2016 - 2019

PROJECT SUPPORT
BY RESEARCH COUNCIL
OF NORWAY

iPROCESS INNOVATION

Total utilization of raw materials in the supply chain for food with a bio-economical perspective

VOL 1

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Project

iProcess 2016-2019

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Total utilization of raw materials in the supply chain for food with a bio-economical perspective

Main objective

Develop novel concepts and methods for flexible and sustainable food processing in Norway – that are to cope with small volume series and high biological variation of the existing raw materials – to enable increased raw material utilization for food products and to increase profitability. These concepts will enable the Norwegian food industry to overcome its long-term national important challenge regarding increased sustainability of raw material use and reduction of loss (edible)/waste (inedible) in a lifecycle context.

Objective 1

Select relevant industrial cases and biggest challenges for food processing industry for more flexible and sustainable food processing.

Objective 2

Develop advanced process analytical technology concepts, to measure and control the quality of raw material to meet the requirements of the end products.

Objective 3

Develop flexible processing concepts that are able to handle small production volume series and adaptively process raw material of high biological variation.

Objective 4

Develop information flow management solutions to support decision making for the food processor to maximize the resource efficiency and profitability.

Objective 5

Develop technology concepts adaptive to raw material that can increase its utilization and minimize waste.

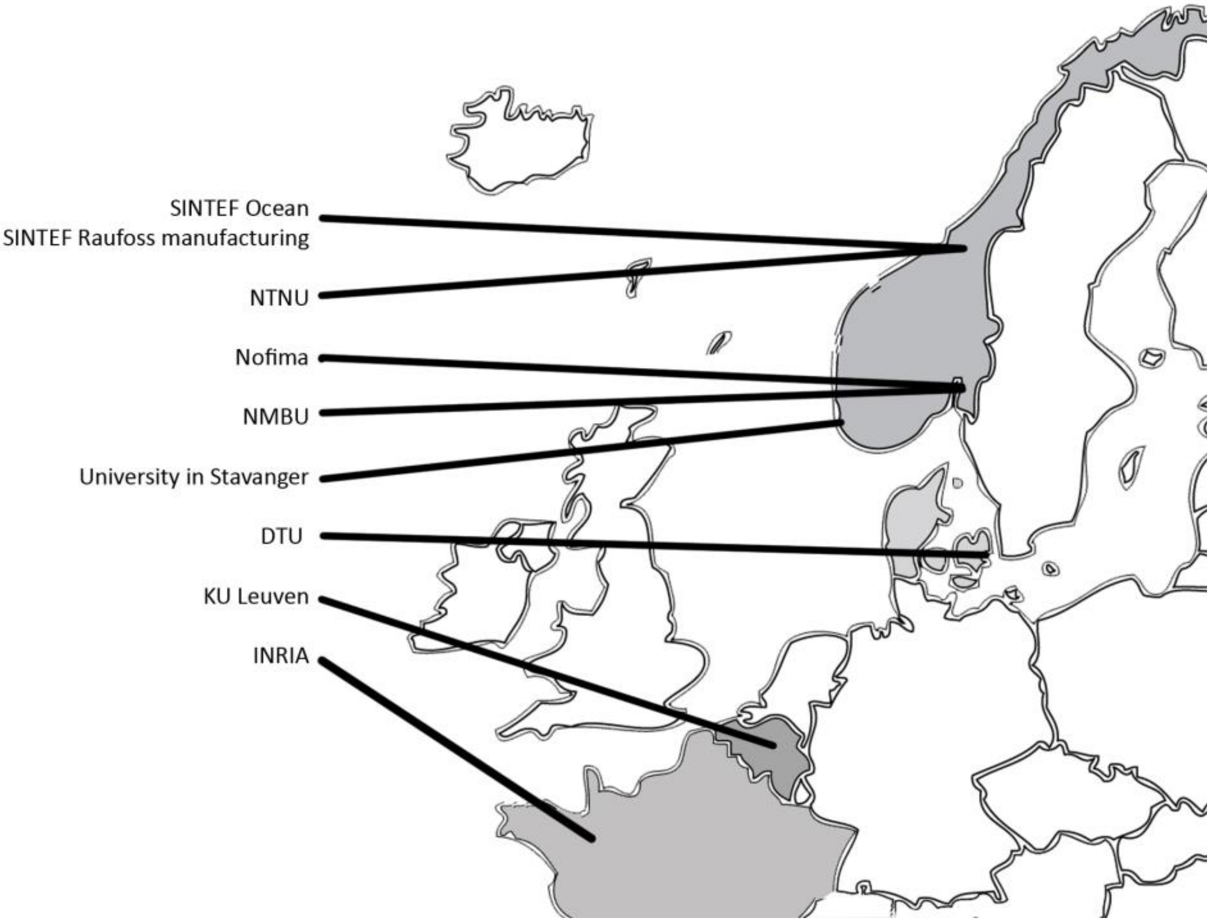
Objective 6

Develop market strategies and models for increased profitability, value generation and markettailored production.

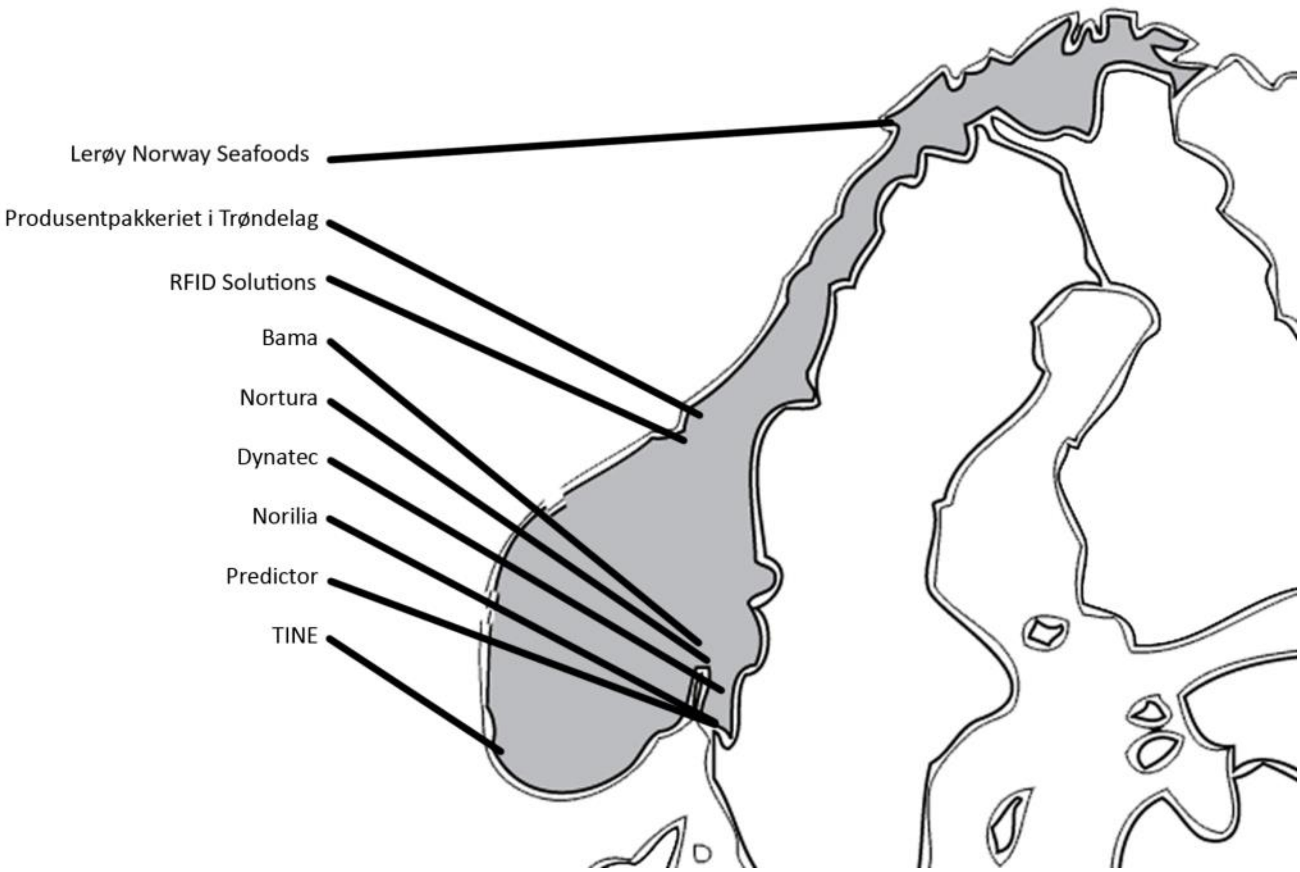
Objective 7

Validation by applying developed concepts and methods to a selected number of industry relevant cases within the developed sustainable approaches to food processing.

Research partners



Industry partners



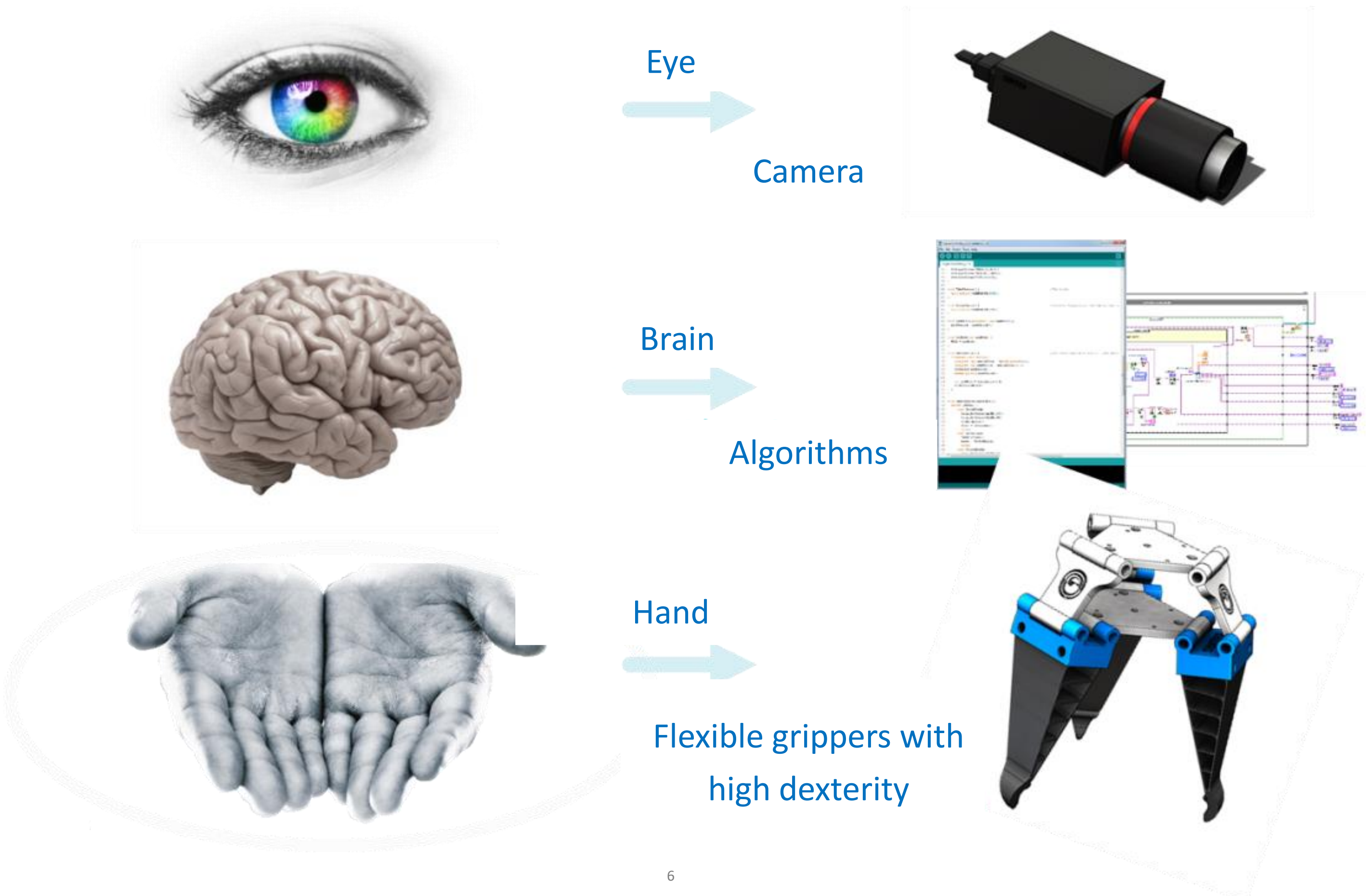
Preface

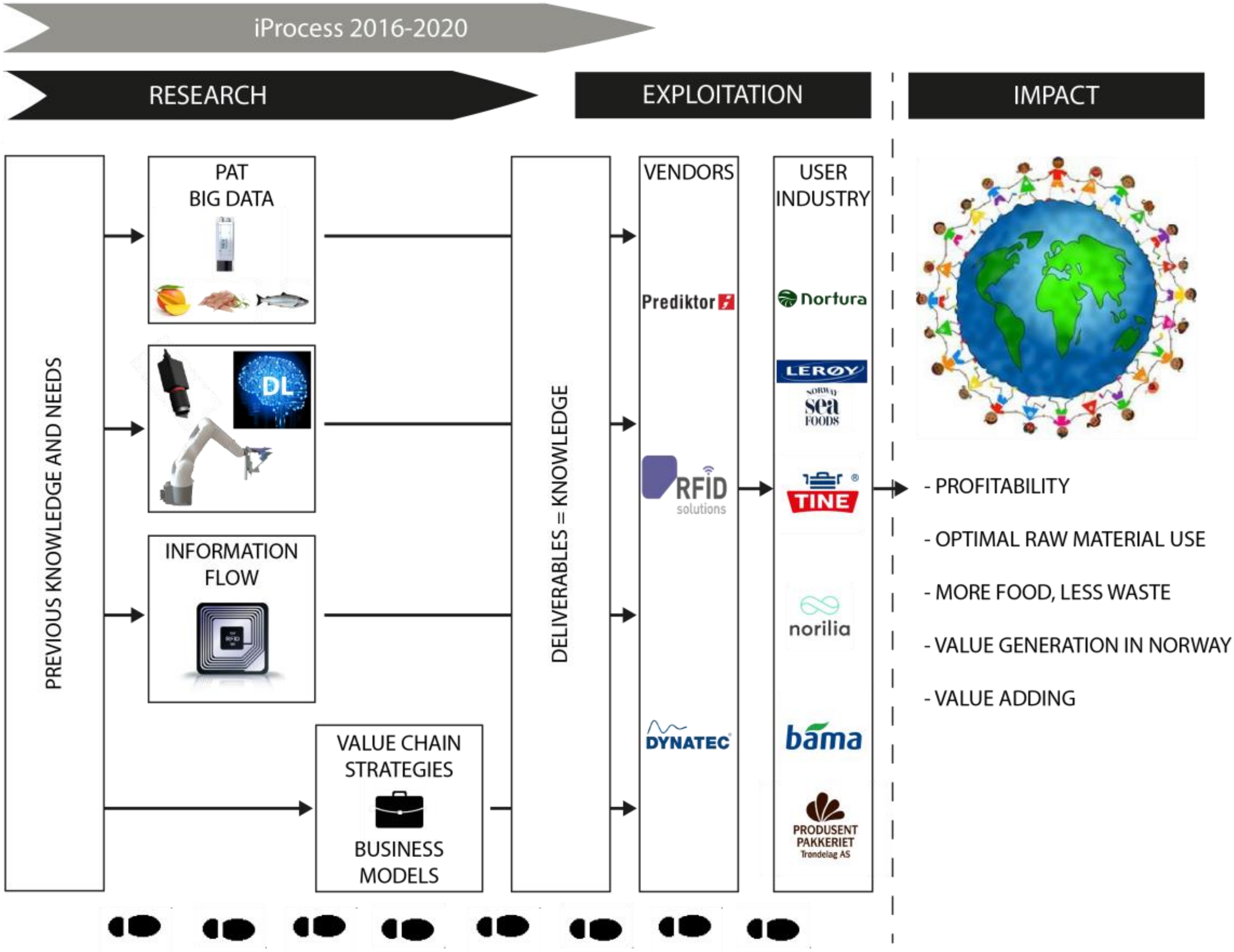
Today, 17% of the total amount of greenhouse gases emitted in the EU, come from the food processing sector. Globally, 1.3 billion tons of food are wasted every year. In the Norwegian food processing industry alone, at least 320,000 tons of food go to waste annually.

