Annual Report 2022

SFI Digital Food Quality

DigiFoods

• **Cover** Photo/cc: Wenche Aale Hægermark, Nofima

Senior Engineer Katinka Dankel from Nofima working the NIR-scanner at Bioco. You can read more about this work in the article on page 12-13 in this Annual report.

• Photo/cc: Jens Petter Wold, Nofima

Non-contact assessment of sugar in strawberry by NIR spectroscopy

Colophon

Multiple authors (2023).

Annual Report 2022.

SFI Digital Food Quality – DigiFoods.

Ås: Nofima, eds.

Design: Raquel Maia Marques at Vitenparken Campus Ås.

Contents

1. Overall progress and summary for 2022

DigiFoods is a Center for Research-based Innovation, funded by The Research Council of Norway and the partners. DigiFoods will develop smart sensors for effective food quality assessment directly in the processing lines and in field.

The intention is that massive assessment and digitalization of essential food quality parameters will be used for optimization of processes and value chains and make the food industry more efficient and sustainable. This research is in the very exiting intersection of food technology, sensor development, process control, robotics and data analysis, and gives rich opportunities for innovation at different levels.

DigiFoods started at the end of 2020 and has now been running for two years. In September 2022 we had a site visit from The Research Council of Norway (RCN). The main purpose of the visit was to review and discuss where we stand in the work with the realization of the centre and potential challenges we have encountered at the start of the work. The feedback we got from RCN was overall positive, which was both motivating and reassuring. In November we had a two-day meeting with our Scientific Advisory Board where our research was reviewed. We had fruitful discussions and received good advice for further work.

The annual meeting with all partners was held in Sandnes/Jæren in June. We visited TINE's large and impressive dairy at Jæren as well as RobotNorge's facilities in Sandnes. It is amazing what you can do with robots! The annual meeting was important for sharing results, ideas and building the DigiFoods team. When you get together, you realize how important it is to utilize the network of partners, because this is where a lot of knowledge, experience and common interests lie.

2022 was a good year for DigiFoods. The Covid-19 pandemic lost its grip and we were able to work as normal, doing experiments out in the food companies and in close physical collaboration with all partners. We conducted small and large measurement campaigns in the process lines. Some lasted a day, others took four weeks! I want to thank the companies for opening the doors, providing technology, and engaging in this kind of work. This sort of activity is the core of DigiFoods, where we can learn about the products and processes, consider the challenges, develop and test the sensors, gather the partners to discuss the results, and together see potential innovation ahead.

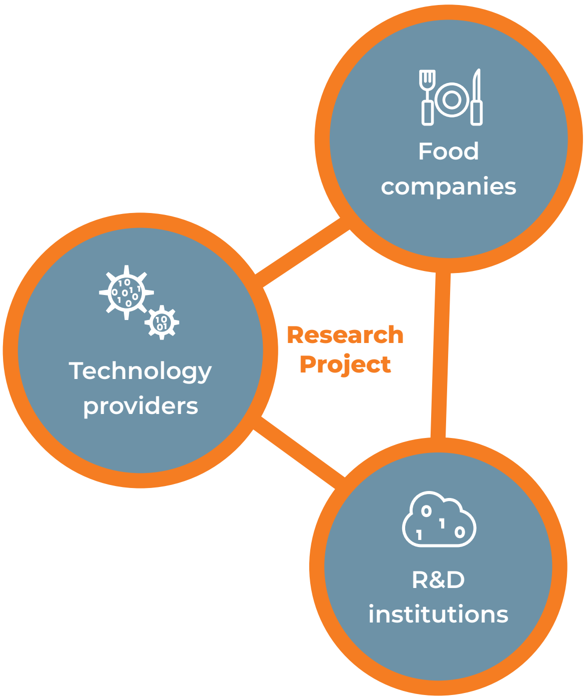
Our working plan is now structured into eleven research projects, spanning topics from sensor and application development to robotics, process analysis and consumer demands. Scientific highlights have been many, the level of innovation in the research is high, and real innovation in the companies is within reach.

Infrared spectroscopy has the potential to measure subtle chemical properties in foods and in 2022 we got closer to four new prototypes that can give easier and better industrial measurements. Three of them are based on lasers and LED technology, while the last is based on FTIR measurements on dried samples. In 2022 we stated that dry-film FTIR can be used for rapid characterization of protein hydrolysates, which is important for the industry.

In 2021 we found that Raman spectroscopy is suitable for determination of the fatty acids EPA and DHA in whole salmon fillets on a conveyor belt. In 2022 we tested Raman for industrial in-line monitoring of protein, fat, collagen and bone in poultry raw material. Raman seems to be a very promising technique for industrial food quality measurements, even for complex and heterogenous foods.

Our team on hyperspectral imaging is working very close to real applications in the fish industry. This is possible because of the efforts from several engaged partners in a multidisciplinary team including technology providers, R&D and food companies.

The projects on robotics have progressed a bit slower than originally planned due to lack of resources, both of researchers and PhD-students. We hope to get this on track in 2023. Regardless, we have seen that it is possible to use a robotic system to control a Raman probe and conduct measurements under complex conditions. In connection with field robots, we have developed a prototype NIR system that can measure sugar in strawberries. This system is suitable for a range of other applications on e.g. seafood and meat and we are considering innovation options.



DigiFoods innovation model: Each research task will assign active partners from all three groups: Food companies, technology providers and R&D institutions. Together they will i) consider the needs and business cases, ii) develop and evaluate technology and iii) implement and commercialise

We collected in-line spectroscopic and other process data from TINE, Nortura, Norilia and Lerøy and analysis of these is underway. The long-term goal is to develop data-driven solutions for process, product, and value chain optimisation. In the coming years we will continue the collection of large-scale data from smart sensors in process, which will be combined with food quality and other process data.

In 2022 we had seven PhDs/post-docs connected to DigiFoods. We plan to recruit a PhD and a post-doc in 2023. We also recruited three master students who start their work in early 2023. Our students are well integrated in the different projects and contribute to many of the centre results and dissemination.

In this annual report we present the main work and results achieved in 2022. In addition, we get to know how TINE uses in-line NIR to improve cheese production, and why NIR is also evaluated in the enzymatic hydrolysis process at Bioco. Small handheld – or robot operated – sensors are trending and in DigiFoods we are developing such novel instruments based on NIR and IR. It is not straight forward, there is a trade-off between size and performance. There is also an article that reminds us that a main goal for DigiFoods is to reduce food waste and elaborates on how we can achieve it.

Jens Petter Wold
Centre Director, DigiFoods

Photo/cc: Wenche Aale Hægermark, Nofima

In June 2022 the DigiFoods Consortium met for their Annual meeting in Sandnes

Article

Waste not, want not – a technology perspective

by Marion O'Farrell, SINTEF

We are now a little further along in DigiFoods and it can be a good idea to reflect on where we are and the goals we set when we started this journey.

In the original proposal, we highlighted that the Norwegian food industry is committed to reducing food loss by 50% by 2030, a goal inspired by the United Nations sustainability goals, which we believe can be addressed by the research in DigiFoods. Norway aimed initially for a 15% reduction by the end of 2020 and the first progress report on this has been released. The figure on the next page shows the distribution of waste per sector in 2020[1].

