, E. Human-Inspired Haptic-Enabled Learning from Prehensile Move Demonstrations. (Submitted for publication in 2020 in *IEEE Transactions of on Systems, Man, and Cybernetics: Systems*).

4. Monago-Maraña, O., Wold, J.P., Rødbotten, R., Dankel, K. R. and Afseth, N. K. Raman, near -infrared and fluorescence spectroscopy for determination of collagen content in ground meat and poultry by-products. *Meat Science*. (Submitted for publication in 2020).

5. Måge, I., Solberg, L. E., Dankel K. R., Wold, J. P. Online measurements of food quality lead to better process understanding. (In preparation).

6. Måge, I. and Berget, I. Optimal sorting of biological raw materials using spectroscopy-based models. (In preparation).

7. Olsen, T., Øttesen, B. and Misimi, E. Sim-to-Real transfer learning based on Deep Reinforcement Learning for gripper vector estimation and grasping of food objects. *Computers and Electronics in Agriculture*. (To be submitted for publication in 2020).

8. Sandvold, H. and Tveterås, R. Successful innovation process (In preparation, not reported to the Research Council of Norway).

9. Sandvold, H. and Tveterås, R. Business models and strategies (In preparation, not reported to the Research Council of Norway).

10. Thakur, M. and Myhre, M.S. A review of blockchain technology and implications for food supply chain traceability. (In preparation).

Reports and theses

1. Boning, M.K., Sefranek, A.L., Rongved and Sivalingam, Z. (2017). *Sales and operations planning in the whitefish industry*. Student report, NTNU.

2. Bjerke, M.M. (2018). *Managing Supply Uncertainty in the Operational Production Planning in a Whitefish Value Chain – A Stochastic Programming Approach.* Master's thesis, NTNU.

3. Boneng, M.K., Rongved, A.L.S. and Sivalingam, T. (2018). *Supply chain planning: the application of information in marked decisions*. Master's thesis, NTNU.

4. Frantzen, Ø. (2018). *Decision Support for Centralised Planning in Production Networks – A Prototype for Whitefish Processing*. Master's thesis, NTNU.

5. Farstad, P.K. and Thomseth, T.N. (2018). *Managing supply uncertainty in supply chain planning-A white fish case study.* Master's thesis, NTNU.

6. Farstad, P.K. and Thomseth, T. (2017). *Supply uncertainties in a white fish industry: Sources of uncertainty and coping strategies*. Student report, NTNU.

7. Kikke, N.Y.S. (2018). *Managing uncertainty in supply for a whitefish processor*. Master's thesis, NTNU.

8. Johansen, U. (2018). *GPU accelerated 3D registration of compliant food objects*. Master's thesis, NTNU.

9. Kongsgård, S.B. (2019). *A Deep Learning-Based 3D Vision Pipeline for Shape Completion of 3D Objects*. Master's thesis, NTNU.

10. Olofsson, A.M. (2017). *Tactile-sensitive robotic grasping of food compliant objects with deep learning as a learning policy*. Master's thesis, NTNU.

11. Olsen, T. and Ottesen, B.M. (2018). *Deep Reinforcement Learning for Gripper Vector Estimation.* Master's thesis, NTNU.

12. Pedersen, O.M. (2019). *Sim-to-Real Transfer of Robotic Gripper Pose Estimation-Using Deep Reinforcement Learning, Generative Adversarial Networks, and Visual Servoing*. Master's thesis, NTNU.

13. Salomonsen, C. (2018). *Designing within the circular economy*. SINTEF Report no. 2018:00938, ISBN: 978-82-14-06911-2.

14. Sengupta, A. (2020). *Visual Tracking of Deformable Objects with RGB-D Camera* (PhD, Université de Rennes 1).

15. Thakur, M. (2017). *Process mapping in the whitefish supply chain – analysis of information and material flow – Deliverable 4.1-iProcess – P4 Information Management*. SINTEF Report no. OC2017 A-197, ISBN: 978-82-7174-318-5.

16. Tveit, G.M., Thakur, M., Vevle, G., Mehta, S., Standal, I.B., Greiff, K., Indergård, E. and Yurt, T. (2019). *Traceability of hides through the supply chain – Norilia Hide Case*. SINTEF Report no. 2019:00728, ISBN: 978-82-14-06391-2.