In order to address the challenges of the Norwegian food processing industry, researchers and industry have worked together in a project called iProcess.

As an interdisciplinary project iProcess has aimed to conduct research for an “Innovative and Flexible Food Processing Technology in Norway”. iProcess will develop novel concepts and innovative methods suitable for the small production volumes that often characterize the Norwegian food production industry, and also for processing raw materials with high biological variation. The ultimate goal is to optimize raw material utilization and increase the industry´s profitability.

iProcess intends to develop highly innovative food processing technology concepts by conducting research in areas such as 3D machine vision, spectroscopic sensors, X-ray imaging, machine learning, Big Data, and flexible robot based automation. These concepts are based on machine and robotic ‘eyes’, ‘brain’ and ‘hands’, capable of performing some of the complex food processing operations, most of which are currently performed manually.





iProcess 2016-2020
RESEARCH
EXPLOITATION
IMPACT
PREVIOUS KNOWLEDGE AND NEEDS
PAT
BIG DATA
DL
INFORMATION
FLOW
VALUE CHAIN
STRATEGIES
BUSINESS
MODELS
DELIVERABLES = KNOWLEDGE
VENDORS
USER
INDUSTRY
Prediktor
RFID
solutions
DYNATEC
Nortura
LERØY
sea
FOODS
TINE
norilia
bama
PRODUSENT
PAKKERIET
Trøndelag AS
- PROFITABILITY
- OPTIMAL RAW MATERIAL USE
- MORE FOOD, LESS WASTE
- VALUE GENERATION IN NORWAY
- VALUE ADDING


DENSO
RIGHTHAND
robotics

In today´s food industry, too much raw material is lost in the processing stages due to a technology that fails to adapt to the variations of each individual fish, chicken, meat carcass, fruit/vegetable, or dairy product that is being processed. To cope with the small production volumes and high biological variation of the raw material, there is a need to develop novel concepts for flexible processing automation, process analytical technology, and information flow management.

By acquisition of large data sets from 3D vision, spectroscopic sensors and X-ray imaging from online measurements, and by exploiting the concept of Big Data, research in iProcess has lead to innovative methodologies for both external and internal characterization of raw material that can go beyond state of the art. Making use of these technology concepts will ensure that the raw material is handled and processed safely, efficiently and individually, optimizing the quality and utilization of the final product.

iProcess has also used the collected data sets to a) exploit new machine learning paradigms including deep learning, and to b) specifically tailor and optimize these algorithms for food processing applications. This has resulted in a sort of computerized 'brain' that is capable of analyzing and interpreting large amounts of visual and other types of sensing-data, in order to improve 3D localization and recognition of raw material.

Inspired by how humans combine visual and force/tactile sensing and their ability to learn new complex tasks we have developed several approaches that enable 3D deformation tracking of the objects during manipulation with a robot based on color image (RGB) and depth (D) data, visual servoing based grasping tasks for compliant food objects, 3D reconstruction of object's model to be manipulated robotically, active vision, shape completion of the objects from a limited number of viewpoints, combination of visual (RGB-D) information for pose estimation and tactile sensing for force prediction during grasping of compliant objects with a robot; force feedback control of robot during robotic manipulation of compliant food objects.

Regarding the information flow, the set of techniques and methodologies that comprise the 'computerized brain' can be used to optimize the communication between the supplier and processor in order to better synchronize the market demand and production. This will help conserve resources, and the mass of information will enhance the transparency of the value chain and lead to innovative ways of utilizing raw material and reduce food loss. Societal and bio-economical change will not be brought about by technology advancement alone. Therefore, iProcess has also dedicated a substantial amount of research in the area of value chain strategies and business models to maximize the societal, economical and environmental impact of the novel concepts for flexible processing technology.

When machine and robotic 'eyes', 'brain', and 'hands' are set to work together, the level of productivity is expected to increase due to higher degree of automation, the volume of food loss and waste is expected to go down, the profitability to increase, and Norway's total value generation is safeguarded. The generated results are iProcess's contribution to the green shift in the Norwegian food processing industry, and to a more profitable and sustainable bio-based industry.

Ekrem Misimi

Project Manager

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Agricultural related research

EKREM MISIMI

Robotic handling of compliant food objects by robust learning from demonstration

Today, robots lack the visual, tactile and cognitive intelligence of humans to perform complex handling and processing tasks. We show how to endow robots these abilities and how to teach them to handle complaint food objects by Learning from Demonstration.

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

Many tasks 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 or self-exploration.

Figure 1:
A close-up image of an autonomous robotic grasping of lettuce based on our multi-modal (visual-tactile) robot LfD learning policy.

LEARNING HOW TO GRASP

Most of the robotic solutions today are based purely on visual information and focused on handling rigid objects. Compliant objects pose a major challenge to be handled robotically due to their deformation during handling in contact with a robot. For example, humans coordinate their visual and tactile information when they grasp or handle compliant food objects. Fusion of visual and tactile information is therefore a prerequisite so that robots can handle food object without quality degradation and be able to track and adjust to the deformation during handling. Development of novel learning strategies that will make use of both visual and force/tactile information in a single control scheme is also crucial so that the robot can learn new complex tasks and perform these autonomously.

When we humans reach to grasp an apple, we use our visual sensing to approach our hand to the apple and make the necessary adjustment of the path while we move the hand so that we can have the "correct" grasping pose of our hand to be able to grasp the apple.

When we initiate the contact with apple, then our tactile sensing through our finger is used to regulate the forces we excert to the apple to be able to grasp, lift and place. We would use different forces if instead of an apple we had to grasp a strawberry. The goal is to endow robots with the same capability so that they can use both visual and tactile sensing to learn new and complex tasks.

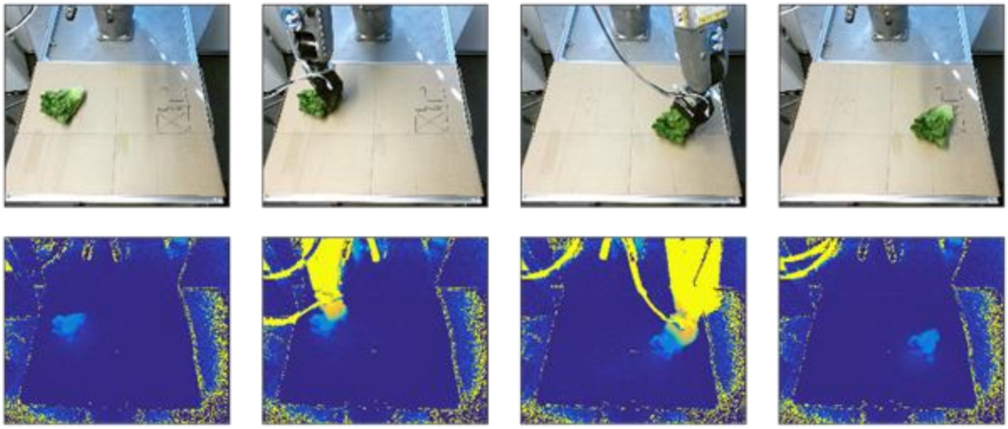

Figure 2:
The gripping sequence shown in RGB (top row) and depth (bottom row) images based on our trained LfD learning policy, where in a) an initial image is acquired and the visual state of the lettuce is computed, b) the robot places a grasp on the lettuce according to the action derived from the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

The resulting approach enables the robot to correctly combine the visual and finger tactile sensing in order to estimate the grasping pose, the grippers correct finger configuration and the forces to be exerted on the object in order to achieve successfull grasping of compliant objects.

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

TEACHING THE ROBOT TO LEARN

The learning, the 'brain' of the robot, is based on supervised learning in the form of learning from demonstration, i.e. the humans demonstrate the task to the robot and then based on the learning policy that is developed the robot can infer on how to reproduce the task for various compliant objects. Since the robot can be taught from different human operators, which can be inconcistent in demonstration, we also developed a robot learning approach that learns only from consistent demonstrations and automatically rejects the inconsistent demonstrations by human teachers.

This approach for human-inspired robotic grasping and robot learning will enable the learner (robot) to act more consistently and with less variance than the teacher (human). The proposed approach has a vast range in robotic automation of tasks in the ocean space, agriculture, and food industries, where the manual nature of tasks and processes leads to high variation in the way skilled human operators perform complex processing and handling tasks.

GOING FORWARD

Focus on more complex and challenging tasks for robot learning, where the human teacher has a greater challenge in providing accurate demonstrations, use of self-exploration and intermittent learning to refine the learning based on visual and force/tactile sensing.

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

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ALEXANDER KRUPA

Tracking non-rigid objects using depth camera

Surface of non-rigid objects, such as leafy vegetables, meats and fishes can be completely and accurately tracked using a depth camera with the approach proposed in this article. This is exceptionally useful while interacting with these objects using a robot.

Automating the handling of meats, vegetables, seafoods and other delicate and irregularly shaped consumables has been a challenging problem for the food processing industry. Using the recent advances in robotic gripper technology, it could be possible to use robots for sorting fruits, vegetables and fresh produce. It can also be used for cutting and slicing seafood and meat.

However, this can only be possible if the robotic system manages to observe and localize the shape and surface of the object it intends to manipulate. This can be done using state-of-the-art computer vision techniques along with the aid of some of the latest depth sensors. One such approach is proposed here, which tracks the surface of deforming objects using an approximate CAD model.

SURFACE TRACKING

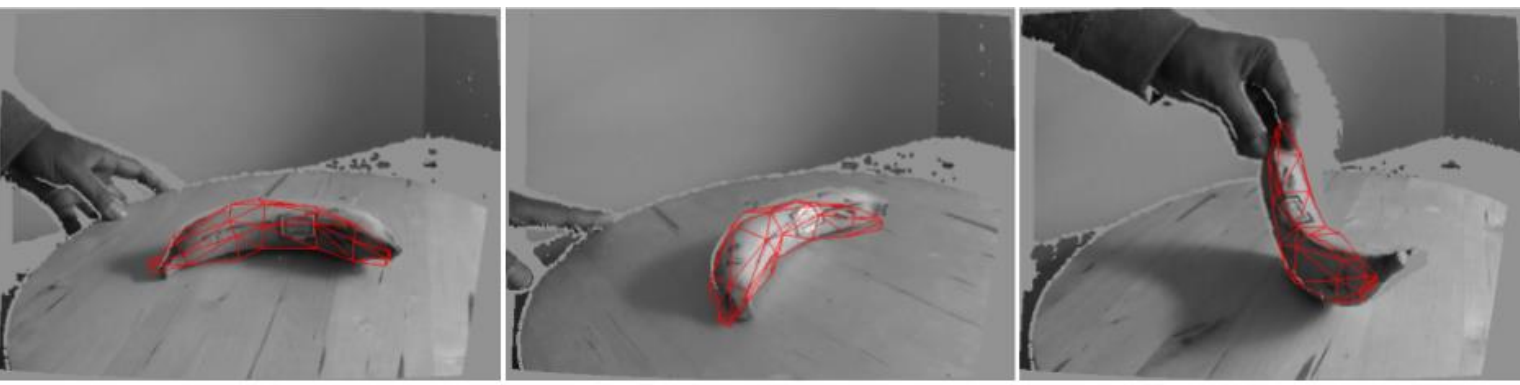
The term 'tracking' is being used in this context to mean spatio-temporal position of the visible surface of the object. The approximate CAD model of the object being tracked is assumed to be known. The food object, while being processed, will be observed using a RGB-D camera. This camera provide color and depth information about the scene. This depth data is utilized to fit the deformed CAD model, such that the entire observable surface of the object remains accountable.

Robotic manipulation of food objects is an interesting application in the food-processing industry. If robots are tasked with cutting, slicing, chopping or deboning of food objects, it is important to enable tracking of the surface of the substance that is being manipulated. The knowledge about this tracking information allows the robot to independently plan where and how it can grasp or cut the object to bring about the desired deformation.

APPLICATIONS

Research has shown two different examples of output from the proposed system. The results are demonstrated on a banana and a pizza. The banana was tracked using the rigid object tracking mechanism. The model used for tracking the banana was obtained from manual measurements. Despite this, the tracking was quite accurate. Pizza is a non-rigid object that was deformed by a large amount. The tracking was accurate and consistent.