In DigiFoods, we are exploring new technology for the agricultural sectors, food- and seafood industry in various subprojects: HYPERSPEC, RAMAN, FTIR, IR and MOBILESENSE, all with an aim to improve quality and reduce waste. According to the progress report, the seafood, food processing and household sectors achieved a total reduction of 14%, 3% and 3% by 2020, respectively. The agriculture sector had a poor data baseline to monitor its progress, but the 2020 numbers show that it is a significant contributor to the total. The total reduction in all food sectors was 9,5%. These reductions are unfortunately below the 15% target, even with extra focus on achieving a reduction. This clearly indicates that more tools are required to hit the targets that Norway and Europe have set. Reasons given for food waste generation in food production are varied: sub-optimal food handling and process lines that result in raw materials falling on the floor, poor quality of products, poor quality control of raw materials, production errors, production lines being held up, fish with blood stains etc. Fruit and vegetables are especially challenging across sectors due to their shelf life and their sensitivity to handling and storage conditions.

The application of technology is essential if we are to achieve many of the measures suggested in the progress report: redesigning and optimising production lines and packaging lines, new production lines that upgrade product quality, better technology for extending shelf life or for handling products with short shelf-life, better systems for monitoring food waste, and optimised storage.

The 2022 EU Strategic Research and Innovation Agenda (SRIA) for Electronics, Components and Systems (ECS)[2] dedicates a full chapter to food and agriculture, which is viewed as one of the major areas that ECS technology should be addressing. ECS comprises technologies such as components, devices, modules, systems, and systems of systems. For food production, the following areas were highlighted:

- In-line food inspection
- Smart (bio-sensing) for high-quality monitoring to optimize processes and prevent contamination
- Industrial Internet of Things (IIoT) systems based on AI and digital twin technology that are flexible enough to tailor-make new products, networked packaging systems and robotic technology in the warehouses
- Intelligent control room systems to enable predictive maintenance of production lines

In addition, photonics (optical systems, spectroscopy, imaging etc), a field which is central to DigiFoods, is identified as a key enabling technology for food

1 https://www.regjeringen.no/contentassets/6b7122fce366433ca028c230b57605ae/no/pdfs/hovedrapport-2020-bransjeavtalen-om-reduksjon-av-m.pdf

2 https://www.kdt-ju.europa.eu/sites/default/files/users/ecsel-comm-team/ECS-SRIA-2022.pdf

“Digitalisation is a tool that enables us to hit targets, such as waste reduction”

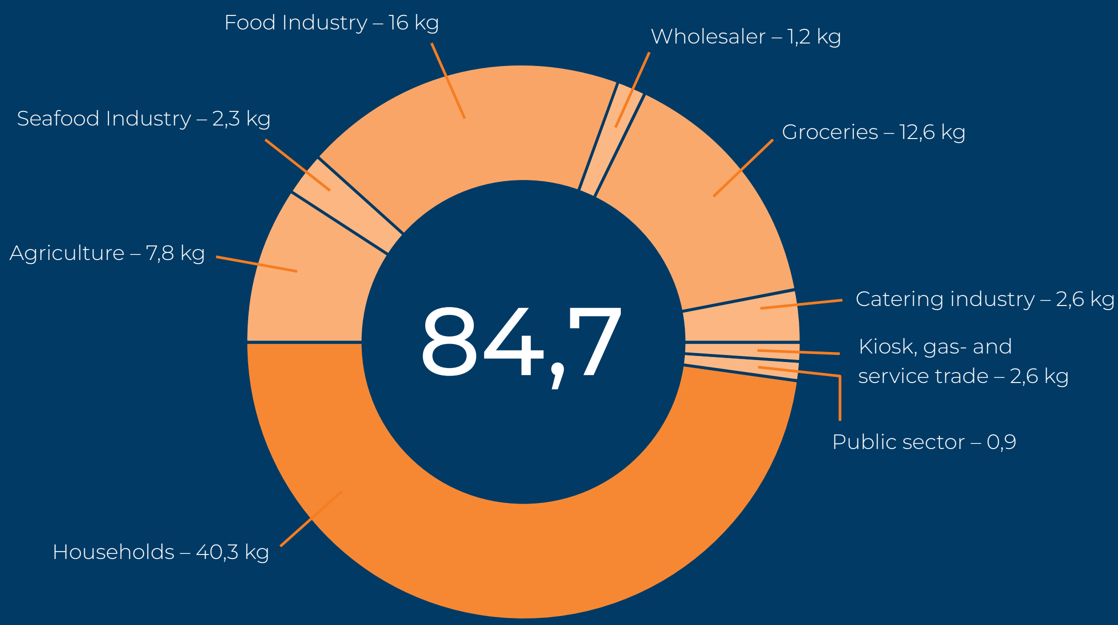


Figure 1: The total amount of food waste in 2020 in kilograms per citizen across different sectors [1]

and agriculture. Photonics is highlighted in both the ECS and Photonics21[3] European strategic documents.

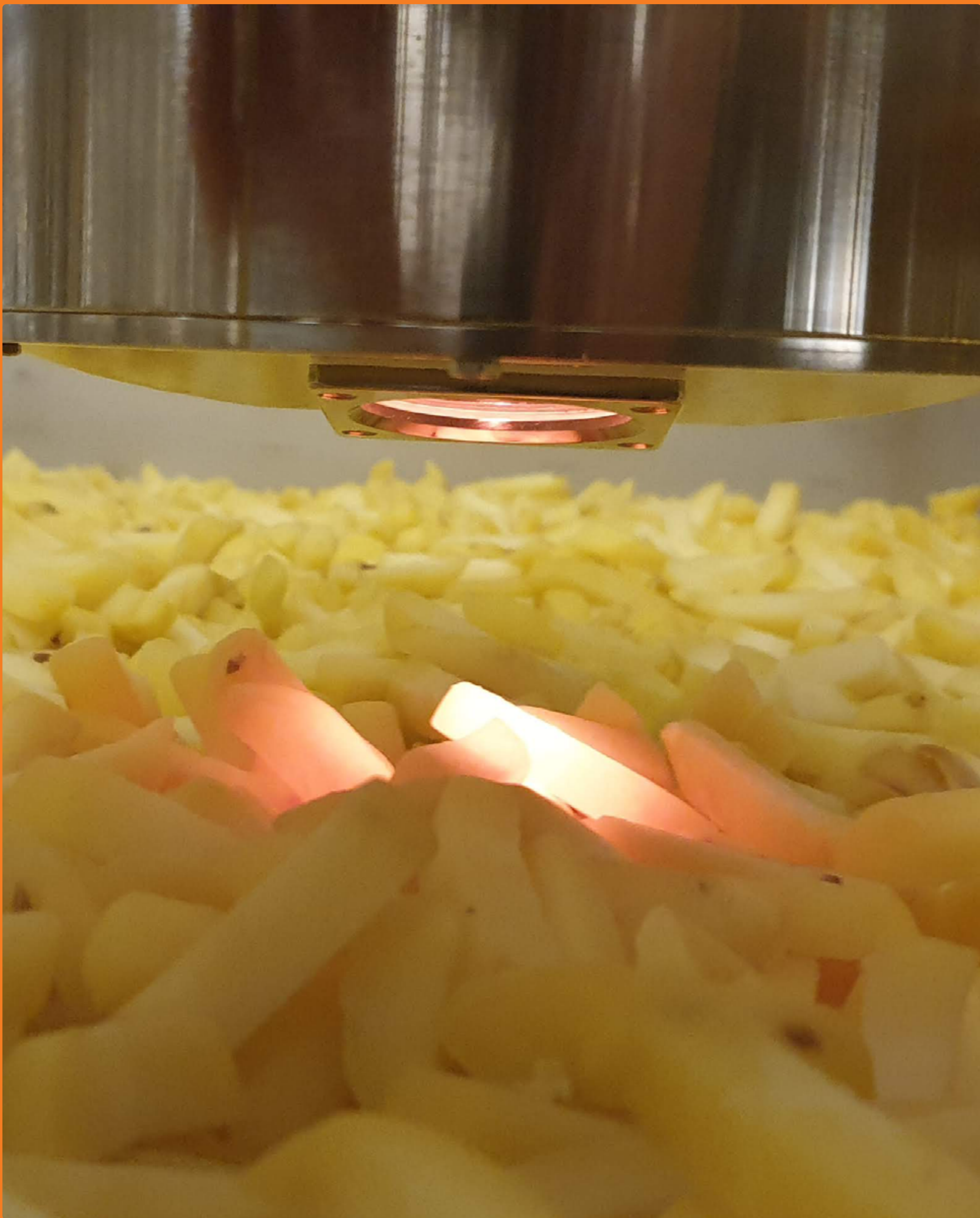
The OPPORTUNITIES project in DigiFoods has coordinated input to the new Photonics21 strategy, which is currently being updated for 2023. Here, we have tried to highlight the technology needs of the industry from the point of view of DigiFoods researchers who have experience in applying sensors and robotics to food and agriculture, i.e. provide input that is not purely technology-driven.