17. Tveit, G.M., (eds.) 2019 *Innovative and Flexible Food Processing Technology in Norway.* SINTEF Report no: 2019:01041, ISBN: 978-82-14-06377-6

Presentations

1. Afseth, N.K., Matousek, P., Böcker, U., Wubshet, S.G., Andersen, P.V. and Wold, J.P. (2018). *Emerging approaches for representative food analysis using Raman spectroscopy.* Biosystems Engineering Congress, Iran, 3-5 September.

2. Andersen, P.V., Wold, J.P., Afseth, N.K. and Narum, B. (2018). *Analyzing intramuscular fat content in pork longissimus lumborum using Raman spectroscopy*. ICoMST (64th International Congress of Meat Science and Technology), Melbourne, Australia, 12-17 August.

3. Aursand. M. (2017). *iProcess - bedre utnyttelse av råvarer i fremtiden*. «Næringsmiddeldagene» conference, 26 January

4. Aursand, M. (2017). *Effektiv og automatisert matproduksjon. Bærekraft som konkurransefortrinn-teknologi som redskap*. Grønt teknologiløft Trøndelag, Norway, 24 August.

5. Aursand, M. (2017). *Havnæringa som inspirasjon for teknologi i jordbruket*. Innovasjon Norge, Go Bio: Smart jordbruk, 24 May.

6. Aursand, M. (2018). *Automatisering i matindustrien, utvikling av fleksible og innovative løsninger.* LandTech, Gardermoen, Norway, 25-26. October.

7. Aursand, M. (2018). *Kan SINTEF bidra til innovasjon i matindustrien?* Mat og landbruks konferansen (conference), Oslo, Norway, 16 January.

8. Aursand, M. (2018). *Nærings og samfunnseffekter – automatisering og robotisering.* SINTEF Ocean Seminar , Trondheim, Norway, 13 April.

9. Eilertsen, A. and Øye R.E. (2018). *Quality of food through vision systems, bringing the future to food inspections.* 1st ReFood symposium Sustainable technologies for food processing and preservation, Goa, India, 7.-9. of February.

10. Eilertsen, A. and Misimi, E. (2018). *Handling food with sensitivity and care, challenges for robotic grasping and manipulation.* 1st ReFood symposium Sustainable technologies for food processing and preservation, Goa, India, 7.-9. of February.

11. Greiff, K. (2017). *Automatisering i matindustrien gjennom utvikling av innovative og fleksible teknologiske løsninger*. Aquatic Food Forum, Oslo, Norway, 5 September.

12. Greiff, K. (2018). *Prosjekter og relevant kompetanse i Agri sektoren*, Landbruk 21/SINTEF Agri seminar. Trondheim, Norway, 2 Ocotber.

13. Isachsen, U. (2018). *GPU accelerated 3D registration of compliant food objects for scanning with robot arm and rgb-d sensor*. iProcess project meeting, Trondheim, Norway, 6 March.

14. Janssen S., Wang Z., Nugraha B., Piovesan A., Boone M., Josipovic I., Verboven P. and Nicolai, B. (2018). *3D pore network quantification of apples using X-ray CT of the microstructure of intact fruit.* 32nd EFFoST International Conference, Nantes, France, (Poster, Abstract), 6-8 November.

15. Krupa, A. (2019). *Tracking of Non-Rigid Objects using RGB-D Camera*. IEEE SMC Conference, **Bari, Italy, October 9, 2019.**

16. Lillienskiold, A. (2020). *Robothender inspirert av mennesker.* TechFood conferense, Trondheim, Norway, 4 February

17. Misimi, E. and Greiff, K. (2016). *Tiltak til å skape merverdi av storfekjøtt i Trøndelag.*

Landbruk 21 seminar, Stjørdal, Norway, May 2016 .

18. Misimi, E. (2016). *iProcess- the project*. NTP Board meeting. SINTEF, Trondheim, Norway, 21 September.

19. Misimi, E. (2016). *Robotics in Food Processing Applications – Challenges and Trends*. INRIA Conference, Rennes, France, 18 October.

20. Misimi, E. (2018). *Deep learning for robotic automation in food industry*. IDI AI-Workshop, NTNU, Trondheim, Norway 11 April.

21. Misimi, E. (2018). *Active vision and deep learning reinforcement learning*. SAV seminar Ploumanac`h, France, 4-5 July.