Figure 1:
A banana being tracked while being moved around freely



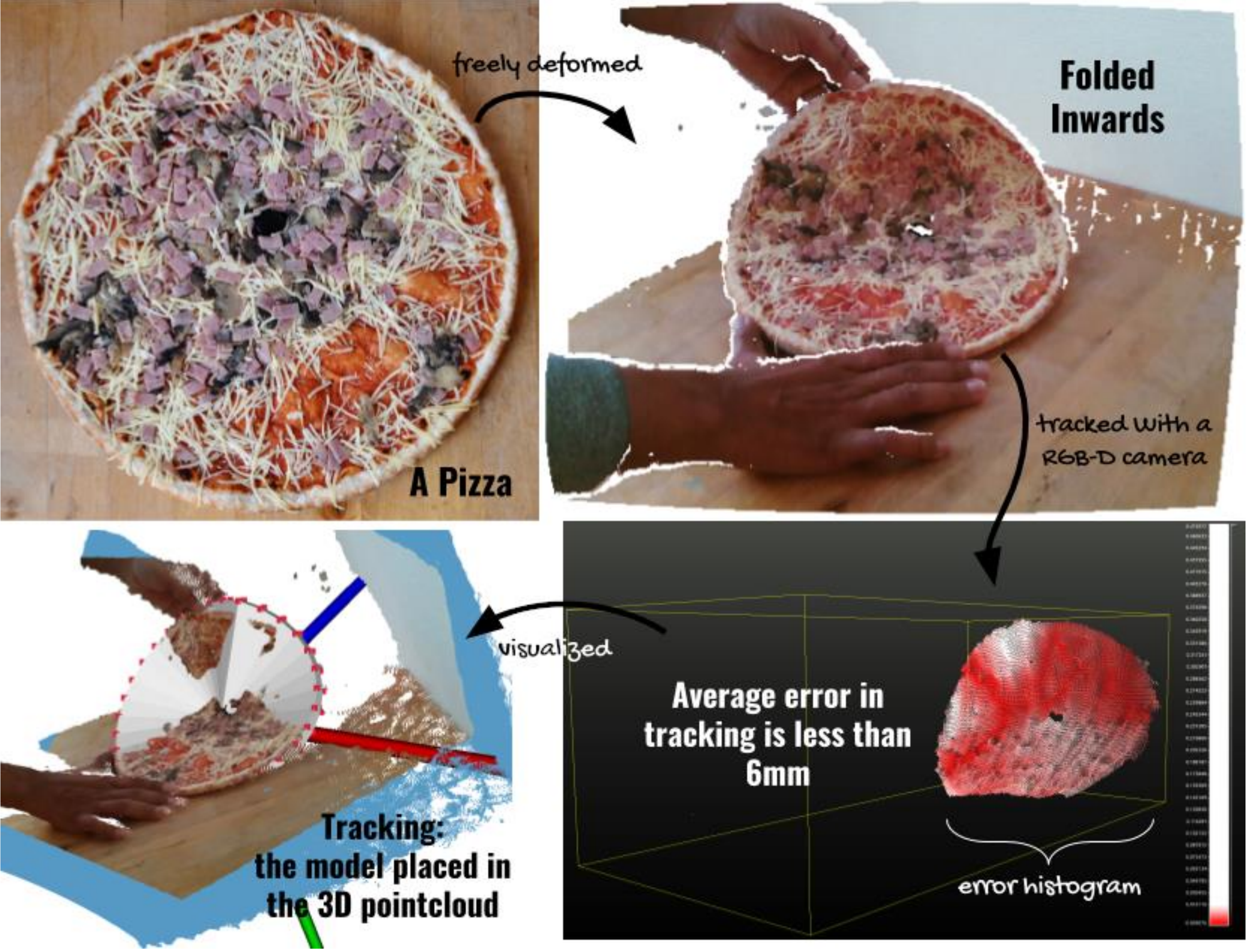


Figure 2:
Tracking of a pizza being deformed

> *If robots are tasked with cutting, slicing, chopping or deboning of food objects, it is important to enable tracking of the surface of the substance that is being manipulated. The knowledge about this tracking information allows the robot to independently plan where and how it can grasp or cut the object to bring about the desired deformation.*

The model deforms and closely follows the surface of the pizza as it deforms. Once the deformed surface gets tracked, the output of the tracking algorithm can be used for many robotic applications such as cutting, grasping, squeezing or picking up any generic deformable objects. Most food objects, including leafy vegetables, meats and fishes, are inherently and extremely deformable. Among other practical applications, deformable surface tracking can also be utilized for augmented reality (AR) or robotic surgeries.

The efficacy of the proposed method has been tested on real and simulated objects and the tracking accuracy is consistently adequate. However, some work can be done towards making the system more robust. It can also be optimized for performing faster.

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PETTER VEJLE ANDERSEN

Raman spectroscopy for quality differentiation of pork

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

Overall meat eating quality is very important for consumer confidence, willingness to pay and repeat purchase of fresh meat. Intramuscular fat (IMF) content, pH, water-holding capacity (WHC) and color are the best indicators of the eating quality of fresh pork. However, these quality indicators are difficult to measure before the meat is sent from processors. Raman spectroscopy is a vibrational spectroscopic technique with the potential to analyze IMF, pH and WHC, all in one analysis. The following study aimed to use Raman spectroscopy to estimate IMF in pork loins by recording spectra from intact samples at the slaughter house.

QUALITY

In general, the quality consumers prefer in pork is characterized by moderate IMF content, an ultimate pH of 5.6-6.0, high WHC and a reddish-pink color. In contrast, most of the pigs reared in Norway are lean, resulting in low levels of IMF. Lower levels of IMF are often associated with undesirable deviations in pH and WHC. This leads to a significant share of the pork being sold having an unknown and inconsistent quality. Consumers will then have to, in most cases, rely on their own knowledge of meat quality when deciding what to buy.

CONSUMER SURVEYS

In international surveys it has been shown that consumers are willing to pay over twice as much for meat of premium quality compared to passable quality. Pricing meat according to its quality is currently an untapped resource in the Norwegian meat industry, and it could increase earnings substantially if systems

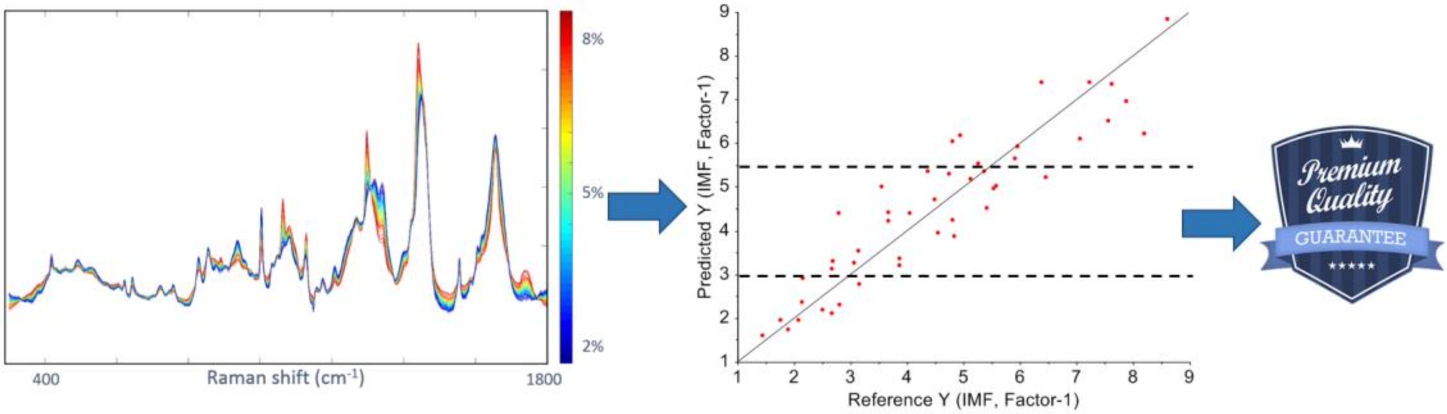

Figure 2:
Raman spectra used for estimation of intramuscular fat content can be a part of quality classification of pork loins.

were put in place for quality differentiation. Objective methods for assessing meat quality should be a cornerstone in this work.

> *Raman spectroscopy can be the future of objective and non-contact meat quality analysis for industrial applications.*

IMF

Using a Raman instrument equipped with a wide area illumination probe, IMF could be estimated successfully both for intact and homogenized pork loins. IMF of the samples ranged from 1.4% to 8.6%, which was considered representative for Norwegian pigs. The PLSR model for intact samples had cross validated r^2 of 0.84 and an error of 0.78%, while the model for homogenized samples had r^2 of 0.94 and an error of 0.47%, only using one factor. These results are clearly good enough to classify meat to different quality grades.

MEAT QUALITY

Results from this study introduced a new application for Raman spectroscopy in meat quality analysis, namely estimation of IMF, and should encourage further research and development to make Raman spectroscopy a useful technique for the food industry.

INDUSTRY APPLICATIONS

Before Raman spectroscopy can be implemented in the meat industry, more research is needed to refine calibration models for IMF and other quality indicators (e.g. WHC and pH). Another important aspect is the need for instrumentation developed to endure the conditions and requirements of the meat industry.

Nofima

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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 per day. We evaluated NIR spectroscopy for on-line determination of fat and dry matter in such cheeses. The motivation is true time control of the production process.

Dairy production involves a range of complex processes where quality of the end product depends on raw material variation as well as process settings. Achieving the target end quality is important for profit and to prevent waste and low grade products. In order to control such processes it is crucial to measure the relevant quality properties in real-time during processing. This gives the opportunity to detect deviations and adjust the process.

A modern dairy factory can produce thousands of cheese blocks every day, but there are so far no tools for on-line determination of chemical composition of such blocks.

“With on-line NIR spectroscopy it is possible to determine fat and dry matter in blocks of cheese during the process.

ON LINE DETERMINATION

In this study we evaluated NIR spectroscopy for on-line determination of fat and dry matter in cheese blocks of approximate size 40 cm ×30 cm ×12 cm. Three different modes of sampling were tested: Scanning reflection, scanning interaction and imaging interaction measurements. The NIR measurements were collected in a pilot plant at three different production stages: 1) On fresh cheese block before pressing, 2) after pressing and 3) after salting.

A total of 160 cheeses from 10 different production batches were measured. Fat and dry matter content were determined in the local lab. Partial least squares regression (PLSR) was used to make calibrations between NIR and chemistry.

QUALITY PROPERTIES

In dairy production, one of the most important products is large blocks of cheese. Of the most important end quality properties are fat and dry matter content. During cheese making both the raw material (the milk) and the different processing steps affect this final chemical composition. The amount of dry matter is also decisive for the profitability of the process, so it is important to control the process towards target quality.

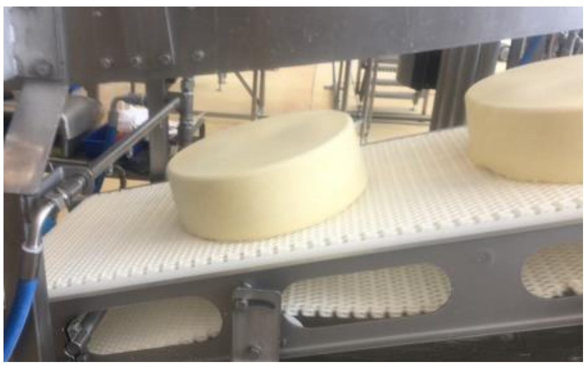

Figure 1: Cheese blocks in production.

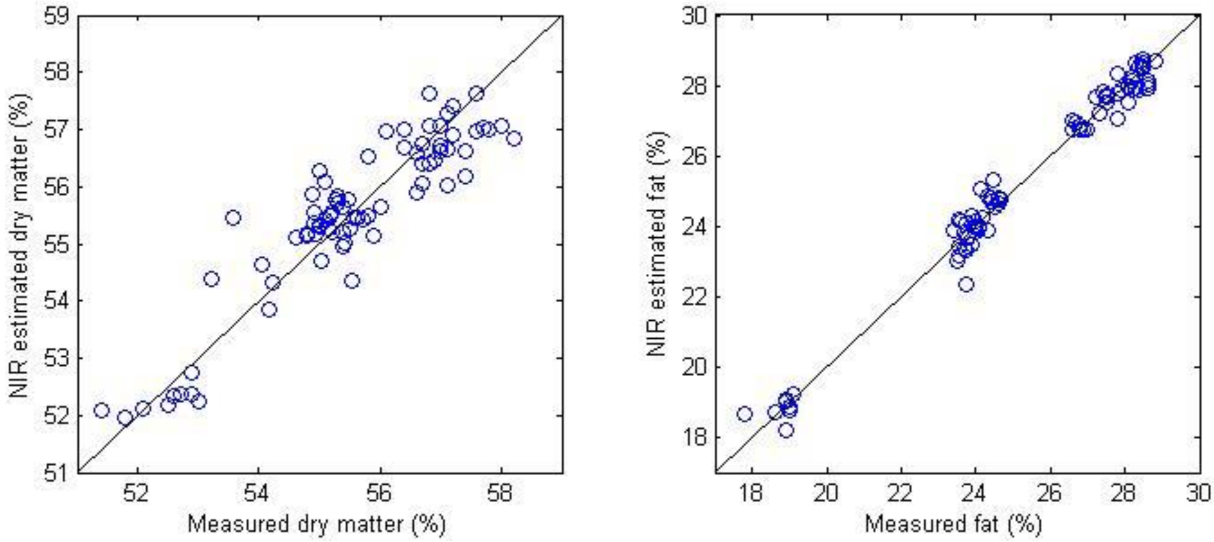

Figure 2:
On-line NIR predicted versus measured dry matter (left) and fat (right) in cheese blocks.

OBSERVATIONS

With NIR scanning reflection and interaction instruments, it was possible to determine fat and dry matter in cheese blocks with an accuracy of about ± 0.53% and ±0.63%, respectively. This is comparable with what you can achieve with a lab NIR instrument on homogenized cheese. This means that the surface chemistry of the blocks was representative for the average chemistry of the blocks.

We also observed that it is possible to predict fat and dry matter in pressed and salted cheeses based on NIR measurements on non-pressed cheese earlier in the process. This is possible as long as the pressing and salting process is the same every day.

IMPROVED CONTROL

The fact that NIR spectroscopy can determine fat and dry matter in cheese blocks at an early process stage, enables improved control of the cheese making process. Quality deviations can be detected, meaning that the process can be adjusted and cheeses outside specifications can be used for other products.

INDUSTRY 4.0

There are on-the-shelf NIR instruments that can be used for this application, so it is possible for dairy companies to implement this solution today. The use of such process analytical technology is expected to increase as food companies are now moving toward Industry 4.0 standards.

> “ *Measurements with on-line NIR spectroscopy enable improved control of the cheese making process, as it could be possible to detect deviations from target quality early in the process.*

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JENS PETTER WOLD

Raman spectroscopy for estimation of residual bone minerals in mechanically deboned chicken meat

Residual bone, measured as %calcium or %ash, is a strictly controlled quality parameter of mechanically deboned chicken meat (MDCM). Raman spectroscopy was developed as a rapid tool for estimation of this important parameter.

Mechanical deboning is a process where protein-reach mince is optimally recovered from animal carcasses. This process typically involves grinding of carcasses to create a meat-bone slurry and subsequently pass the slurry through a thieving system to separate out the meat from bone residues. According to European food safety authorities, one of the control parameters for mechanically separated meat is calcium (or ash) content, which is an indicator of residual bone. Currently there is no analytical tool that allows the rapid measurement of both calcium or ash levels in meat and bone mixtures in industrial environment.

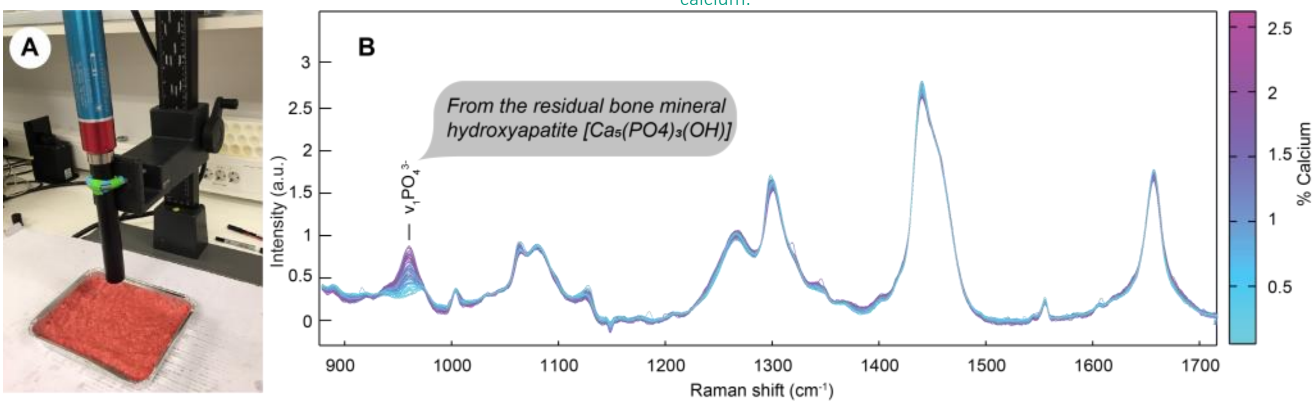
BONE GRANULAS

Depending on the process settings and carcass composition, fine granules of bone could be introduced to MDCM. Therefore, bone content of such meat is usually controlled by setting calcium or ash limits. The currently practiced analytical procedures for determination of calcium and ash in mechanically separated meat are based on methods such as titration and combustion, respectively. These methods are time consuming and are typically performed offline on few grams of sample that are expected to represent an entire batch of production. Therefore, these methods cannot be directly used to control calcium and ash content in a large-scale industrial production.