We have stated that there is as much need for robustness and performance as there is for size and cost, and we emphasised the following:

- The need for technology that optimizes the sorting and monitoring of raw materials and food products, addressing the reduction of food waste
- The need to achieve more automation and autonomy by combining research in photonics, sensors, and robotics in the same projects
- The importance of a multi-disciplinary, multicomponent research approach beyond the core sensor technology. For example, addressing the challenges in sample handling and presentation, technology useability, the effects of motion on sensors, robustness over time, system calibration, predictive model development, seasonal variation and bio-logical variation
- New technology to control and optimise new industrial bioprocess, for example, hydrolysis and fermentation, which can play a significant role in increasing the value of food by-products and reducing waste

DigiFoods has a vision to digitalise the food industry, but digi-talisation is not the goal itself. Digitalisation is a tool that enables us to hit targets, such as waste reduction, that are proving too difficult to address if we continue as we always have and not exploit its potential.

3 https://www.flipsnack.com/photonics21/photonics-strategic-research-and-innova-tion-agenda/full-view.html



• Photo/cc: Lars Erik Solberg, Nofima

Different NIR sensors are tested for inline measurements on potatoes at HOFF

Vision and objectives

The goal of SFI Digital Food Quality is to develop smart sensor-driven solutions that deliver the essential food quality information required for successful process optimisation and digitalization of the food industry.

Food processes are extremely complex and challenging to measure due to the inherent high level of biological variation in raw materials. The development of advanced solutions that are built on a fundamental understanding of food science, will allow the food industry to effectively measure and handle these variations, enabling a ground-breaking digital transformation of the industry.

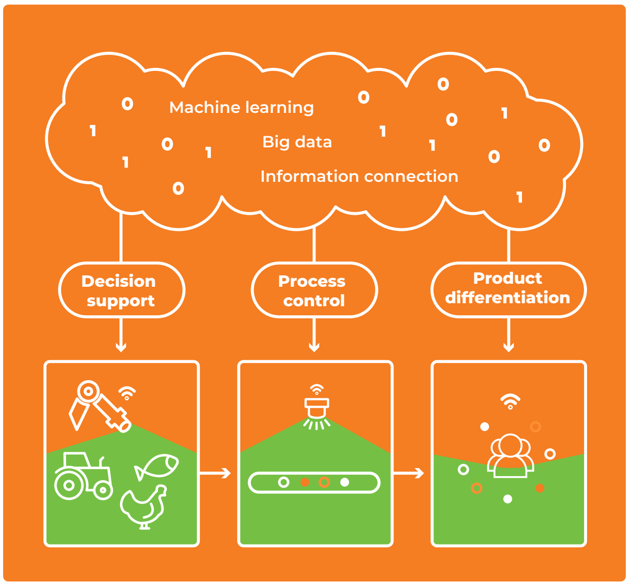
The **Primary objective** of DigiFoods is to develop digital solutions for food quality assessment as cutting-edge technological basis for optimal food value chains.

Besides this there are seven **Secondary objectives**:

1. Develop novel in-line sensor systems and applications for measuring critical food quality parameters
2. Develop automation and robotic solutions for enhanced sensor operations in process and in field
3. Develop solutions and strategies for successful sensor implementation in the food production
4. Develop data-driven strategies for process, product and value chain optimisation based on extensive food quality measurements
5. Build and transfer competence in industry and academia and educate master students, nine PhDs and three post docs
6. Foster innovations, patents and spin out companies by the project partners from food industry, technology and research
7. Disseminate knowledge to the industrial sector, the research community, and to the general public

DigiFoods strives to change food production by enabling optimization, control and differentiation based on measurements of food quality. The results will lead to a more efficient and sustainable food industry, internationally competitive Norwegian technology companies, and enhanced knowledge transfer and researcher training.

The DigiFoods objectives range from fundamental technology knowledge to practical industry and market implementations, which are equally important for achieving successful innovations. We aspire to bridge the gap between research and industry by building a strong, business-oriented research network of innovation-oriented companies, and national and international R&D institutions. These expected impacts are in line with the centre goals and the overall objectives for the SFI scheme.



The DigiFoods vision: Extensive food quality assessment enables new insights and radical changes from farm to fork

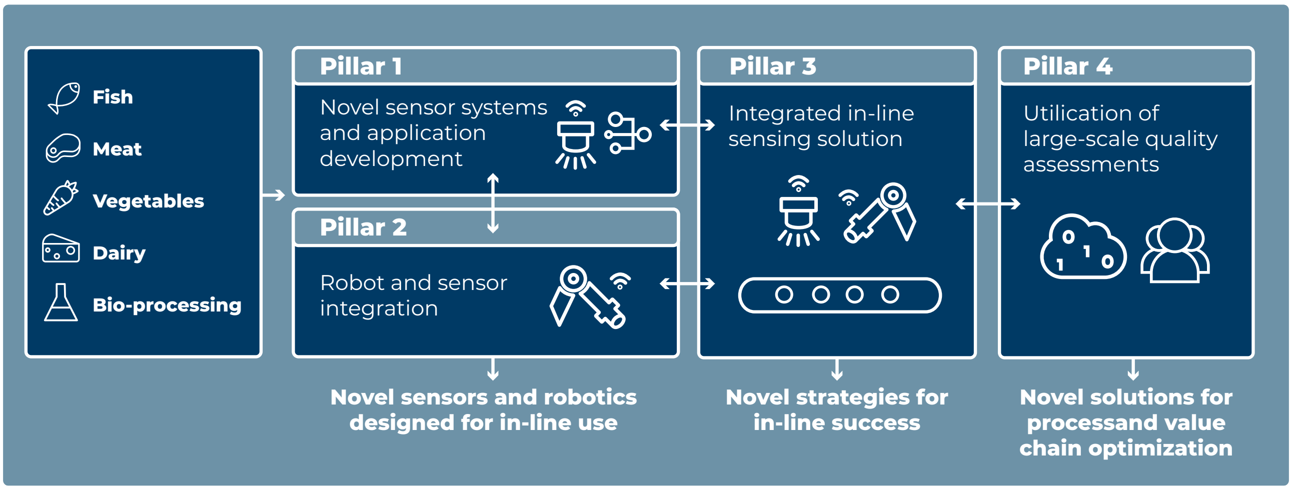
2. Research plan and strategy

The main research hypothesis of DigiFoods is that in-line food quality measurements can be used to understand, optimize and radically improve food value chains.