22. Misimi, E. (2018). *Automation needs in the poultry and food industry.* In connection with the visit of the Norwegian Minister of Agriculture to SINTEF Ocean. Trondheim, Norway, 5 September.

23. Misimi, E. (2018). *Deep Learning for robotic automation in food industry*, IDI AI-Workshop, NTNU, Trondheim, Norway, 11 April.

24. Misimi, E., Olofsson, A., Eilertsen, A., Øye, E.R. and Mathiassen, J.R. (2018). *Robotic Handling of Compliant Food Objects using Robust Learning from Demonstration*. IROS conference, Madrid, Spain, 1-5 Ocotber.

25. Misimi, E. (2019). *Robotic Manipulation of 3D Compliant Objects of Marine and Agricultural Origin.* iProcess Project Meeting, Rennes, France, 11 March.

26. Misimi, E. (2019). *Robotisert Automasjon med applikasjoner fra hav og landbruk - eksempler fra iProcess prosjektet*. SKI Agri– Konsernsatsning, seminar, SINTEF, Trondheim, Norway , 7 May.

27. Misimi, E. (2019). *Robotisert Automasjon med eksempler fra iProcess-prosjektet.* Raufoss Seminar, Manufacturing Technology Norwegian Catapult Centre, 27 August.

28. Misimi, E. (2020). *Robotlæring for manipulasjon av matobjekter.* TechFood conferense, Trondheim, Norway, 4 February

29. Misimi, E. (2020). *Disruptive innovation- Digitalisation and key enabling technologies* .NorFishing conferense, Trondheim, Norway, 18 August

30. Nugraha B., Verboven P., Janssen S. and Nicolai D. (2018). *Non-destructive porosity mapping of fruit and vegetables using X-ray CT*. Poster at the European Federation of Food Science and Technology International Conference, Nantes, France, 5-8 November.

31. Nugraha, B., Verboven, P., Janssen, S. and Nicolai D. (2019). *Respiratory gas diffusivity mapping of horticultural product using X-ray CT*. VI International Symposium on Application of Modeling as an Innovative Technology in the Horticultural Supply Chain-Model, Molfetta, Italy, 6-9 June.

32. Nugraha, B., Verboven, P., Janssen S. and Nicolai, D. 2019. *How respiratory gas diffusivity correlates with porosity of plant organ tissues*. 3rd International Symposium of Agricultural and Biosystems Engineering, Makassar, South Sulawesi, Indonesia, 7-8 August.

33. Olsen, T. and Øtessen, B. (2018). *Deep reinforcement learning for gripper vector estimation.* iProcess Project Meeting, Trondheim, Norway, 6 March.

34. Pedersen. O.M., Misimi, E. and Chaumette, F. (2020) Visual servoing assisted robotic grasping from grasping agent trained in simulation. In: *IEEE International Conference on Robotics and Automation*, virtual conference, Paris, France.

35. Sandvold, Hilde Ness (2017). *iProcess*. Workshop at the UiS Business School, Centre of Innovation Research, Oslo, Norway, 20 November.

36. Sandvold, H.N. (2019). *Økt automatisering i norsk næringsmiddelindustri: Utfordringer og drivere for teknologisk endring*. NHO Matindustien, Trondheim, Norway, 25 April.

37. Sengupta, A. (2018). 3D *pose estimation and tracking.* iProcess Project Meeting, Trondheim, Norway, 6 March.

38. Sengupta, A. (2018). *3D deformation tracking and pose estimation of deformable objects.* Ploumanac'h, France, 4 July.

39. Sengupta, A. (2019). *RGB-D tracking of complex shapes using coarse object models*. IEEE ICIP Conference, Taipei, Taiwan, September 25.

40. Sengupta, A. (2020). *Simultaneous Tracking and Elasticity Parameter Estimation of Deformable Objects.* IEEE International Conference on Robotics and Automation (ICRA), Paris, France, June 3.

41. Thakur, M., Vevle, G., Tveit, G.M. and Greiff, K. (2019). *Traceability and feedback system in the meat processing industry*. 33rd EFFOST International Conference, Rotterdam, Netherlands, 12-14 November.

42. Thakur, M., Myhre, M.S. and Jafarzadeh, S. (2020). *Blockchain technology for improving resource efficiency and circularity in food supply chains*. Abstract submitted to the 34th EFFOST International Conference, Online Event. 10-12 November.