RAMAN SPECTROSCOPY

In the present study we have developed Raman spectroscopy as a rapid tool for estimation residual bone (i.e., ash and calcium) in MDCM. In contrast to the existing methods for measuring calcium content, e.g. titration, the presented strategy is rapid and requires minimal or no sample pre-treatments. Such analytical tool can further be developed and adopted to a production line to allow optimal recovery of MDCM while maintaining permissible calcium or ash levels.

Figure 1:
EMSC-corrected Raman spectra of the 79 samples from mechanical deboning of chicken. All spectra are color-weighed according the % calcium.



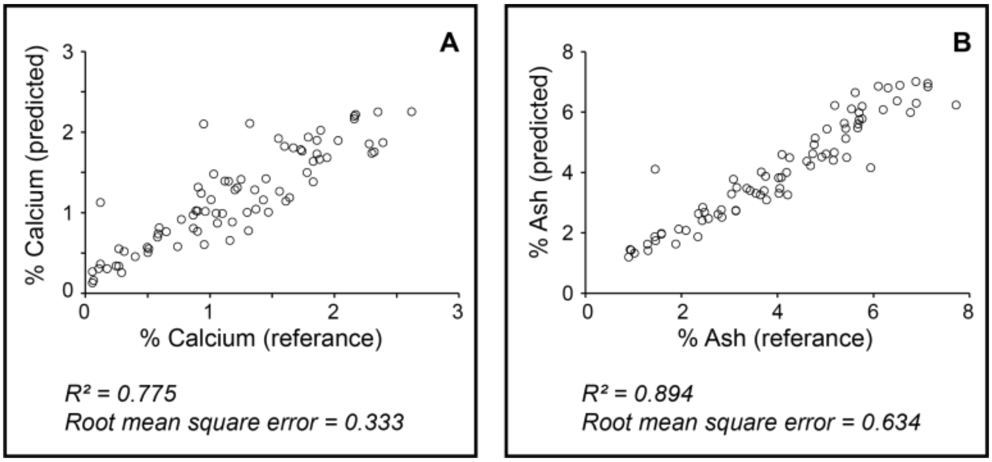


Figure 2:
PLSR correlation plot of calibration for determination of % calcium (A) and % ash (B) using the EMSC corrected Raman spectra.

SAMPLES

Raman spectra were acquired on 79 meat-bone mixture samples from four different production days of industrial mechanical chicken deboning (Figure 1). Principal component analysis (PCA) of the spectra reveled qualitative variation between the samples collected from the four production days (Figure 2). These variations were attributed, in addition to differences in calcium (or ash) content, differences in fatty acid compositions.

> *In EU member states, mechanical deboning is typically performed by setting the separation pressures below 100 bar for the production of low pressure mechanically separated meat. However, without a process control tool, such arbitrary settings of the separation force cannot always guarantee neither a permissible level of calcium nor an optimal yield. The here-presented tool based on Raman spectroscopy can serve as a rapid tool to control the level of calcium in industrial mechanical deboning of chicken meat.*

Raman-based partial least squares (PLS) regression models were developed, based on the preprocessed spectra, for estimation of both ash and calcium content. The prediction model based on extended multiplicative scattering correction (EMSC) corrected Raman spectra afforded the lowest root mean square error of cross-validation and the highest coefficient of determination (Figure 3).

CALSIUM AND ASH

The present work represents the first application of Raman spectroscopy for estimation of calcium and ash content in bone and meat mixtures from mechanical deboning of chicken. This technique holds a promising potential as industrially feasible on- or at-line tool for controlling quality of mechanically deboned chicken meat or similar food matrices.

FUTURE

Further work in expanding the calibration data set as well as optimizing the data acquisition setup are required in order to develop a robust prediction models that can be used in an industrial process control.

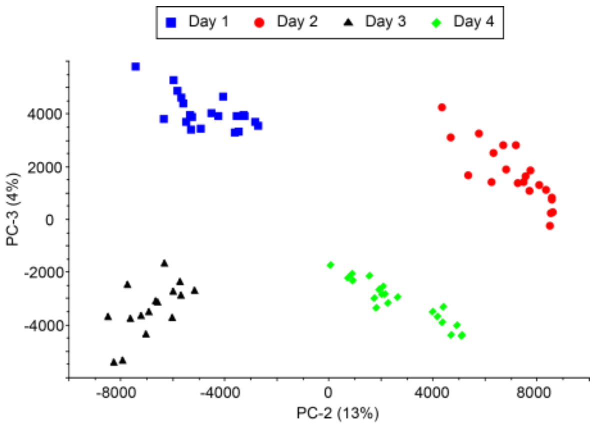


Figure 3:
Score plots from principal component analysis of the Raman data obtained for the 79 samples collected from four production days of mechanical chicken deboning.

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MAITRI THAKUR

Traceability of hides through the supply chain

Hides are one of the most important rest raw materials or plus-products produced by the meat industry as they are further processed and used in leather production.

The hide supply chain consists of a producer (farm), slaughterhouse, hide processor and a tannery. A lot of data is generated in this supply chain but there is an information gap due to lack of full traceability system between the tanner who can evaluate the quality of hides, and the farmer who is in the best position to influence the quality.

Traceability systems can help bridge this gap and result in a better product itself as well as a more environmentally sound process. Benefits of this level of traceability can also help in monitoring of animal health and growth.

NORWEGIAN HIDE PRODUCTION

Norwegian farmers use a great deal of time to make sure that their animals are doing well. Farms are small, and farmers have a lot of knowledge about animal husbandry, with a focus on animal health. Norwegian cattle hides are world-class and are used in the luxury market for the production of handbags, belts, shoes, and upholstery. Hide production in Norway was about 2.1 thousand tonnes in 2015, declining by an average annual rate of 15.3 % from 2008. In 2017 a total of 293 371 cattle hides were produced in Norway. Norwegian hides are known for their high quality and farmers earn up to 30 euros per animal when sold to international tanners. This hide is turned into luxury handbags each costing up to 470 dollars by big brands.

TRACEABILITY

Many international as well as Norwegian brands, like Gucci, Bolia and Dressmann are concerned about the impact of leather production and ethical sourcing and are demand higher levels of traceability. Leather supply-chains are multi-step and globalized, making it challenging to define criteria for sustainable leather and study the whole supply chain. Traceability can be used as a tool to drive leather sustainability. Traceability methods and systems for animal hides is an emerging field driven by a customer demand for sustainable and ethically sourced leather.

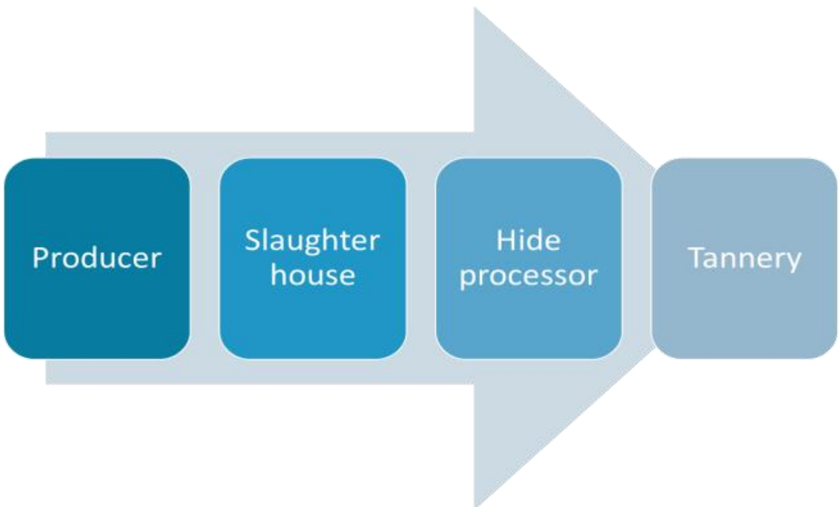

Figure 1:
Example of a typical supply chain of cattle hides.

Figure 2:
Example of laser tagged hide from tests done in collaboration with Norilia.

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

The hide supply chain was mapped using the process mapping methodology and a traceability system is proposed to track the hides from the farm to the tannery. Data capture points were identified, and various tagging methods like RFID, dot peening and laser tagging were evaluated.

SUITABLE TECHNOLOGIES

On their way from the farm to the tannery, the hides travel through many harsh environments, and it proved tricky to find a suitable technology to use for the tracking. Many of the tags were lost during the process or were unreadable after the tanning process. Tracking of hides using RFID technology showed the best results, and could be used for thracking of hides until the tannning step. The only technology that survived the tanning process was laser markings. Marking the hides with laser gave readable results also after the tanning process.

Tracking of hides is useful in authenticating the hides by linking them to a specific farm. The data generated through the supply chain from the quality inspections can also be used as a feedback to the producer and used to improve the handling practices on the farm as well as during the transport and slaughter of the animals.

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PIETER VERBOVEN

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

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

The porosity of a fruit or vegetable quantifies the amount of air spaces inside the product. The porosity strongly determines to what extent and how it dries out, or how well the product responses to modified or controlled atmopshere conditions.

A horticultural product transports required oxygen and many waste materials such as carbon dioxide and water through the pores. The porosity will therefore also have an influence on all kinds of changes that are associated with defective disposal of these waste materials, or a lack of oxygen. Examples are internal brown discolouration of apple or celeriac.

UNDERSTANDING POROSITY

The transport of gases in fruit and vegetables is more difficult in those parts of the fruit that contain small pores. Porosity is very heterogeneous throughout fruit and vegetables with sometimes very open and very dense parts. That is why it is important to quantitatively visualize porosity throughout the fruit in order to better understand the transport of respiratory gases.

KU Leuven demonstrated that X-ray CT (computed tomography) is a good method to map the porosity distribution of a whole fruit non-destructively and accurately, based on a simple correlation model between shades of gray (on a CT image) and porosity. The correlation is valid for different products, demonstrating wide application potential.

By locating the dense tissues in a product, we can better understand why certain patterns of abnormalities / symptoms occur in particular products or cultivars. This will help in optimizing storage conditions, understand storage and shelf life and design appropriate MA packaging.

“The new porosity measurement technique is convenient and easy to translate to other products”

A non-destructive method for porosity mapping is also a first step towards sensor development for inline measurement of porosity on sorting lines for specific quality assessment in relation to storability. Porosity maps of Jonagold apples, Purple-globe eggplants, Purple-top turnips and Conference pears confirm that fruits and vegetables cannot be seen as a uniform structure (Figure 1). Differences in porosity in

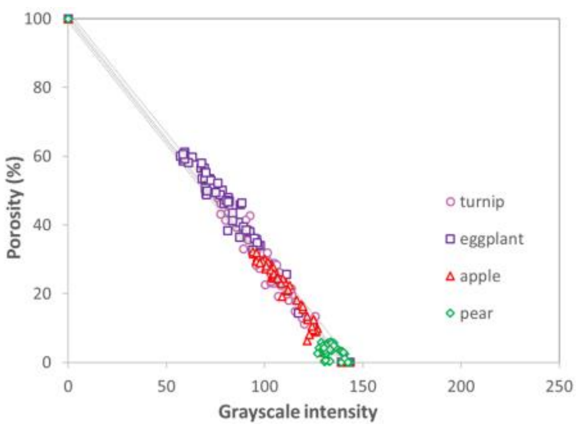

Figure 1:
Correlation between grayscale intensity of CT images and actual porosity (%) of eggplant, turnip, apple and pear .

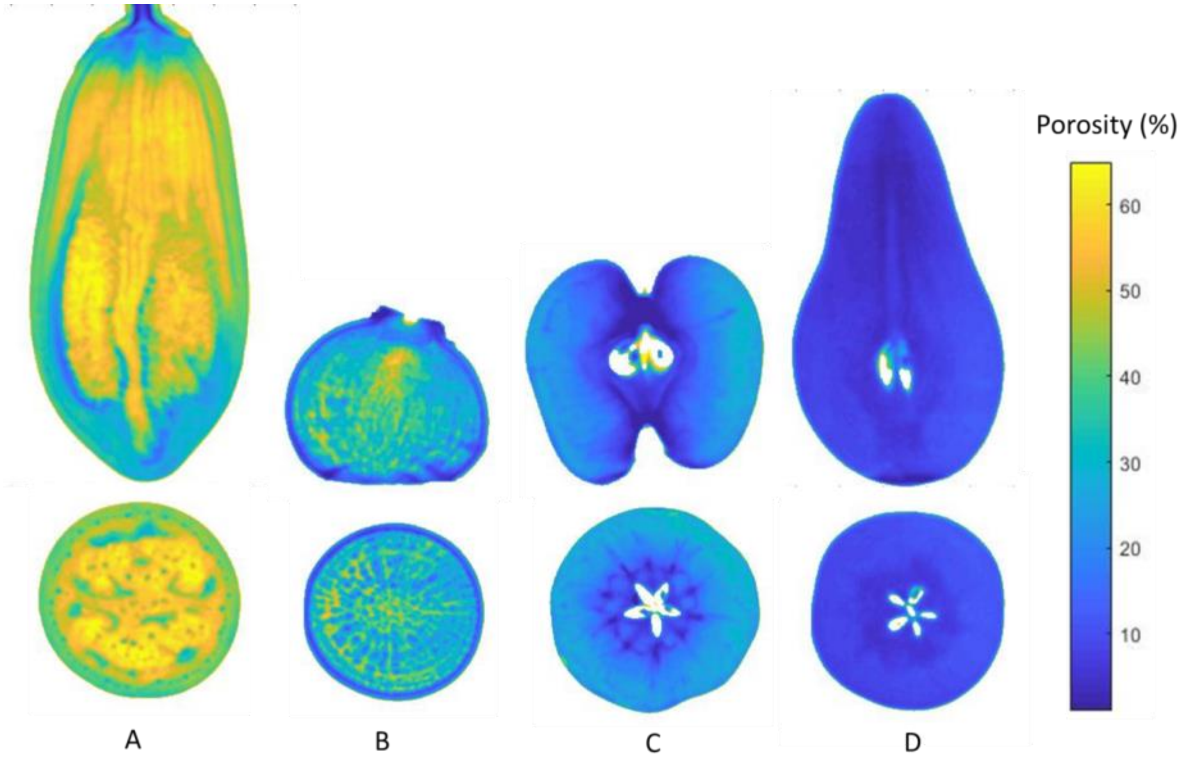

Figure 2:
Transaxial (X-Y, top) and coronal (X-Z, bottom) slices of eggplant (a), turnip (b), apple (c), and pear (c) porosity maps translated from

The technique will help in optimizing storage conditions, understand storage and shelf life, design appropriate MA packaging and is a basis for inline internal quality inspection.

specific tissues can be accurately predicted and visualized. On average, eggplant has the most porous structure (41.8 ± 1.0% porosity), followed by turnip (23.3 ± 3.4%), apple (19.7 ± 1.1%) and pear (4.0 ± 1.6%).