The innovations in DigiFoods will be accomplished by combining basic and applied research. A major difference from traditional research in this area lies in the scientific method; prototypes will be tested at the end-users at an early stage, as part of the technology development. This includes large-scale trials in fields, onboard fishing boats and in industrial food process lines, and secures relevance and industry involvement. The research activities are organized in four pillars, and involves value chains for fish, meat, vegetables, dairy and bio-processing. These pillars are not at all silos; some activities will straddle two pillars or more and others have already progressed from one pillar into another.

Pillar 1 will develop novel sensor systems that address critical in-line challenges and industrial needs. Pillar 2 will design novel integrations of robotics and sensors. Pillar 3 will develop strategies for successful implementation of in-line sensors in processes. In Pillar 4, the in-line food quality measurements will be placed in a broader perspective and combined with other relevant data sources to realize improvements at farm, industry and value chain level.

Most of the experimental work in Pillar 3 and 4 is taking place in the food industry, in the field or onboard fishing boats. These serve as important research facilities for securing relevance and usefulness of the technology, and for collecting extensive amounts of food quality data.



Partner companies representing the major food value chains will define relevant research activities for the four research pillars

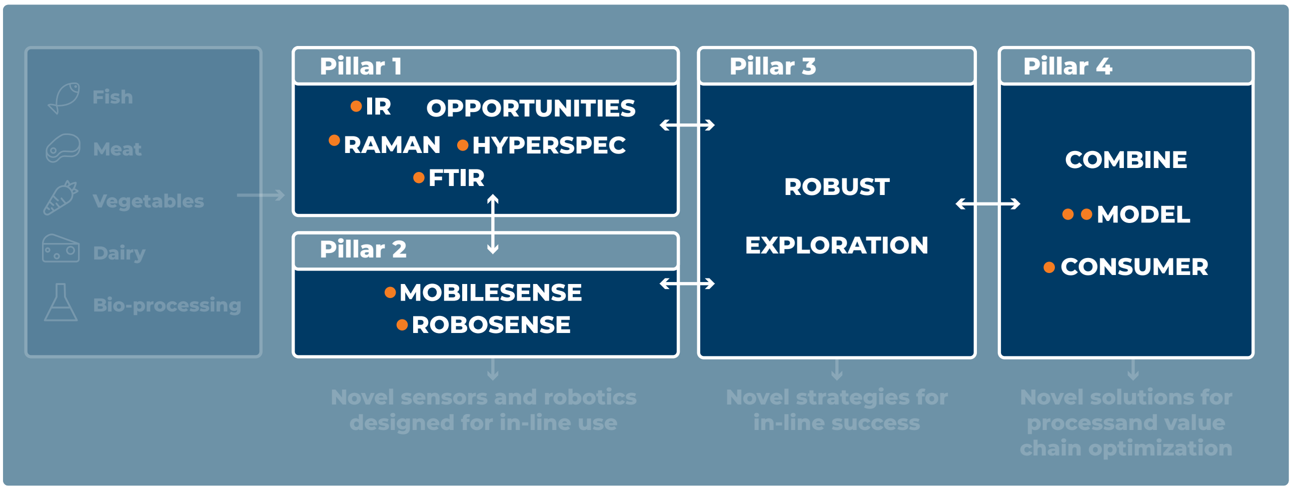
“The research activities are organized in four pillars, and involves value chains for fish, meat, vegetables, dairy and bio-processing”

All activities will as far as possible include participants from all three partner groups (food companies, technology providers and R&D institutions) to ensure practical relevance, inter-disciplinary and relevant competence. This project organisation is the core of the centre’s innovation model, meaning that the partner groups together are considering business cases and innovation opportunities associated with the research.

To implement the research that was proposed in the SFI application we have divided the activities into research projects, eleven in 2022 plus our Opportunities project. The projects address the outlined goals and envisioned innovations, targeting gaps in knowledge and technology.

All partners are involved in the planning of the projects, ensuring relevance and securing in-kind contributions through active involvement in the ongoing work.

Projects in Pillars 1 and 2 are collaborating to develop prototype solutions and these will be evaluated for industrial use in Pillar 3, together with already existing sensors. Results from Pillar 3 will also be fed back to Pillar 1 & 2 to optimise and improve the solutions based on in-line performance. Well working solutions developed in Pillar 3 will provide Pillar 4 with essential quality data on an industrial scale.



SFI projects allocated in research pillars according to the figure on the previous page.

● For all projects except "Opportunities", "Robust", "Exploration" and "Combine", PhD or postdoc students will be affiliated

Article

Analysing properties of various enzymes to develop top-quality protein powders

by Wenche Aale Hægermark, Nofima

Experts at Bioco, Nofima, Norilia, Nortura and SINTEF are collaborating to better utilise rest raw materials from chicken and turkey. The goal is to develop healthy ingredients for human consumption.

Nortura Hærland, in Inner Østfold, processes up to 100,000 chickens every single day. This results in many packs of breast fillets, thigh fillets, minced meat, thighs and breasts – and there is a lot left over. Quite a lot of meat is left on the carcass. This is called rest raw material or residual biomass and is mostly used for animal feed. The goal is to develop ingredients for human consumption because this raw material contains nutritious components that can be utilised in various foodstuffs.

The development and production of the new ingredients take place right next door to Nortura's chicken slaughterhouse in Hærland. This company is called Bioco and is Norway's only facility that converts chicken and turkey raw materials into high-quality ingredients. Two parallel pipes which lead from just under the roof of the slaughterhouse across the road to Bioco carry this raw material.

Large variation

The composition of rest raw materials may vary. For example, there is a difference in nutrients between rest raw materials from turkey and rest raw materials from chicken. The same is true for skin as opposed to the meat left on the carcass. In order to make products of the same quality day after day, it is important that the raw material mixtures have as consistent a quality as possible, or that one is aware of the differences and knows what type of process is required to achieve a consistent quality.

That is why the scientists have installed an NIR sensor just behind the grinder that grinds the rest raw materials into a mince. Among other things, the sensor measures the contents of fats, proteins and bones in the mixture that continuously flows past.

"In this way, we can learn more about how much the raw material actually varies, and how the variation affects the process and the final product", says Nofima Senior Engineer Katinka Dankel.

Together with doctoral research fellows Bijay Kafle and Marco Cattaldo, she has spent many workdays at Bioco following up on the NIR measurements and collecting more data from the process and the product.

The ground raw material is mixed with water and enzymes, and then a so-called hydrolysis process takes place. This is an imitation of what happens in the body's digestive system where enzymes break down larger protein molecules into smaller peptides and amino acids. After about an hour, the process ends and the mixture is separated into three different fractions: fats, water-soluble proteins and a sediment rich in minerals.

"The unique thing about this process is that all the raw material is converted into valuable products – nothing is wasted. In the current tests, we are focusing on the protein part", says Nofima Senior Scientist Nils Kristian Afseth.

Enzymes affect the taste

The water-soluble proteins obtained from the process are called a hydrolysate, and the hydrolysate mainly contains peptides and amino acids. It is important for Bioco that as much protein as possible in the raw material ends up in the hydrolysate; this produces high yields. In addition, it is important that the hydrolysate has the correct nutritional composition and tastes good. The experts are now testing different enzymes to see if and how they affect both the composition and the yield.