43. Tveterås, R. (2017). *Industriens behov i et konkurranse- og lønnsomhetsperspektiv*. Sjømat Norge seminar "Kampen om råstoffet", Oslo, 14 March.

44. Van De Looverbosch, T., Verboven, P., Sijbers, J. and Nicolai, B. (2019). *An Efficient X-Ray Projection Simulator of 3D Fruit Shapes for Use in Non-Destructive Internal Quality Inspection.* 4th International Conference on Food and Biosystems Engineering, Crete, Greece, 30 May - 2 June.

45. Wold, J.P. (2019). *On-line analyse og NIR. Muligheter og utfordringer*. Næringsmiddelkonferansen. Bergen, Norway, 13-14 March.

46. Wold, J.P. (2019). *On-line målinger for bedre styring av hydrolyseprosesser*. Seminar: Marint protein nettverk. Gardermoen, Norway, 14 February.

47. Wold, J.P. (2019). *On-line NIR som virker: muligheter og utfordringer*. Open industry science day: Spektroskopi og prosesstyring i matindustrien, Nofima, Ås, Norway, 20 September.

In addition, researchers from the iProcess project have made presentations on individual work packages during annual iProcess status meetings.

Media and social media

1. Misimi, E. and Hanad, A. (2017). *Intelligente roboter kan innta landbruket.* Nationen, 17 August.

2. Misimi, E. (2017). *Roboten som skal berge matbransjen.* Dagens Næringsliv, *1 September.*

3. Misimi, E. (2017). *Roboten som skal berge matbransjen.* GEMINI, 4 September.

4. Misimi, E. (2020). *Robotlæring via 3D syn og kunstig intelligens,* Norsk Sjømat 6-2019

5. Misimi, E. (2020). *Lærer roboten å se og føle.* Gemini 24 March

6. Misimi, E. (2020). *Teaching robots to see and feel,* Forskning.no, 16 April.

7. Misimi, E. (2020). *Teaching robots to see and feel,* TechExplore, 16 April.

8. Misimi, E. (2020) *Teaching robots to see and feel,* EurasiaReview , 16 April

9. Misimi, E. 2020. *Nå kommer de følsomme robotene.* Fiskeribladet 19.07.2020.

10. Salomonsen, C. (2020). *Ressursene skal videre, vi må tenke fra vugge til vugge.* Fiskeribladet, 16 February.

11. Schenk A., Nugraha B. and Verboven P. (2019). *Porositeitsbeelden geven inzicht in inwendige structuur.* English summary: *Porosity maps provide insight into internal structure*. Proeftuinnieuws, 7, pp. 29-30, 5 April.

12. Skoglund, U. and Misimi, E. (2017). *Roboten den nye bonden?* GEMINI, June edition.

13. Skoglund, U. and Misimi, E. (2017). *Lærer roboten å bli bonde.* Aftenposten Vitenskap, 18 August.

14. Tveterås, R. (2016). *Tvangsforeldling.* Fiskeribladet Fiskaren, 2 May.

15. Tveterås, R. (2017). *Etterlysning: kreative politikere.* Fiskarbladet Fiskaren (10), no. 37, p.2. 27. mars, 2017 .

16. Tveterås, R. (2017). *Matindustri og sjømatindustri – samme marked men ulike rammebetingelser.* Unpublished article submitted to *Sjømat Norge* on 17 August.

17. Tveterås, R. (2017). *Digital utvikling.* Fiskeribladet (11) no. 40, 9 April 2018.

18. Wold, J.P., Afseth, N.K. and Tchudi, J. (2017). *Smarte sensorer gir best utnyttelse av maten.* Viten Aftenposten, 27 April.

The iProcess project has posted 12 items on the SINTEF website, 35 items on the iProcess News website and 44 items on Facebook during the project period 2016-2020.

Researchers

Researchers involved in iProcess

Senior Research Scientist Ekrem Misimi
Role in iProcess: Project leader (PI); WP3 leader; PhD Co-supervisor for WP3
SINTEF Ocean, Department of Seafood Technology
Ekrem.Misimi@sintef.no, +47 98222467

Senior Research Scientist Maitri Thakur
Role in iProcess: WP4 leader
SINTEF Ocean, Department of Seafood Technology
Maitri.Thakur@sintef.no, +47 45792572

Research Scientist Aleksander Lillienskiold
Role in iProcess: PhD-student at NMBU in WP3
SINTEF Ocean, Department of Seafood Technology
Aleksander.Lillienskjold@sintef.no, +47 91837987