The highest porosity is in the core of the eggplant and turnip (45 - 65%). More towards the surface of the vegetables, the porosity of the flesh lowers to 30 to 45%. Certain zones have a porosity of less than 10%. In apple the porosity increases from core to surface, varying between 10 and 30%. The porosity of pear is very low and below 10% with a more dense tissue in the core.

"By locating the dense tissues in a product, we can better understand why certain patterns of abnormalities / symptoms occur in particular products or cultivars."

The new porosity measurement technique is more convenient than many previously used methods, because only a juice reference scan and a homogeneous water sample are needed to draw up porosity maps of other horticultural products. Based on the simple linear correlation, expansion to other products can therefore be done fairly quickly and easily.

The porosity maps will be of considerable value to comprehensively understand transport phenomena of metabolic gasses and water during postharvest handling and storage. Furthermore, this may lead to non-destructive online measurement methods for porosity in the framework of internal quality inspection.

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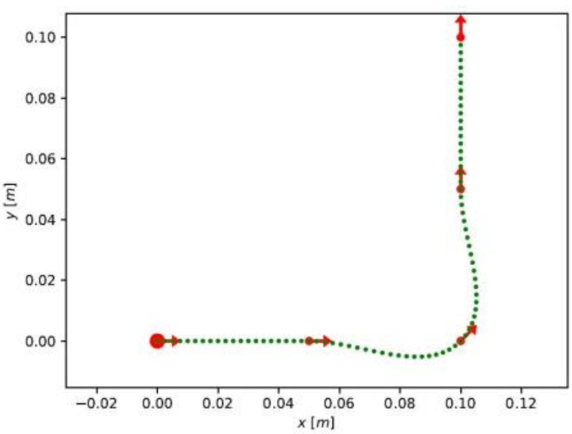
Intermediary Real-Time Trajectory Interpolating with Cubic Hermite Splines

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

When robot motion generation for a processing task is dependent on real-time sensor feed-back from the processing tool, the motion must be, by it's nature, generated at the temporal micro to meso level in real-time. Some open robot controllers allow real-time trajectory feeding at the micro level. These are 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 utilized for alleviating the application from the micro real-time requirement of the robot controller. This, in turn, opens for freedom of choice of the application platform, framework, or programming language.

"Doing the tough robot motion generation stuff with an adequate level of coding effort "



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 at the order of 10 µs or 100 µs. Good contact control under stiff conditions require 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. The macro level may adequately be called real-time task generation.

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

INTERPOLATOR

The interpolator is an independent, network-connected process with long life-time, maintaining the robot controller operative in it's real-time modus of operation over several application runs.

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

An example process: Cutting of meat is a fairly complex physical process, but the interaction is also fairly compliant and with good real-time tolerance. Hence the sensor integration for the motion generation may adequately be performed at the meso level.

With only a meso level requirement for the sensor to servo control loop, one may switch from the complexity of C++ code to something much more flexible, such as the interpreted language Python, for developing the entire control application. The robot controller itself, however, may still need to be fed 1 ms interpolated trajectory points.

The maintained operation of the robot controller modus by the interpolator plays a major role with respect to experimentation and development, since restarting the robot controller system is a process which generally requires some amount of manual interaction and waiting time.

“This framework enables teaching the robot complex motion trajectories during advanced manipulation tasks such as f.e. cutting, with a relatively low coding effort, which is important for fast development cycles during research investigations"

SOFTWARE

A software program have been developed which utilizes Cubic Hermite Splines for generating a smooth trajectory at a resolution of 1 ms, which is fed in real-time to the robot controller. At the other end, this program listens for a network connection from an sensor-based application motion generator, which is required to real-time feed a trajectory at the meso level of resolution; 10 ms to 100 ms. For sufficiently smooth application trajectories this software is performing well.

The software has not yet been taken into application use. Experiments with using it in a Python-based motion generation framework shows that the principle is sound.

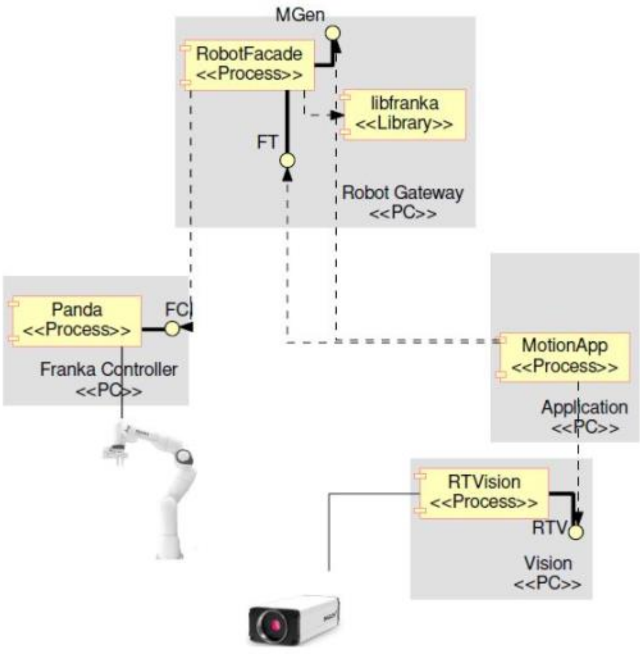


Figure 2:
Illustration of the deployment of components surrounding the interpolator component. The interpolator is named "RobotFacade" in the diagram.

NETWORK COMMUNICATION

Network communication glitches may distort the communication to the robot controller. This may lead to divergence between the generated trajectory and the actual robot position. This again leads to large accelerations in the robot arm, exceeding the allowed limits. Avoiding and handling such network commutnication glitches is the current focus of activity.

Avoiding or minimizing glitches is achieved by using adequate computing and network hardware and optimizing the real-time performance of the software.

Handling the glitches is a matter of "picking up" the robot in it's actual state afterwards, and smoothly transitioning it back to the planned trajectory under execution.

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Marine

related research

MAITRI THAKUR

Information sharing strategies in whitefish supply chain

Information sharing is one of the main supply chain strategies for reducing uncertainty and is vital for supply chain efficiency. All actors can benefit from sharing relevant information in a timely manner and improve supply chain coordination.

Whitefish supply chains are complex in nature due to seasonal variations, high supply uncertainty and rapid quality deterioration due to handling and temperature variations. In Norway, most wild cod is exported as lower-value products preserved in salted, dried, and frozen forms. In-season whitefish processors typically buy from coastal vessels that deliver fresh fish and in off-season buy from sea-going vessels that deliver frozen fish. This lack of vertical integration seems to limit information sharing between the fishing vessels and the processors. With limited data, there are limits for decision support at the processing stage and this also limits any data flow upstream in the value chain.

INFORMATION FLOW

The Event-driven Process Chains (EPC) technique was used to develop an AS-IS model of the whitefish processing chain depicting the current material and information flow practices between the fishing vessels and the processors. Case study methodology was used to analyse the whitefish chain including the fishing and processing operations. Information about the data management and supply chain planning practices was gathered through semi-structured interviews.

Management of food supply chains are particularly complex due to an intrinsic focus on product quality. Various motivation factors for supply chain information sharing are mentioned in the literature and include legislative requirements, efficient product recalls, optimization of business processes and product diffe-

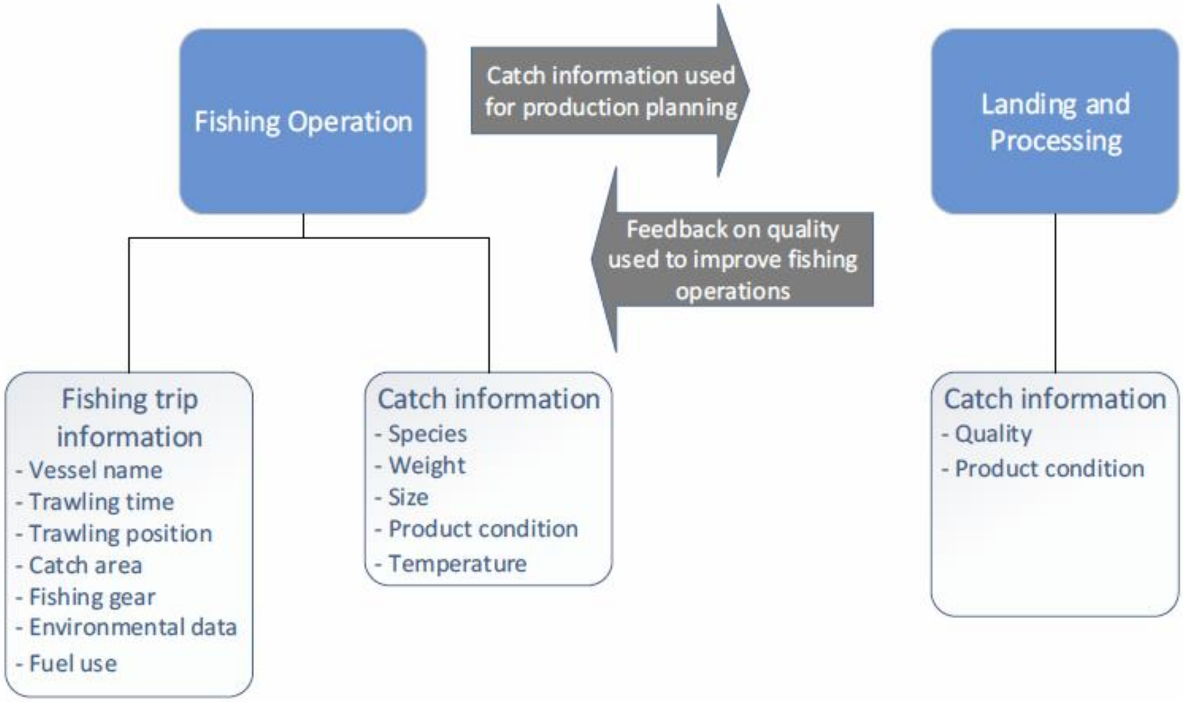

Figure 2:
Suggested information exchange in whitefish supply chain

> *The question is how to share the right information at the right time in the right format to maximize the mutual benefits of the whole supply chain as well as the individual business players."*

rentiation. In recent years, several studies have been conducted on the value of information sharing in supply chains and its impact on supply chain performance.

A lot of information is available about each fishing trip but is not being used in an optimal way to improve either the fishing operations or the production planning. In addition, detailed catch information such as temperature and product condition is available onboard the fishing vessels but is not shared with the processors. If available in advance, this information can be used by the processors to improve their production planning decisions.

CONSIDERING QUALITY

The information on quality and the fishing trip can be used to optimize the fishing operations, for example, selecting the best fishing areas. The information linked to each operation is already available in the existing systems such as the eCatch and TrackWell. The quality information is recorded by the processors in their internal databases.

Improved information sharing can in turn impact production planning and can be used for differentiation of the products in market. Access to real-time catch and fleet information can be used to harmonize fishing effort by many fishing vessels and can also be used to decide the delivery times and locations of the different vessels. Use of historical information about season, catch area and effects on catch quality can be used to improve the fishing plans.

Further work is needed to study the willingness to share information in the supply chains, barriers and opportunities for both parties – the fishermen and the processors. In absence of vertical integration, the concept of vertical coordination needs to be explored where fishermen and processors willingly share information for mutual benefits.

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

Managing supply uncertainty by a formal stochastic programming approach demonstrates how expected profit may be increased due to more robust production plans.

PRODUCTION PLANNING

Operational production planning deals with establishing optimal production plans. A production plan determines which production lines to utilize, which products to produce and allocation of resources such as personnel and machines. At the time of planning the supply of raw material for use in production is unknown with respect to volumes, quality and distribution of species.

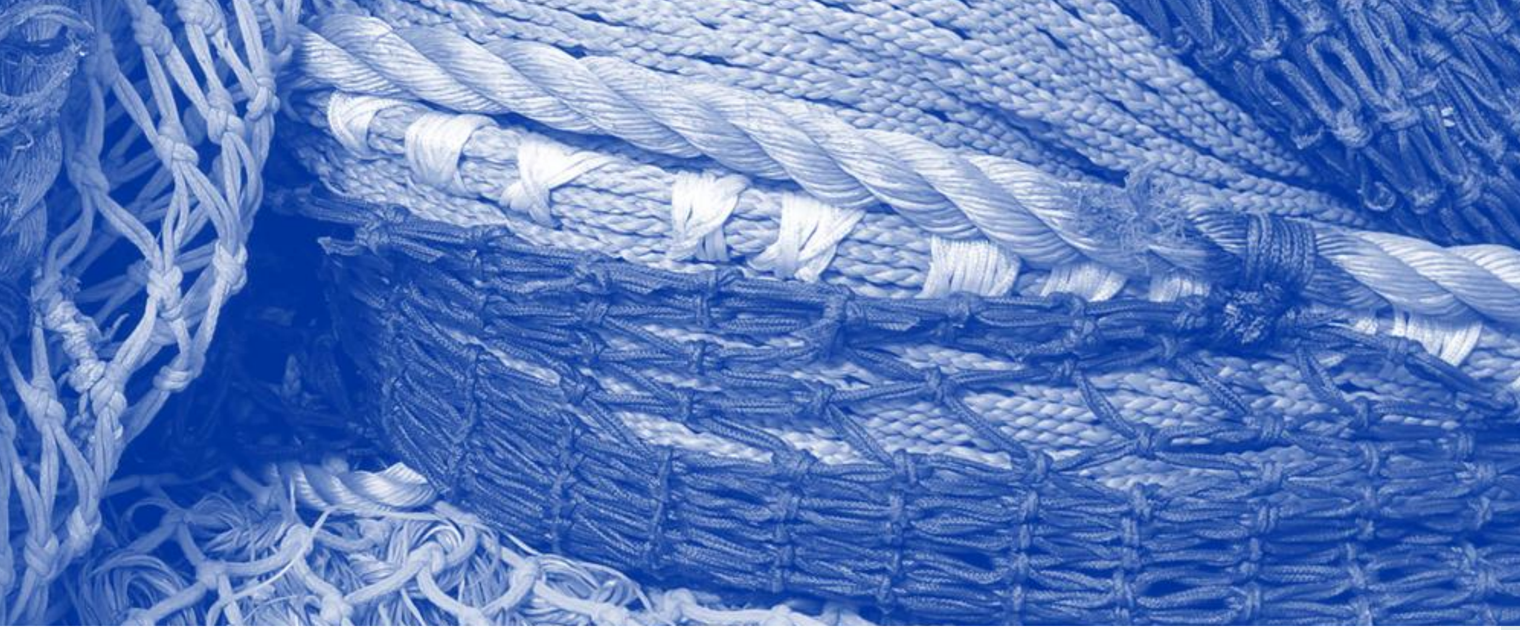
A production plan which is optimal in case of high catch volumes may turn out to be very costly in case of a low catch scenario. Stochastic programming is an approach to establish plans that maximize expected profit taking such uncertainty into account.

PROGRAMMING

The research explores a stochastic programming approach for handling supply uncertainties in operational production planning. In the problem structuring phase focus has been on identification of decision variables such as content of different execution plans, how many hours to follow each execution plan, how many workers to allocate for the work and whether to pay extra for over time. Next the various uncertainty factors are made operational, i.e., by assigning probabilities for various scenarios. A scenario is a discretization of the supply with an adding probability, for example high catch, high percentage of high catch quality, medium percentage of haddock and Pollock.