"The goals of the trials we are now conducting are to analyse how changes in both the raw material and the enzymes affect the hydrolysates", says Nofima Senior Scientist and Data Analyst Ingrid Måge.

She is responsible for compiling and analysing all the data from the tests. Marco Cattaldo is also part of the data analysis team. He is a doctoral research fellow at DigiFoods and is investigating how the NIR measurements can be used to adjust the process so that the yield is high while the hydrolysate is always of the right quality.

Testing five different enzymes

There is a major test underway that is running over several weeks. Every week, a new enzyme is tested, while the process operators make controlled changes in raw materials and the addition of water. To see how the hydrolysate is affected by these changes, samples must be extracted from the process. That means someone has to put on protective gear, open a hatch in a tank, and fill a small plastic tube with steaming hot liquid. During the test weeks, this is done many times every day, around the clock, and as frequent as every ten minutes during some periods. To achieve this, both process operators from Bioco and Nofima employees have been working really hard.

The samples are taken to Nofima's laboratory where they are thoroughly analysed using many different measurement methods to characterise both protein composition and other properties. One of the measurement methods that has proven to be well suited for measuring protein quality is Fourier-transform infrared spectroscopy (FTIR).

Transporting the samples to an external laboratory is cumbersome, so scientists from SINTEF and Nofima are working to develop a portable FTIR instrument that can be used to directly measure protein quality in the factory. An instrument like this will make it possible for the industry to control product quality quickly and easily, which is not possible today. Among other things, this is the goal of Bijay Kafle's doctoral thesis.

Sensory judges assess the taste

After spray drying, the hydrolysate becomes a protein powder, and it has been challenging to achieve a neutral taste. There are several factors that affect the taste - the enzymes, the process and the composition of raw materials. The powder can sometimes taste bitter or burnt. The goal is for the protein powder to have a neutral taste.

Protein powder from all the different batches will undergo several taste assessments by Nofima's professional sensory judges.

The Bioco staff has visited Nofima's sensory laboratory and received taste assessment training. They are now making a number of their own assessments, which are part of the quality assurance of the protein powder. They have developed a system in which they describe the characteristics of the different samples, giving a total grade between 1 and 9, where 7 to 9 is good.

Knowledge about enzymes is important

There are major differences between how the various enzymes affect the hydrolysis process. In the tests that are currently underway, the hydrolysis process is run under the same process conditions regardless of which enzyme one uses.

For the experts at both Bioco and Nofima, the tests provide good opportunities to obtain new knowledge.

"We learn how different enzymes work in terms of yield percentage, taste and process conditions. The next step will be to analyse what will be optimal process conditions for the enzymes we choose to proceed with. For example, this might include extending the hydrolysis process", says Jonathan Fjällman, Operations Manager at Bioco.

• Photos/cc: Wenche Aale Hægermark, Nofima

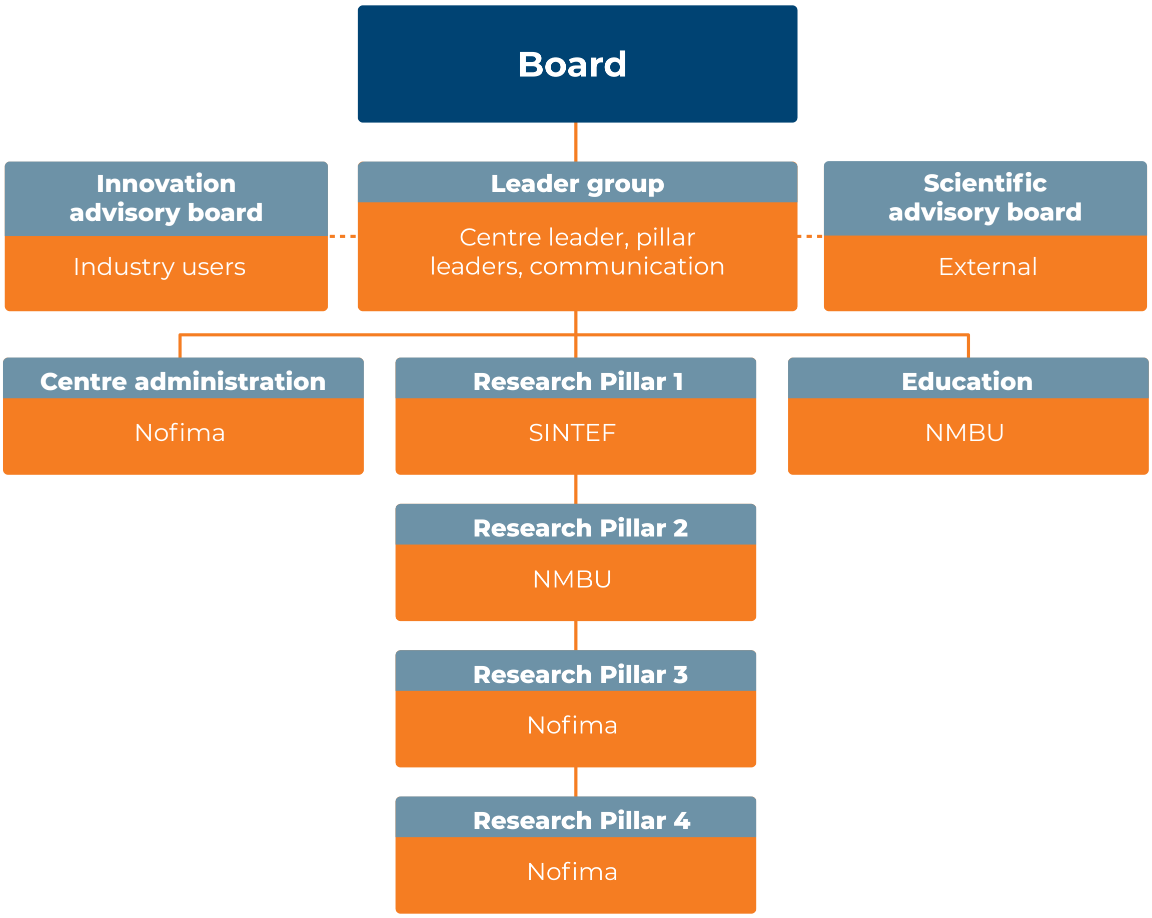
From left: Nils Kristian Afseth, Katinka Dankel, Ingrid Måge, Jonathan Fjällman og Marco Cattaldo in front of the process line for continuous enzymatic hydrolysis in tubes

3. Organization

Organizational structure, and cooperation between the centre's partners

DigiFoods has a decentralized organizational structure. It's headquarter is at Nofima, Campus Ås. The food industry is by nature decentralized and the technology companies are also located around Norway. The organisation is shown in the figure below.

The DigiFoods Board oversees that obligations are fulfilled, and decide on financial, partnership and IPR matters, as well as ratifying annual research plans made by the leader group. In 2022, the Board met for two physical meetings, one following the Annual meeting in June and one in November. The Board consists of the following elected members (see next page).



Chairperson of the DigiFoods Board

Anne-Cathrine Whist, TINE

Board Member

Ingvild Dalen, Lerøy Norway Seafoods

Board Member

Silje Ottestad, NEO

Board Member

Odd Arne Kristengård, Maritech

Board Member

Mats Carlin, SINTEF

Board Member

Anne Cathrine Gjærde, NMBU

Board Member and representing the host institution

Eva Veiseth-Kent, Nofima

The DigiFoods Board

In addition, Mona Gravningen Rygh, the contact person for DigiFoods at the RCN, has an an observer status at the board meetings.