Research Manager Kirsti Greiff
Role in iProcess: WP6 leader, participant in WP1, WP4 and WP7.
SINTEF Ocean, Department of Seafood Technology
Kirsti.Greiff@sintef.no, +47 47903891

Research Scientist Guro Møen Tveit
Role in iProcess: Participant in WP1, WP4 and WP6
SINTEF Ocean, Department of Seafood Technology
Guro.Tveit@sintef.no, +47 93002709

Research Scientist Cecilie Salomonsen
Role in iProcess: Participant in WP1 , WP5 and WP6
SINTEF Ocean, Department of Seafood Technology
Cecilie.Salomonsen@sintef.no, +47 92812817

Research Manager Harry Westavik
Role in iProcess: Previous WP1 leader
SINTEF Ocean, Department of Seafood Technology
Harry.Westavik@sintef.no, +47 92690216

SINTEF

Special Adviser Marit Aursand
Role in iProcess: Previous project leader, WP1 leader, participant in WP6 and WP7
SINTEF Manufacturing, Department of Production Technology
Marit.Aursand@sintef.no, +47 48200159

SINTEF

Senior Research Scientist Morten Lind
Role in iProcess: Participant in WP3
SINTEF Manufacturing AS, Department of Production Technology
Morten.Lind@sintef.no, +47 92662194

SINTEF

Research Scientist Tone Beate Gjerstad
Role in iProcess: Participant in WP3
SINTEF Manufacturing, Department of Production Technology
Tone.B.Gjerstad@sintef.no, +47 92803046

SINTEF

Professor Jørn Vatn
Role in iProcess: Participant in WP4
NTNU, Department of Mechnical and Industrial Engineering, Faculty of Engineering
Jorn.Vatn@ntnu.no, +47 41473730

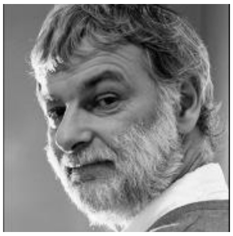
NTNU

Professor Heidi Carin Dreyer
Role in iProcess: Participant in WP4
NTNU, Department of Industrial Economics and Technology Management, Faculty of Economics and Management
Heidi.C.Dreyer@ntnu.no, +47 98291146

NTNU

Professor Ragnar Tveterås
Head of Centre for Innovation Research
Role in iProcess: WP5 leader
UiS, Department of Innovation, Management and Marketing,
Faculty of Engineering
Ragnar.Tveteras@uis.no, +47 51831640

Post Doctoral Fellow Hilde Ness Sandvold
Role in iProcess: Participant in WP5
UiS, Department of Innovation, Management and Marketing
Hilde.Sandvold@uis.no, +47 51831619



Senior Research Scientist Francois Chaumette
Role in iProcess: Participant in WP3
Francois.Chaumette@inria.fr, +33 299847255

PhD-student Agniva Sengupta
Role in iProcess: Participant in WP3
Agniva.Sengupta@inria.fr

Research Scientist Alexandre Krupa
Role in iProcess: Participant in WP3
Alexandre.Krupa@inria.fr, +33 299842585

Professor Bjarne Kjær Ersbøll
Role in iProcess: Participant in WP2
DTU, Department of Applied Mathematics and Computer Science
bker@dtu.dk, +45 45253413

PhD-student Kira Dynnes Svendsen
Role in iProcess: Participant in WP2
DTU, Department of Applied Mathematics and Computer Science
kdsv@dtu.dk, +45 61662161

Senior Research Scientist Jens Petter Wold
Role in iProcess: WP2 Leader
NOFIMA
Jens.Petter.Wold.nofima.no, +47 95979749

Research Fellow Pieter Verboven
Role in iProcess: Participant in WP3
Division of Mechatronics, Biostatistics and Sensors
Pieter.Verboven@kuleuven.be, +32 16321453

Tim Van De Looverbosch
Role in iProcess: Participant in WP3
Tim.vandelooverbosch@kuleuven.be

Bayu Nugraha
Role in iProcess: Participant in WP3
Bayu.Nugraha@kuleuven.be

Professor Pål Johan From
Role in iProcess: Participant in WP3, PhD-supervisor
Pal.Johan.From@nmbu.no, +47 67231603

PROJECT FUNDED BY

Forskningsrådet
The Research Council of Norway