SUPPLY UNCERTAINTY

To reduce supply uncertainty a statistical prediction model has been developed. Operations planners in the industry have addressed the challenge of efficient planning under uncertainty and how information regarding type of vessels, fishing gear, weather etc may be used for improved catch prediction and reduction



“A systematic approach to uncertainty enables robust production plans where opportunities and risks are balanced to give the long term best performance”.

in uncertainty. Finally from literature it is well known that treating uncertainty explicitly in optimization problems outperforms an approach where uncertain variables are replaced by their expected values.

To simplify modelling main focus has been on critical activities such as filleting and cutting in the production line. Only processing of cod is considered, thus future models needs to include other species like haddock and Pollock. Rather than considering the flow of raw material in the production line the modelling treats a limited number of so-called production plans. The main decision variable is how many hours per day a given production plan shall applied.

CASE STUDY

From the case study the stochastic programming approach gives a 70% higher expected profit compared to the situation where uncertainty is ignored. Refining the model by adding more discretization levels in the scenario building gives even better result, but at the cost of more complex models.

The catch prediction model developed is able to explain more than 60% of the variability by weather forecast and type of vessel as explanatory variables.

The approach has identified an approach where the value of more refined uncer-tainty models is quantified. This enables the developers of production planning tools to include only the most significant uncertainty factors in a manner where expected gain is balanced with the complexity of the model. Further, the catch prediction model may be used to reduce the supply uncertainty.

A limited number of uncertainty factors have been included, and it remains to investigate uncertainty in quality deterioration rate, initial quality distribution of the catch, production resources and demand/selling prices. The current model only deals with a 3 day period, and hence the model should be expanded to a rolling horizon model. Finally a multi-plant production planning model will demonstrate how production could be distributed across plants in an optimal manner.

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Integrated planning in white fish supply chains

Through integrated supply chain planning by sharing information, uncertainty is mitigated leading to improved supply chain performance in whitefish processors.. During the iProcess project, NTNU has had several researchers and students at NTNU has worked on tasks related to this.

Throughout the Norwegian history, fishing and the fishing industry has been a basis for life and culture, contributing significantly to economic growth, export earnings and industrial innovation.

Despite the downturn of the industry with respect to profitability, downscale of facilities, and employees, the industry has managed to increase the market reach and initiate product and process innovation. However, the industry is operating in a highly global and competitive market forcing performance improvement, efficiency and market responsiveness. By managing the supply chain operations, securing alignment of demand and supply applying integration and coordination mechanisms, information sharing performance can improve.

MASTERSTUDENTS

Through the iProcess project several students have written their master thesis on the research conducted in the iProcess project. Their research explores the impact of supply and demand uncertainty on supply chain operations: how tactical supply chain planning can improve performance, particularly the role of information and technology. The analysis proposes a process design for integrated tactical supply chain planning.

SUPPLY UNCERTAINTY

Literature have highlighted the negative impact of supply uncertainty on supply chain performance, such as inefficient capacity utilization, risk and cost of over- and understocking, unreliable availability of materials and poor service level. Supply chain planning (SCP) aims to mitigate uncertainty through coordinating and integrating key business processes from raw materials procurement, production, distribution and sales, and by managing demand and supply. This is particularly relevant in environments as the whitefish interesting

In iProcess we have identified sources of supply uncertainty has been identified and ranked, and applied to propose how whitefish processors can improve the ability to increase capacity utilization, service level (availability of products) and profitability. Further, the analysis shows the high demand sensitivity to price mechanisms, and identifies the importance of the access to updated information about raw material quality and market information (short and long term).

SUPPLY AND DEMAND

Through analysis of supply and demand uncertainty, mitigation strategies are proposed. The integrated tactical planning design proposes to integrate suppliers and customers in the planning, and to make us of updated information and technology to support planning. Additionally, suppliers can be involved in supplier development programmes leading to collaboration, commitment and contractual terms with collaborative incentives (price mechanisms and risk sharing). Information dash-

> *There is so much information flowing, often in unorganized forms, through dialogue with customers, phone calls, WhatsApp chats... You have to try to extract the necessary information for making good decisions and just accept the dynamics and sporadic tendencies in the fresh market*

boards providing information for market related decision can improve performance.

Planning at a tactical supply chain level is particularly important in environments with long term uncertainty where decision makers struggle to predict internal and external long-term changes such as seasonality and quota systems.

GLOBAL CHALLENGE

Supply uncertainty has because of globalization, outsourcing, lean principles and competitiveness become a critical source of uncertainty, particularly for sectors based on raw material from natural resources with limited possibilities for storage, such as the food sector. Except from characteristics such as supply quantity, quality, lead time, price and product/raw material (size and type) less is known about the supply uncertainty profile in terms of likelihood, severity and contextual factors, which makes the planning more efficient and robust.

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KIRA SVENDSEN

5 points to consider before setting sails in data science projects in the food industry

In the slipstream of the digitalization of modern food industry, part of Industry 4.0, a paramount need to handle larger and larger amounts of data has called for new developments in both the analytical toolbox and in digital infrastructure. It has expanded the possibilities of the creation of value from data.

Terms like Data Science, Big Data, Machine Learning and more recently AI flourish. The possibilities rising from these techniques are immense. However, it should be stressed that it is no Columbus' egg. One size does not fit all and going full steam on advanced data science can be a bumpy ride if not thought through and done properly. Here we list a few points to consider before starting a data science project in the food production industry.

WHAT IS OUR GOAL?

A sharp question calls for a sharp answer, also when the question is put to data. We have experienced data science projects started up with a description a la "we would like to learn more about what is going on" or "we must be able to use AI/Big Data on all the data we have". It would be intriguing if a data scientist could answer that, but it is also highly unlikely. Vague goals yields vague results.

Before proclaiming a need of AI and Big Data it is advisable to consider what you hope to achieve. What would bring most value to the company? That might not be insights from fancy complex algorithms. If a simple display of your data brings value you may not need fancy AI to begin with.

> *Vague goals yields vague results.*

ACCESS TO DATA

Even though there is a lot of data, how accessible is it truly?

- *Data kept in paper files*. Making paper-data suitable for analytical work calls for manual handling. This might be labor intense and time consuming, hence expensive.
- *Data stored in detached databases without keys*. The data cannot be linked and the Big Data dream is in reality just many smaller data nightmares. Detective work in cooperation between the data owner and the data scientist might be able to deduct keys in a somewhat cumbersome time-consuming joint venture.
- *Data stored in detached databases with keys*. When keys do exists, the logistics of gathering the pieces and getting data in to shape is doable, but all parties should be realistic in planning the project. This part is time-consuming. Analyses of how data scientists spend their time estimate that between 51% and 79% of the time is spend on cleaning and organizing data [1,2,3].
- *Data stored in a database*. Even when your data looks easily accessible there will be a phase where the data scientist massages his or her way into data. Often, the variables have cryptic names and lack description. The project that did not find skeletons in the data closet has yet to be experienced.

Figure 1:
Data from many sources can be quite a challenge to sort out and bring together.

- *Legal green light*. Compliance with the rules for data sharing, GDPR and other interests should be cleared before starting the project.

DATA QUALITY

Data quality is a great many things. A few to consider are:

- Relevance. Data should relate to the questions asked. You may e.g. be interested in learning about quality variations or occurrences of faults in your production, but these may not be a well-defined measure nor registered to match your purpose.
- Correctness. No amount of wrong data will give you the right answer. If data is deeply flawed, there really is not much to do about that. That said, missingness, outliers and other artifacts can (to some extent) be handled in different machine learning methods.
- Amount. Naturally, there should be an adequate amount of data, but when quality goes up the need for data in order to find signals goes down. And vice versa – large amounts of irrelevant data is not useful. Another issue can be that fundamental changes, like new equipment, means that data cannot be compared before and after the change, which consequently limits the amount of data for the analysis.
- Variation. In food production, a recipe is usually followed leading to very little variation in the data. This is good for the production, but if the objective of the project is to learn how the recipe in some ways expands beyond the usual production frames, then observing variation is crucial.

- General dirtiness. This is what is usually refeed to as janitor-work, and it might just still be one of the biggest hurdles to finding insights in data [4]. It can be so many things like labels changing over time, finding and handling missing data, finding and handling outliers, dates and timestamps, finding a suitable feature representation, etc. It is important to notice that this task usually consumes the majority of the project hours and is crucial for the outcome, but often has limited focus in comparison.

> *Before proclaiming a need of AI and Big Data it is advisable to consider what you hope to achieve.*

ENGAGEMENT

Success in a data science project requires engagement from all parties as they bring very different but equally important knowledge and competences to the table. Data science might have been oversold as a 'silver bullet'; just hand over your (big) data to the experts, leave them simmering for a while, and groundbreaking new knowledge will emerge. This is not how it works. The data owner possess knowledge crucial for the project.

- *Data collection*. Changes in equipment, procedures or sensors etc. over time. Data engineers are an important addition to the data scientist in overcoming data infrastructure issues as well as general dirtiness.
- *Domaine knowledge*. What are we looking at? What can we expect? What do we already know and thus can be incorporated in the modeling work? Are there important factors that are *not* measured or registered (there always is)?

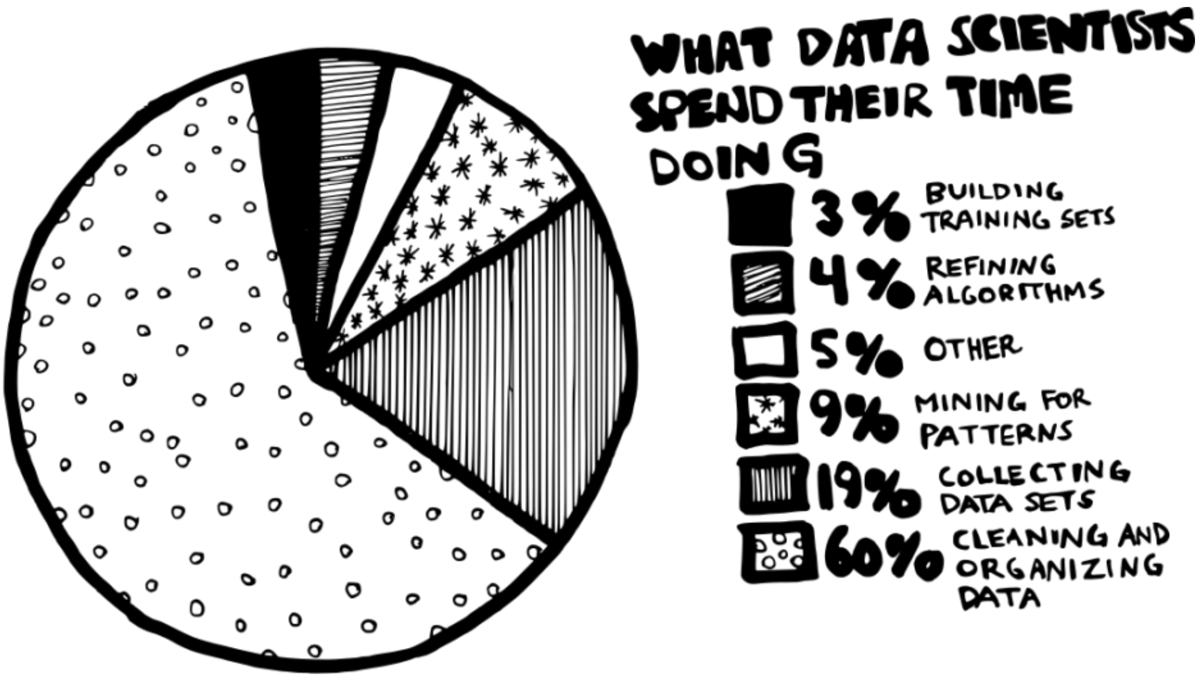

Figure 2:
Cleaning and handling data is the most time-consuming and often forgotten task in data science projects [2]. .

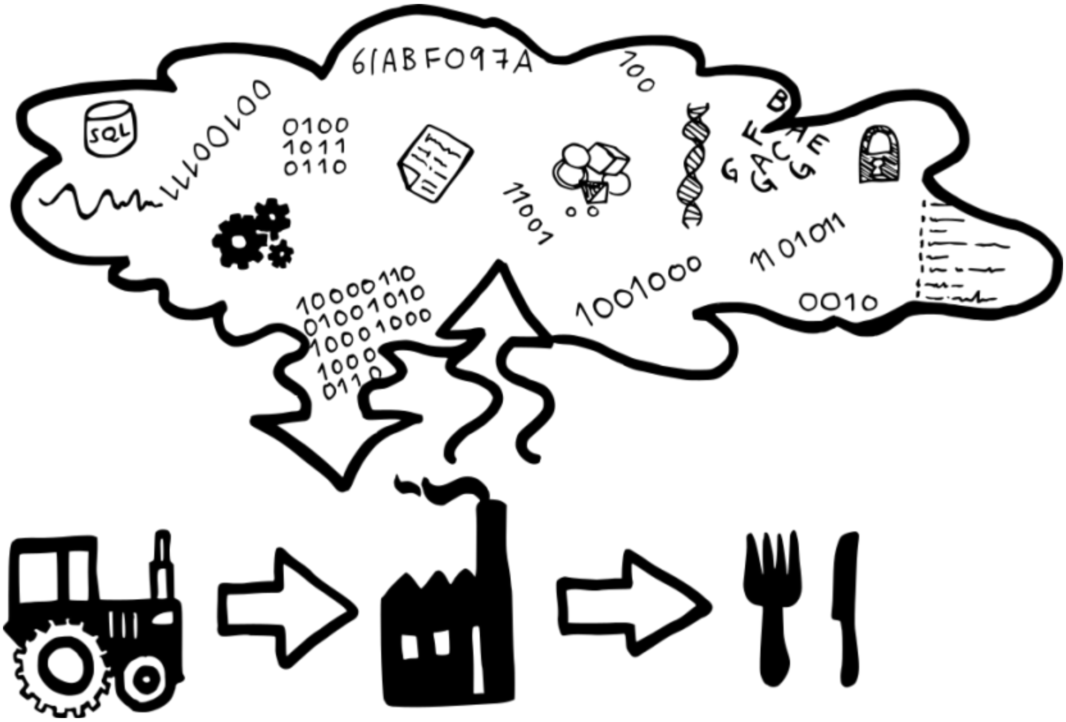

Figure 3:
Cleaning and handling data is the most time-consuming and often forgotten task in data science projects [2].

- *End users*. What are the expectations and requirements of the users, which can be operators, managers, etc. Putting the outcomes into a context can guide the project towards success in terms of ownership, adaptation of results, as well as value creation.

PLAN FOR THE FUTURE

Long term sustainable solutions based on data science need anchoring of the model in the business. The project should from the beginning, and as it proceeds, consider how the results of the analyses can be implemented and equally important maintained for the future benefit of the business. The model will need checkups and updates over time to stay relevant. A solid hand over is crucial for the longevity of the project success.