The centre scientific work is organised through close collaboration between four Pillars:

- Pillar 1 Novel sensor systems and application development (Lead: SINTEF)
- Pillar 2 Robot and sensor integration (Lead: NMBU)
- Pillar 3 Integrated in-line sensing solutions (Lead: Nofima)
- Pillar 4 Utilization of large-scale quality assessment (Lead: Nofima)

Furthermore, NMBU leads the recruitment and education process in DigiFoods.

The leader group manages and leads DigiFoods, such as ensuring strategic planning and running of projects, recruitment of qualified personnel, providing a good working environment, accounting, dissemination and reporting.

Photo/cc: Marion O'Farrell, SINTEF

Our Scientific Advisory Board gathered at a two-day meeting in November for a review of the research in DigiFoods. From left: Onno de Noord, Bjarne Kjær Ersbøll, Søren Balling Engelsen and Ole Alvseike. Centre leader Jens Petter Wold to the right

The leader group consists of:

- Jens Petter Wold (Nofima) – Center Director, overall scientific and administrative leader
- Marion O'Farrel (SINTEF Digital) – Scientific Manager of Pillar 1
- Pål Johan From (NMBU/Saga Robotics) – Scientific Manager of Pillar 2
- Nils Kristian Afseth (Nofima) – Scientific Manager of Pillar 3
- Ingrid Måge (Nofima) – Scientific Manager of Pillar 4
- Kristian Hovde Liland (NMBU) – Manager Recruitment and Education
- Stine Thøring Juul-Dam (Nofima) – Centre Coordinator
- Wenche Aale Hægermark (Nofima) – Communication Leader
- Anne Risbråthe (Nofima) – DigiFoods Controller

A Scientific Advisory Board (SAB) has been appointed for DigiFoods, consisting of researchers with competencies in the fields of research in the centre. An important task for the SAB is to review results and research plans and give advice on research methodology and industrial and societal relevance. The members are:

- Prof. Søren Balling Engelsen, Dept Food Science, Univ. Copenhagen
- Prof. Bjarne Kjær Ersbøll, Dept. Applied Mathematics and Computer Science, Technical Univ. of Denmark
- Ole Alvseike, Head of division Animalia, Norway
- Onno de Noord, Advanced Data Analysis Consultancy, Amsterdam

The centre has also appointed an Innovation Advisory Board (IAB) with representatives recruited from user companies. The members oversee, evaluate and advice on how innovation processes are promoted and incorporated in the research activities, including knowledge transfer, learning and innovation arenas, as well as industry involvement and business case development.

The members are:

- Silje Ottestad, NEO
- Marije Oostindjer, Norilia
- Atle Rettedal, Robot Norge
- Roy Martin Hansen, Lerøy Norway Seafoods
- Loek Vredenberg, IBM

DigiFoods is organized to facilitate excellent collaboration between three groups of partners: R&D institutions, food companies and sensor, robotics and digital platform companies. The user partners are as far as possible involved in the planning of experiments, execution and discussion of results. Research is conducted in the end-users process lines and requires that scientists, engineers and user partner personnel are involved.

Frequent meetings are organized at Board level (each six months), Centre level (annual meetings), leader group (every third week), with IAG (once a month) and thematic or project level (as required). In addition to physical and digital meetings, DigiFoods has an internal SharePoint site with a news feed where centre participants can post e.g. news, links to documents, research plans, results, pictures and videos. In addition to a formal news channel, the SharePoint will also act as a social media, thus contributing to build the DigiFoods team spirit.

• Photos/cc: Samuel Ortega, Nofima

Hyperspectral scanning of cheese

Partners

Research partners

Nofima is one of Europe's largest institutes for applied research within the fields of fisheries, aqua culture and food. Nofima's vision is "Sustainable food for everyone", while our objective is to actively contribute to solve the large social challenges such as increased food security, better food safety and health, reduced food waste and reduced environmental and climate footprints. We have excellent knowledge in food quality science and are recognized for our research on applied bio-spectroscopy, rapid spectroscopic measurements of food quality, for multivariate data analysis and consumer science over the last 30 years. Nofima is the host institution of DigiFoods and will contribute with peak expertise in applied spectroscopy (Raman, NIR, fluorescence, FTIR and hyperspectral imaging), process analytical technology, data analysis, consumer science and food science. Nofima will also provide an extensive state-of-the-art lab for spectroscopic analysis, food pilot plants and food technology labs. Our key personnel contributing will be DigiFoods Centre Director Dr. Jens Petter Wold, Centre Coordinator Stine Thøring Juul-Dam, Pillar 3 Lead Dr. Nils Kristian Afseth, Pillar 4 Lead Dr. Ingrid Måge, Dr. Karsten Heia, Dr. Lars Erik Solberg, Dr. Erik Tengstrand and Dr. Paula Varela. A group of about 16 scientists and technicians will also take part in the research.

University of Lincoln has established an international reputation for the quality of its research and teaching. Two of the University's leading research centres will participate in DigiFoods, namely the Lincoln Centre for Autonomous Systems Research (L-CAS) and the Lincoln Institute for Agri-food Technology (LIAT). L-CAS specializes in systems integration, bringing together technologies to tackle challenging real-world applications in food manufacturing and agriculture, security, assistive care, and intelligent transportation. LIAT's mission is to develop new technological solutions for the business of producing food through agriculture at all stages of food production including cultivation, harvest, processing and packaging. The undertaken research is strongly applied, with many links to the local, national and global agri-food industry. Our main contribution to DigiFoods will be with our world leading expertise within agricultural robotics. The University will also welcome students, PhD scholars, faculty, and practitioners from industry to spend time in Lincoln with the objective to strengthen collaboration within the centre. We expect that DigiFoods will enable continued collaboration in agricultural robotics and new collaboration in food automation, both with academic and industry partners. Our key personnel contributing in DigiFoods includes Emma Vincent, Katherine James, Dr. Grzegorz Cielniak and Prof. Simon Pearson.

Ulm University (UULM) is ranked #8 among the Young Universities and overall #148 in the world (Times Higher Education Ranking). The Institute of Analytical and Bioanalytical Chemistry (IABC) is leading several national and international projects dedicated to the development of advanced vibrational spectroscopic sensing concepts for industrial, medical, environmental, and food quality/ safety applications. In DigiFoods, IABC provides expertise in food quality and safety monitoring/ sensing technologies, sensing networks, and data mining via advanced analytical techniques and strategies developed at IABC ensuring food safety and public health. Especially, IABC@UULM develops miniaturized mid-infrared sensing platforms based on thin-film semiconductor and diamond waveguides for analyzing relevant food constituents, contaminants and pathogens. We anticipate that this collaborative effort will result in the submission of joint publications and the development of further collaborative research projects. Our key personnel contributing in DigiFoods will be Professor Boris Mizaikoff and team members working in the field of food analysis.

NMBU's mission is to contribute to the well-being of the planet. Our interdisciplinary research and study programs generate innovations in food, health, environmental protection, climate and sustainable use of natural resources. As a University, NMBU aims to educate outstanding candidates, perform high-quality research that produces new perspectives, and create innovation. Two research groups from the Faculty of Science and Technology at NMBU take part in DigiFoods: The Biospectroscopy and Data Modeling group (BioSpec group), led by Professor Achim Kohler, and the Robotics group, led by Professor Pål Johan From. In DigiFoods, the BioSpec group contributes to the development and application of novel handheld and portable infrared devices for quality measurements of food. The first prototypes of handheld and portable infrared devices are established and will in short time be tested for food quality measurements. The Robotics group contributes with competence in robotics, in particular agricultural robotics, and develops autonomous robots for automation in food processing, sampling for spectroscopic measurements, and automatic data collection in the field. The two research groups have employed one PhD student who will work on novel infrared sensors for food quality measurements and one research assistant who has worked on robotics within the project Robosense (leader: Associate Professor Antonio Leite) and Mobilesense (leader: Associate Professor Weria Khaksar). Professor Kristian Hovde Liland from the department of Mechanical engineering and technology management is responsible for the education of master students.

SINTEF AS Smart Sensor Systems has been developing in-line sensor systems for industry, including the food industry, for more than 30 years, resulting in many process-applied publications and patents of international relevance.
SINTEF has specific competence in designing optical measurements systems, based on e.g. spectroscopy, x-ray or cameras and data analysis. A core part of the research involves designing and building robust optical measurement prototypes based on novel measurement concepts, moving as quickly as possible from the lab to the field, and gaining a fuller understanding of the industrial measurement environment. In DigiFoods, SINTEF will contribute by designing and building new sensor prototypes for measurement in industrial processes or in the field, and adapting existing scientific instrumentation to industrial sites for inline process characterisation measurements. SINTEF will work closely with the PhD students in DigiFoods so that they have a greater understanding of the theory behind the sensor prototypes, and make modifications as required. Our key personnel contributing in DigiFoods will be Pillar 1 Lead Marion O'Farrell, Senior Researchers Jon Tschudi, Kari Anne Hestnes Bakke and Trine Kirkhus, and Researchers Anders Hansen and Tim Dunker.

The Universitat Politècnica de València (UPV) is the only Technical University in Spain in the top 500 world's most prestigious universities based on the Academic Ranking of World Universities 2018. It is particularly relevant in the areas of Engineering and Sciences and a national leader in patent license income and start-up creation. The Multivariate Statistical Engineering Research group was established with the aim of offering the scientific community and the business & technological enterprises a working environment in which to develop research, development and innovation (RDI) in the area of multivariate statistical techniques for quality & productivity improvement. The group is active in Data Analytics, Six Sigma, Process Analytical Technology (PAT), Multivariate Image Analysis (MIA), Process Chemometrics and Statistical Methods for Knowledge Discovery. In DigiFoods we are sharing our experience working with industry and research-based innovation. Getting involved in DigiFoods is allowing us to share our experience working with industry and research-based innovation. In addition, it is being an excellent opportunity to be exposed to the needs of the high-tech food industry, opening new research lines to get involved. UPV is providing joint supervision with Nofima of one PhD student on data analytics and real-time process control & optimization. Our key personnel contributing in DigiFoods is Professor Alberto J. Ferrer-Riquelme.

Food companies

TINE SA is a cooperative, owned by Norwegian dairy farmers. One of TINE's most important tasks is to develop tasty dairy products based on Norwegian milk and by this, secure farmer income through usage of a given milk volume. The vision is to contribute to milk production all over the country. TINE organizes the retrieval of milk from every farm in Norway and process the milk in one of TINE's 30 dairies. The dairies are specialized to a certain extent, producing different dairy products, but there are also juice products ready-made meals, and desserts. TINE has Norway as its main market, but also subsidiaries internationally. TINE's strategic goal is to implement Integrated operations (IO) as our future operational standard within dairy production. For TINE, IO means the integration of people, disciplines, organizations, work processes, information and communication technology to make smarter decisions. DigiFoods will provide us with the opportunity to develop and test technology with deeper research requirements, but also higher potential beneficial outcomes, i.e. a deeper understanding of our raw material – the milk. Our key person contributing in DigiFoods will be Director R&D Anne-Cathrine Whist.

Nortura is the largest brand supplier in Norway in the meat and egg business, our main brands are Gilde and Prior. We are organized as a cooperative, owned by more than 17 000 Norwegian farmers that supply more than 240 000 tons of raw material from all relevant animal species to our slaughter- and processing plants. Nortura slaughters, cuts, refines and develops meat and egg products that are sold to retailers, restaurants, food-services and other food related industry with the aim of creating value for our unit-holders. Nortura has a strong focus on innovation and R&D and is involved in more than 35 national and international research projects. In DigiFoods we will concentrate our work on our poultry, beef and pork value chains using sensors and big data. We expect to optimize our production and processing lines and hope to get more value out of our raw material. By optimizing processes and products we will achieve higher yield and less food waste and thereby reduce the impact on the environment. One main goal with participating in DigiFoods is to serve our customers and consumers with high quality products in the future. Our key personnel contributing in DigiFoods will be Research Director Per Berg, Development Director Atle Løvland and Technology Manager Hans Christian Gutu.

Norilia refines and sells rest raw materials (plus products), from the Nordic meat and egg industry, thereby contributing to a more sustainable and profitable agriculture. Our biorefinery Bioco uses enzymatic hydrolysis to refine poultry offcuts. There is a large potential for refinement of other raw materials as well, and Norilia has the ambition to implement and industrialize viable processes. This may include new lines using enzymatic hydrolysis on different raw materials, such as bones and offal from pork, beef and lamb, feather or blood, or through fermentation. In DigiFoods, Norilia will offer our process line at Bioco for development and use of new sensor systems and optimization approaches, as well as for pilot and industrial testing. We will also contribute with our competence and know-how on enzymatic hydrolysis, products (raw material, hydrolysates, fats and sediments) and markets (pet food, food and dietary supplements). DigiFoods will be a great platform to develop new knowledge and tools that will enable us to realize our ambition. Our key personnel contributing in DigiFoods will be Director Business Development Heidi Alvestrand and Chief Advisor Bioprocesses and Business Strategy Marije Oostindjer.

Lerøy Aurora is a world leading company in salmon and trout farming and slaughtering, as well as the manufacture of products based on these raw materials for the consumer market. We have long experience with handling large amounts of fish, both in the fish farms, through the slaughter process and in production of consumer products. Our overall strategy is to secure a sustainable economic future for fish farming and production, both locally and worldwide. DigiFoods represents a unique opportunity to share knowledge and learn from other companies. The possibilities for new knowledge and innovations seem very promising and can be both of a generic nature (sector independent) as well as specific for our business. Our key person contributing in DigiFoods will be Factory Manager Tore Pedersen.

Biomega was founded in 2000 on the premise of advancing innovative biotechnology to release the full nutritional and functional value of otherwise underutilized side streams from the salmon industry. Today, Biomega has a rich patent family of various technologies, with the continuous enzymatic hydro lysis process at its core. We continuously invest in innovation through R&D to ensure best-in-class technology and respond to customers' needs, including product development, traceability and sustainability. In our biorefineries we turn food-grade fresh salmon raw materials into premium feed and food-grade ingredients. Sophisticated bio refining processes ensure careful separation of nutritional components. Biomega's mission is to transform undervalued raw material into premium food and petfood ingredients through accelerated biorefining. In DigiFoods, we will be an industrial test facility for new in-line monitoring solutions, and our expectations is that along the DigiFoods lifespan new in-line process monitoring equipment is devolved that could contribute to a more stable production and end-product quality. Our key personnel contributing in DigiFoods will be CTO Andrew Dustan and CSO Bjørn Liaset.