[1] https://visit.figure-eight.com/rs/416-ZBE-142/images/CrowdFlower_DataScienceReport.pdf
[2] https://www.forbes.com/sites/gilpress/2016/03/23/data-preparation-most-time-consuming-least-enjoyable-data-science-task-survey-says/#3038fafb6f63
[3] https://www.kaggle.com/surveys/2017
[4]https://www.nytimes.com/2014/08/18/technology/for-big-data-scientists-hurdle-to-insights-is-janitor-work.html

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RAGNAR TVETERÅS AND HILDE SANDVOLD

Barriers to increased automation and technological development in food processing

The most important barrier for introduction of technology with artificial intelligence in processing of food in Norway, is the complexity of the new technology. The new technology is difficult for firms to adopt with their current knowledge base.

INCREASED AUTOMATION

Increased use of automation with artificial intelligence has changed the production processes in almost every industrial sector the last decades. Processing of food has so far been an exception to this trend. Several explanations can be given for this, with the product itself as the largest. New innovative technology, which can better handle fragile raw materials, are now available. However, the degree of automation is still low. This indicate obstacles in further technological development and raise questions like: Why is the degree of automation still so low? What kind of barriers do the firms face? In this survey, we aim to analyse why this industry lag behind, and why these firms seem to struggle to adopt new and more flexible technology. The purpose of the study is to investigate if the firms experience any particular barriers, or bottlenecks, for adoption of technology with artificial intelligence.

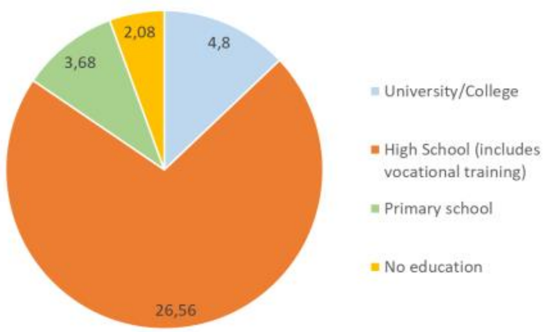

Figure 1:
Level of education for most of the employees in the food processing industry.

SURVEY

In order to analyse the challenges in technological development for Norwegian food processing firms, we conduct a tailored innovation survey. In total, 250 firms of different size attended. This accounted for 10 % of all processing firms in Norway. The firm's processes raw material from both agriculture and seafood. The data collection took the form of telephone interviews with the chief executive. The 25 questions were mainly related to automation, but the firms were also asked about their R&D capabilities, motivation factors for increased innovation and collaboration skills.

NEW BUSINESS MODELS

The overall purpose of the survey is to investigate if there are any strategies or business models that are more successful than others when firms consider to adopt new technology. This is important because introduction of new and more flexible technology has the ability to foster higher efficiency and better profitability, which again will contribute to increase the valued added. Therefore, to improve the understanding of the factors that increase the competitiveness of the Norwegian food processing industry, it is important to examine the barriers for adoption of new technology.

The econometric analyses indicate that several barriers for introduction of new technology is present. The fact that new technology is too complex and too difficult to understand seems to be the most important challenge for technological development. However,

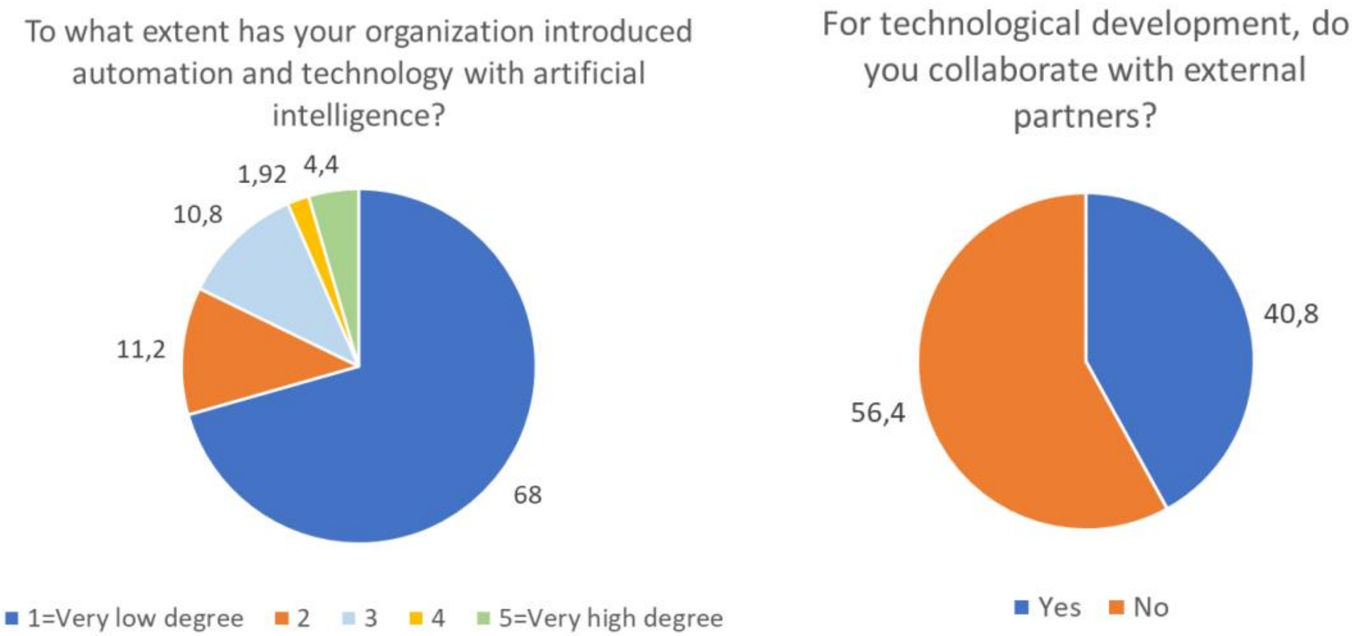

Figure 2:
To the left — The degree of automation and use of artificial intelligence in the Norwegian food processing industry.
To the right — Different types of collaboration partners in the innovation processes in the Norwegian food processing industry.

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

DECISIONMAKING TOOL

In processing of food, the firms first and foremost need increased technological competencies to understand the new technology in a proper way. According to this, the collaboration skills seems to be developed, both in the national and international context.

the low level of education and low degree of collaboration in the industry will also have large effects on the technological adoption. We find that only 12 % of the employees have higher education, and only 56 % of the firms collaborate with others in technological issues. Furthermore, 64 % of the firms do not have employees that are particularly dedicated to R&D work, and 75 % does not have a dedicated R&D budget.

According to our finding, there is reason to believe that firms that seeks to increase automation need to increase their competence in several areas.

There is reason to believe that the business models will change in the years to come. Structures that emphasises technological and collaboration skills will be more important than ever to increase the use of artificial intelligence in processing of food in Norway.

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CECILIE SALOMONSEN

Designing within the circular economy

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

Circular design is a tool used in the circular economy. The future must become more sustainable than what it is today, and designers can pave the way forward by using circular design.

CIRCULAR DESIGN

In circular design, the idea is to design the product so that it influences the whole system around it in a circular way. To do this, the industrial designer must step further away from the product that what one usually does. To look at different levels of complexity isn't new, but this holistic approach requires that the designers think about the system that a product or service is a part of. Circular design is never done, it's not like "linear design" where you design a product and send it off into the world. In circular design, the product will return to become repaired, upgraded, reused or recycled. In "linear design", the main focus is on the end user, in circular economy one widens the view and considers all stakeholders and users of a product in every phase of the products life cycle. For a designer, this includes building feedback loops into the product and knowing the life cycle of the materials that are being used.[1]

DESIGN STRATEGIES

There are two main design strategies to work with. These as designing for slowing resources loops and designing 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, design strategies such as Biomimicry, Life Cycle Analysis and Cradle to cradle design is other options to use on the way towards sustainable design.

FOCUS AREAS FOR THE FOOD INDUSTRY AND THEIR VENDORS

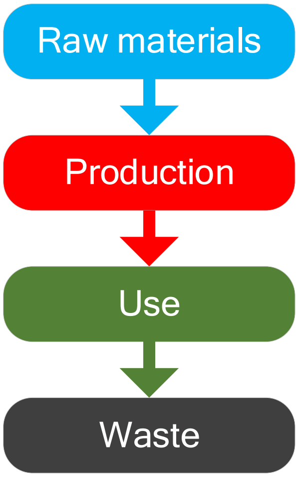
The two main focus areas for the food industry are how to use rest raw material for high value products and packaging design with all its issues to consider. For the food vendor companies, there are different focus areas. This is material knowledge, design for disassembly and upcycling, hygienic design, design for maintenances, upgrading and repair and design for professional user groups and stakeholders to mention some key focus areas.

iPROCESS APPLICATIONS

In the iProcess project, there are several cases that investigates how new and flexible technology can improve todays production methods. One case investigates how to measure fat- and dry matter in cheese. There are also quite different cases that looks into robotics and how robots can be used for cutting down ham or packaging of fragile and compliant objects with variations in shape and size such as fish. What these different cases have in common is how to bring these technologies into products that will be a part of the every day use in different production plants. When we look upon this task from a circular design perspective, the strategies for slowing down resource

[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.



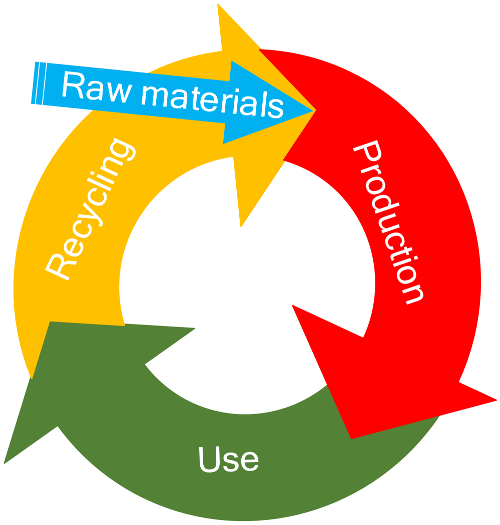


Figure 1:
Linear versus circular economy.

> *Circular design is never done, it's not like "linear design" where you design a product and send it off into the world. In circular design, the product will return to become repaired, upgraded, reused or recycled.*

loops are important to have in mind. One needs to design for durability and reliability. It's also important to design for product life extension so that it is easy to clean, maintain, repair and the possibility to change parts when needed or upgrade the software. And last, but not least, to design for dis- and reassembly so that the different materials that the product consists of can be taken care of in their respective cycles for a new afterlife. This will also contribute to design for closing the material loops.

Other cases in the iProcess project investigates information flow. As previous mentioned, hides from Nortura are being used by Norilia for different products. The iProcess project is looking into the information flow from farm to tannery, which technology can be used to transfer information throughout the process and give feedback to previous stages. This information can then be used to improve each stage performance so that the hides for every improvement in the production line from farm to tannery will improve the quality of the hides. With an improved quality of the hides, the producers will have an increased flexibility to choose what to produce from the hides. This will give the producer a greater chance to meet the consumers demands and create products suited for a circular economy.

Another case that investigates information logistics, and raw material flow is two cases on whitefish. How much information is on board a fishing vessel about the catch, can more information be captured and how soon can this information be transferred to the production plant, so they can start planning their production? With an optimized production plan, more of the raw material can be used for suiting applications that fits the marked. Optimized production planning that takes the marked into consideration will in a circular economy point of view possibly reduce the amount of cascading at the retailer and end consumer stage and more of the products will be used as intended.

CONCLUSIONS

There is always a challenge when starting with a new approach, but circular design is the way forward to create a sustainable future. Industrial designers can pave the way by showing how different methods can be used within a company. Designers can be the drivers for a change towards circular economy by creating products and services that matches the demands for a sustainable future.

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Dissemination

iProcess dissemination

Scientific publications:

1. Dreyer, H.C., Kiil, K., Dukovska-Popovska, I. and Kaipia, R. 2018. Proposal for enhancing tactical planning in grocery retailing with S&OP. Journal of Physical Distribution and Logistics Management. Vol 48. Issued: 2. pp. 114-138.

2. Sileshi Wubshet, Jens Petter Wold, Nils Kristian Afseth, Ulrike Böcker, Diana Lindberg and Ingrid Måge (2018). "Feed-Forward Prediction of Product Qualities in Enzymatic Protein Hydrolysis of Poultry By-products: a Spectroscopic Approach." Food and Bioprocess Technology **11**(11): 2032-2043.

3. Misimi, E., Olofsson, A., Eilertsen, A., Ruud Øye, E., Mathiassen, J.R. (2018). Robotic Handling of Compliant Food objects by Robust Learning from Demonstration. 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), IEEE.

4. Sileshi Wubshet, Jens Petter Wold, Ulrike Böcker, Sanden, K. W., Nils Kristian Afseth (2019). "Raman spectroscopy for quantification of residual calcium and total ash in mechanically deboned chicken meat." Food Control **95**: 267 -273.

5. Thakur, M. and V. N. Gunnlaugsson (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): 240-252.

6. Dreyer, H.C., Kiil, K., Dukovska-Popovska, I., Kaipia, R. (2018). "Proposals for enhancing tactical planning in grocery retailing with S&OP." International Journal of Physical Distribution & Logistics Management **48**(2): 114-138.

7. Farstad, P.K., Thomseth, T.N., Dreyer, H.C., Hedenstierna, C.P. (2018). The impact of supply chain uncertainty on supply chain planning process: reflections from a whitefish case study. (Conference paper – proceedings)

8. E. Misimi, A. Olofsson, A. Eilertsen, E. R. Øye, J. R. Mathiassen. 2018. Robotic Handling of Compliant Food Objects using Robust Learning from Demonstration. IROS 2018.Wubshet SG, Wold JP, Böcker U, Wahlstrøm Sanden K, Afseth NK. 2018. Raman spectroscopy for quantification of residual calcium and total ash in mechanically deboned chicken meat. Foot Control. 95: 267-273

9. Wubshet SG, Wold JP, Afseth NK, Böcker U, Lindberg D, Ihunegbo FN, Måge I. 2018. Feed-Forward Prediction of Product Qualities in Enzymatic Protein Hydrolysis of Poultry By-products: a Spectroscopic Approach. Food

and Bioprocess Technol. https://doi.org/10.1007/s11947-018-2161-y

10. M. van Dael, P. Verboven, A. zanella, J. Sijbers, B. Nicoali (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." Post-harvest Biology and Technology **148**: 218-227.

11. Eskildsen, C. E., Sanden, K. W., Wubshet, S.G., Andersen, P.V., Øyaas, J., 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: 0967033519855436.

12. Nugraha B., Verboven P., Janssen S., Wang Z., Nicolai B. (2019). Non-destructive porosity mapping of fruit and vegetables using X-Ray CT. POSTHARVEST BIOLOGY AND TECHNOLOGY, 150, 80-89.

13. Sengupta, A., Krupa, A. Marchand, E. (2019). Tracking of Non-Rigid Objects using RGB-D Camera. IEEE International Conference on Systems, Man, and Cybernetics.

14. Sengupta, A., Krupa, A. Marchand, E. (2019). RGB-D TRACKING OF COMPLEX SHAPES USING COARSE OBJECT MODELS. IEEE International Conference on Image Processing (ICIP) .'

15. A. Lillienskiold, R. Rahaf, P. R. Giordano, C, Pacchierotti, E. Misimi. (2019) Human-Inspired Haptic-Enabled Learning from Prehensile Move Demonstrations. (Submitted to IEEE Transactions of Human-Machine Systems)

16. Janssen, S., Verboven, P., Nugraha B., Wang, Z. Boone, M., Josipovic, I., Nicolaï, B.M. 2019. 3D pore structure analysis of intact 'Braeburn' apples using X-ray micro-CT. Postharvest Biology and Technology, 159, 111014 [available online]

17. Nugraha B., Verboven P., Janssen S., Wang Z., Nicolai B. (2019). Non-destructive porosity mapping of fruit and vegetables using X-Ray CT. Postharvest Biology and Technology, 150, 80-89.

18. Eskildsen CE, Sanden KW, Wubshet SG, Andersen PV, Øyaas J, Wold JP. 2019. On-line estimation of dry matter and fat content in production blocks of Swiss cheese during production by near-infrared spectroscopy. J Near -Infrared Spectrosc. 27(4): 293–301.

Publications in progress:

1. KU Leuven, Development of a generic 3D CAD model for compliant objects . (In progress, not reported to Forskningsrådet)
2. Sandvold, H., Tveterås, R. Papers T1 +T2: Successful innovation process (In progress, not reported to Forskningrådet)
3. Sandvold, H., Tveterås, R. Papers T2 + T3: Business models and strategies (In progress, not reported to Forskningsrådet)
4. A. Lillienskiold, R. Rahaf, P.R. Giordano, C. Pacchierotti, E. Misimi, 2019 Human-inspired Haptic-enabled Learning from Prehensile Move Demonstrations. IEEE Trans. Human-Machine Systems (submitted).
5. U. Isachsen, E. Misimi, 2019 Fast and accurate GPU accelerated robotic 3D reconstruction of soft objects. ICRA 2020 (to be submitted).
6. Th. Olsen, B. Ottesen, E. Misimi. Deep Reinforcement Learning for Grasping of 3D compliant objects. ICRA 2020 (to be submitted).
7. O.M. Pedersen. E.Misimi, F.Chaumette. Visual servoing assisted robotic grasping from grasping agent trained in simulation. ICRA 2020 (to be submitted)
8. M. van Dael, P. Verboven, A. Zanella, J. Sijbers, B. Nicolai, 2018. 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, In press. https://doi.org/10.1016/j.postharvbio.2018.05.020
9. A. Sengupta, A. Krupa, E. Marchand: Tracking of complex shapes using RGB-D camera. Submitted to ICRA 2019. (INRIA's work regarding pose estimation of the rigid object based on a fine 3D CAD model and depth image from a RGB-D camera is also sent to publication:)
10. U. Isachsen, T. Theoharis, E. Misimi. GPU accelerated 3D Registration – Evaluation of 3D registration algorithms for robotic scanning of compliant objects. Submitted to ICRA 2019.
11. T. Olsen, B. Øttesen, E. Misimi. Sim-to-Real transfer learning based on Deep Reinforcement Learning for gripper vector estimation and grasping of semi-compliant objects. Submitted to ICRA 2019.
12. O.M. Pedersen, E. Misimi, F. Chaumette. Grasping Unknown Objects by Coupling Deep Reinforcement Learning, Generative Adversarial Networks and Visual Servoing. (Submitted to International Conference on Robotics and Automation, 2020)
13. Sengupta, A., Lagneau, R., Krupa, A., Marchand, E., & Marchal, M. Simultaneous Tracking and Elasticity Parameter Estimation of Deformable Objects. (Submitted to International Conference on Robotics and Automation, 2020).
14. U. Isachsen, T. Theoharis, E. Misimi, Fast and accurate GPU accelerated 3D registration for robotic 3D reconstruction of food and similar compliant objects. (Submitted to International Conference on Robotics and Automation, 2020)

Reports and thesis:

1. Thakur, M 2017. Process Mapping in the whitefish supply chain: analysis of information and material flow. SINTEF Report No. OC2017 A-197 (ISBN: 978-82-7174-318-5)

2. Olofsson, Alexander Martin (2017). Tactile-sensitive robotic grasping of food compliant objects with deep learning as a learning policy. Closed Master Thesis at NTNU.

3. Maja Kristine Boning, Andrea Louise Sefranek Rongved and Zaria Sivalingam (2017). Sales and operations planning in the whitefish industry, NTNU student report, December 2017.

4. Peter Kvande Farstad and Tord Thomseth (2017). Supply uncertainties in a white fish industry: Sources of uncertainty and coping strategies, NTNU student report, December 2017.

5. Alexander Olofsson: MSc thesis - Tactile-sensitive robotic grasping of food compliant objects with deep learning as a learning policy, NTNU IDI June 2017.

6. Farstad, P.K., Thomseth, T.N. (2018). Managing supply uncertainty in supply chain planning. Closed Master Thesis at NTNU.

7. Boneng, M.K., Rongved, A.L.S., Sivalingam, T. (2018). Supply chain planning: the application of information in marked decisions. Closed Master Thesis at NTNU.

8. Bjerke, M.M. (2018). Managing Supply Uncertainty in the Operational Production Planning in a Whitefish Value Chain - A Stochastic Programming Approach. Closed Master Thesis at NTNU.

9. Kikke, S., Yelte N. (2018). Managing uncertainty in supply for a whitefish processor. Closed Master Thesis at NTNU.

10. Ulrich Johansen: MSc thesis - GPU accelerated 3D registration of compliant food objects. NTNU IDI, June 2018.

11. Thomas Olsen, Birk Øttesen; MSc Thesis – Deep reinforcement learning for gripper vector estimation for grasping. NTNU, IDI June 2018.

12. Frantzen, Ø. (2018). Decision Support for Centralised Planning in Production Networks. Closed Master Thesis at NTNU.

13. Nicolaas Yelte Serle Kikke (2018). Managing uncertainty in supply for a whitefish processor, NTNU student report, NTNU, May 2018.

14. Salomonsen, C., (2018). Designing within the circular economy. SINTEF report 2018:00938, ISBN: 978-82-14-06911-2.

15. Tveit, G.M., Thakur, M., Vevle, G., Mehta, S., Standal, I.B., Greiff, K., Indergård, E., Yurt, T. (2019). Traceability of hides through the supply chain—Norilia case. SINTEF report 2019:00728, ISBN: 978-82-14-06391-2.

16. Ole-Magnus Pedersen: MSc Thesis - Sim-to-Real Transfer of Robotic Gripper Pose Estimation. NTNU, June 2019.

17. Sondre Bø Kongsgård: MSc Thesis - A Deep Learning-Based 3D Vision Pipeline for Shape Completion of 3D Objects, NTNU June 2019

18. Guro Møen Tveit Maitri Thakur Geir Vevle Shraddha Mehta Inger Beate Standal Kirsti Greiff mfl. (2019) Traceability of hides through the supply chain - Norilia Hide Case. SINTEF report. ISBN 978-82-14-06391-2

Presentations

1. Misimi, E., Greiff, K. (2016). Tiltak til å skape merverdi av storfekjøtt i Trøndelag. Landbruk 21 Trøndelag, Ertsgaard Stjørdal.
2. Misimi, E. (2016). iProcess- the project. NTP-board meeting. SINTEF, Trondheim.
3. Misimi, E. (2016). Robotics in Food Processing Applications- Challenges and Trends. INRIA, Rennes, France.
4. Aursand. M. (2017). iProcess - bedre utnyttelse av råvarer i fremtiden. Næringsmiddeldagene 2017.
5. Tveterås, R (2017). Industriens behov i et konkurranse- og lønnsomhetsperspektiv. Sjømat Norge seminar "Kampen om råstoffet", Oslo.
6. Greiff, K (2017). Automatisering i matindustrien gjennom utvikling av innovative og fleksible teknologiske løsninger. Aquatic Food Forum, Oslo, Norway.
7. Aursand, M. (2017). Effektiv og automatisert matproduksjon. Bærekraft som konkurransefortrinn-teknologi som redskap.
8. Aursand, M. (2017). Havnæringa som inspirasjon for teknologi i jordbruket. Innovasjon Norge, Go Bio: Smart jordbruk.
9. Sandvold, Hilde Ness (2017). «iProcess». Presentation Work shop 20.11.2017, at UiS Business School, Centre of Innovation Research
10. Misimi, E. (2018). Deep learning for robotic automation in food industry. NTNU IDI
11. Sengupta, A. (2018). 3D deformation tracking and pose estimation of deformable objects. Ploumanac`h, France.
12. Misimi, E. (2018). Active vision and deep learning reinforcement learning. Ploumanac`h, France.
13. Misimi, E. (2018). Automation needs in the poultry and food industry, in connection to the visit of the Minister of Agriculture of Norway to SINTEF Ocean.
14. Eilertsen, A., 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.
15. Eilertsen, A., 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.
16. Aursand, M. (2018). Automatisering i matindustrien, utvikling av fleksible og innovative løsninger. LandTech 25.-26.10, Scandic Airport Hotel Gardermoen.
17. Aursand, M. (2018). Kan SINTEF bidra til innovasjon i matindustrien? Mat og landbruks konferansen, Oslo, Norway 16.01.18.
18. Aursand, M. (2018). Nærings og samfunnseffekter – automatisering og robotisering. SINTEF Ocean Seminar

19. Greiff, K. (2018). Prosjekter og relevant kompetanse i Agri sektoren, Landbruk 21/SINTEF Agri seminar.

20. A. Sengupta. 2018. 3D pose estimation and tracking, iProcess project meeting, March 2018.

21. T. Olsen, B. Øtessen. 2018. Deep reinforcement learning for gripper vector estimation, iProcess project meeting, March 2018.

22. U. Isachsen. 2018. GPU accelerated 3D registration of compliant food objects for scanning with robot arm and rgb-d sensor, iProcess project meeting, March 2018.

23. E. Misimi, 2018. Deep Learning for robotic automation in food industry, NTNU IDI, April 2018.

24. A. Sengupta, 2018. 3D deformation tracking and pose estimation of deformable objects, Ploumanac'h, France, July 2018.

25. E. Misimi, 2018. Active vision and deep reinforcement learning, Ploumanac'h, France, July 2018.

26. E. Misimi, 2018. Automation needs in the poultry and food industry, in connection to the visit of Minister of Agriculture of Norway to SINTEF Ocean, September 2018.

27. Janssen S., Wang Z., Nugraha B., Piovesan A., Boone M., Josipovic I., Verboven P., Nicolai B. (2018). 3D pore network quantification of apples using X-ray CT of the microstructure of intact fruit. Presented at the 32nd EFFoST International Conference, Nantes, France, 06 Nov 2018-08 Nov 2018, Poster, Abstract, 1.

28. Nugraha B., Verboven P., Janssen S., Nicolai D., 2018. Non-destructive porosity mapping of fruit and vegetables using X-ray CT. Presented as a poster at European Federation of Food Science and Technology, 5-8 November 2018.

29. E. Misimi, A. Olofsson, A. Eilertsen, E. R. Øye, J. R. Mathiassen. 2018. Robotic Handling of Compliant Food Objects using Robust Learning from Demonstration. Presented at IROS, Madrid, Spain, 2018.

30. Sandvold, Hilde N. (2019). «ØKT AUTOMATISERING I NORSK NÆRINGSMIDDELINDUSTRI: UTFORDRINGER OG DRIVERE OR TEKNOLOGISK ENDRING». NHO Matindustien. 25 april 2019. Hell, Trondheim.

31. Wold, J.P. On-line analyse og NIR. Muligheter og utfordringer. Næringsmiddelkonferansen 2019, Bergen.

32. Wold, J.P. On-line målinger for bedre styring av hydrolyseprosesser. Fagdag Marint protein nettverk, 14. februar 2019.

33. A. Krupa. 25-September-2019: RGB-D tracking of complex shapes using coarse object models. ICIP 2019 at Taipei, Taiwan.

34. A. Krupa. Tracking of Non-Rigid Objects using RGB-D Camera 06-October-2019: SMC 2019 at Bari, Italy

35. E. Misimi, Robotic Manipulation of 3D Compliant Objects of Marine and Agricultural Origin. iProcess prosjektmøte; Rennes, France, March 2019.

36. E. Misimi. Robotisert Automasjon med applikasjoner fra hav og landbruk - eksempler fra iProcess prosjektet. SKI Agri - Konsernsatsning SINTEF, Trondheim, May 2019.

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

38. Van De Looverbosch T., Verboven P., Sijbers J., Nicolai B. (2019). An Efficient X-Ray Projection Simulator of 3D Fruit Shapes for Use in Non-Destructive Internal Quality Inspection. In: Proceedings of 4th International Conference of Food and Biosystems Engineering (120-128). Presented at the 4th International Conference on Food and Biosystems Engineering, Crete, 30 May 2019-02 Jun 2019.

39. Nugraha B., Verboven P., Janssen S., Nicolai D., 2019. Respiratory gas diffusivity mapping of horticultural product using X-ray CT. Presented at VI International Symposium on Application of Modeling as an Innovative Technology in the Horticultural Supply Chain-Model IT, 6-9 June 2019 (not published yet)

40. Nugraha B., Verboven P., Janssen S., Nicolai D., 2019. How respiratory gas diffusivity correlates with porosity of plant organ tissues. Presented at 3rd International Symposium of Agricultural and Biosystems Engineering, 7-8 August 2019 (not published yet)

41. Wold, J.P. On-line NIR som virker: muligheter og utfordringer. Spektroskopi og prosesstyring i matindustrien, Nofima, Ås, 20. september 2019

42. Afseth, Nils Kristian; Matousek, Pavel; Böcker, Ulrike; Wubshet, Sileshi Gizachhew; Andersen, Petter Vejle; Wold, Jens Petter. Emerging approaches for representative food analysis using Raman spectroscopy. Biosystems Engineering Congress; 2018-09-03 - 2018-09-05, Iran.

43. Andersen, Petter Vejle; Wold, Jens Petter; Afseth, Nils Kristian; Narum, Bjørg. Analyzing intramuscular fat content in pork longissimus lumborum using Raman spectroscopy. ICoMST (64th International Congress of Meat Science and Technology); 2018-08-12 - 2018-08-17. Melbourne, Australia.

Additionally, there have been presentations from all work packages during the yearly iProcess meetings..

Media & Social media

1. Tveterås, R. (2016). Gjesteskribent: Tvangsforeldling. Fiskeribladet Fiskaren 02.05.2016.

2. Tveterås, R. (2017). Etterlysning: kreative politikere. Fiskarbladet Fiskaren Vol. 10, no 37, p.2.

3. Wold, J.P., Afseth, N.K., Tchudi, J. (2017). Smarte sensorer gir best utnyttelse av maten. Viten Aftenposten 27.04.2017.

4. Skoglund, U., Misimi, E. (2017). Roboten den nye bonden? GEMINI June, 2017.

5. Misimi, E., Hanad, A. (2017). Intelligente roboter kan innta landbruket. Nationen 17.08.2017.

6. Skoglund, U., Misimi, E. (2017). Lærer roboten å bli bonde. Aftenposten Vitenskap 18.08.2017.

7. Misimi, E. (2017). Roboten som skal berge matbransjen. Dagens Næringsliv 01.09.2017.

8. Misimi, E. (2017). Roboten som skal berge matbransjen. GEMINI 04.09.2017.

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

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

11. R. Tveterås (2017). ”Digital utvikling”, Fiskeribladet, 9. april 2018, Årgang 11, nr. 40, uke 15, s. 2.

SINTEF WEB page: 11 posts.

iProcess web news: 24 posts.

Facebook posts: 41 posts.

Researchers

Researchers involved in iProcess

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