Hoff SA is Norway's largest potato processing company, processing 1/3 of Norway's potato production. Hoff is producing a range of different potato-based food products and food additives, such as e.g. french fries, mashed potatoes, potato starch, potato glucose syrup and potato spirits. We believe that DigiFoods can help us solve specific challenges related to variations in potato quality, in addition to generic challenges related to technology and data handling. Hoff wishes to make use of in-line measurements (NIR) either at intake of the potatoes or during processing. The NIR measurements will hopefully give us useful information concerning process control which in turn, and in combination with our participation in the projects ROBUST and MODEL, can help us develop a statistical process control (SPC). We also see great value in sharing knowledge and learn from other food companies with similar challenges. Our key person contributing in DigiFoods will be Process and Product Development Manager Ingvild Sveen.

Lerøy Norway Seafoods is Lerøy's quality brand for sustainable white fish caught in the wild – and sourced from the Arctic seas in the north. The very best raw ingredients are picked, processed and packaged, then distributed to markets world-wide. With a history of more than 140 years of fishing in these waters, it is safe to say that our products are the result of developing and preserving a proud craft. Our main activities are within processing for filet products and ready-to-eat meals. Lerøy has high focus on improving the utilization of our raw material and thereby reduce food waste and increase profitability as well as consumer satisfaction. Assessing key quality properties by advanced sensors will help achieving this, and by combining data from different sources – knowledge and improved processes can be obtained. In DigiFoods, we will contribute with user expertise and production lines and we see this as a unique opportunity to discuss innovation ideas and improvements for our quality development work, e.g. sensors that are easy to use, practical and cost efficient. Our key person contributing in DigiFoods will be Quality Manager Rune Hansen.

Lerøy Havfisk is a large trawler company in Norway. We have long experience in handling large amounts of fish and facing quality challenges in whitefish production, with highly skilled personnel. Our strategy for improved handling of fish is making it possible to sort fish into different quality grades. These are key factors, as we see it, in order to secure a sustainable economic future for the fishing fleet and the land-based seafood industry. DigiFoods represents a unique opportunity to share knowledge and learn from other companies. The knowledge and innovations to be generated can be both of generic nature (sector independent) as well as specific for our business. It is hard to see that all outlined innovations can be established without this joint initiative. Our key person contributing in DigiFoods will be Operation Manager Odd Johan Fladmark.

Sensor & Robotic

NEO Norsk Elektro Optikk AS is a privately owned research company within the field of electro optics. NEO's main commercial interest is within hyperspectral imaging. Our line of hyperspectral cameras (HySpex) is recognized as the most advanced and accurate hyperspectral instrumentation available in the market. Through DigiFoods we want to develop new methods for applying our hyperspectral imaging technology to different food industry applications and to develop integral customized solutions. We could also be interested in designing dedicated instruments for one or more of the food partners both within imaging and point spectroscopy. Our main contribution in the SFI will be testing the suitability of our instrumentation for measuring different food quality parameters. We have our own camera lab and expertise within data analysis. Rental of instrumentation for use by other partners will also be one of our main contributions. We expect that DigiFoods will allow us to gain a better understanding of the need for spectroscopic information within the food industry and that this will help us identify new commercial opportunities within our field of expertise. Our key personnel contributing in DigiFoods will be Senior Research Scientist Silje Ottestad, Hyperspectral Applications Manager Julio Hernandez and CEO Trond Løke.

RobotNorge was established in 2003 as a private spin-off from ABB Robotics at Bryne. The history goes back to the root of robotics in Norway, i.e. the development of the first paint robot in the 1960s. Now, RobotNorge develops robotic solutions for future production needs. New technology that advances sensory, camera and AI is combined with traditional, industrial ABB robots. Our vision is to develop new innovative solutions enabled by robots and AI to solve dangerous and repetitive tasks. This is good for the environment, improves working conditions, increases profitability and frees up human labor for more creative tasks. Over the past two years, RobotNorge has stepped up activities within food handling and production. Recent developments within sensor/vision technology, AI and robotics control, provide potential for a new range of advancements and better solutions for the food industry. We believe that DigiFoods has the potential to become an important enabling Centre and a catalyst for these developments and foresee a Centre which can provide context, network, shared experience, distribute research project results and give support to new initiatives. Our key personnel contributing in DigiFoods will be Executive Chairman Atle Rettedal and Chief Software Developer Tommy Jonsson.

nanoplus focuses on the development of customer specific optoelectronic devices for sensor applications and has significant experience with complex coupled distributed feedback (DFB) laser diodes, but also the GaSb material system and associated challenges like water-free chip processing. nanoplus will in particular contribute to DigiFoods by bringing in capabilities and related expertise in the field of ICL and QCL technology. DigiFoods will enable us to maintain a strategic position with respect to emerging technology and related market opportunities concerning infra-red emitters in the food industry field, and to related investigations for future device applications in biophotonics. Our key person contributing in DigiFoods will be Johannes Koeth.

MarqMetrix offers a simple, stable and powerful Raman spectroscopy platform built for field and process applications at a performance level previously available only in costly lab instrumentation. We make affordable solutions that operate at scale to monitor and control processes in real-time for efficiency and quality optimization. Our fast and non-destructive sampling technology allows you to simply "touch" a sample to analyze gasses, liquids, solids and slurries. MarqMetrix has years of experience using Raman spectroscopy for analyzing lipids, collagen, and carotene concentrations in salmon fillets and cooking oil. We are excited about our participation in DigiFoods because it will enable close collaboration with food companies and third parties to innovate and broaden the applicability of Raman technology in the food and beverage industry. Our key personnel contributing in DigiFoods will be CEO Brian Marquardt, VP of Data Analysis Thomas Dearing and VP of Strategy Marc Malone.

Saga Robotics develops robots for the agricultural domain. We have developed the Thorvald platform which is a modular and completely autonomous robot that carries out a wide variety of agricultural tasks. The modularity of the robot allows us to operate in open fields, greenhouses, and poly-tunnels where the robot uses advanced sensor systems and machine learning to navigate autonomously in the field. A very specific outcome that we expect from DigiFoods is a close collaboration with developers of sensors and tools that have products or can develop new products that they would like to put onto our robots to collect large amounts of data that has not previously been available to farmers or researchers. We look forward to sharing our knowledge and experience in the DigiFoods partner network and see this as a good basis and opportunity to discuss innovation ideas. We will also offer an autonomous robot for field trials with sensors. Saga will work on integrating sensor systems on field robots and to test these in the field. Our key person contributing in DigiFoods will be CTO Lars Grimstad and CEO Pål Johan From.

OptoPrecision is a small, yet leading company in research, development, and production of high-quality optical sensing devices and solutions. Today, we address with our products applications in the chemical and steel industry, security and observation business and also in the pharmaceutical market. The strategic goal of OptoPrecision is to strengthen and expand its business via network actives with research institutes and complementary companies to new fields of applications based on the adaption of already available in-house solutions as well as the joined development of new technologies. In DigiFoods, we are contributing in terms of developing multi-purpose driver electronics for different infrared emitters (LEDs or lasers) and detection electronics as well as the corresponding embedded software to operate these circuit boards for the development of novel sensing technologies. First demonstrators have been built in 2021 and have been tested together with coworkers from the NMBU and UUlm team in 2022. In particular, we have realized a mid-infrared laser-based spectroscopic measurement setup for liquide samples to analyse the light absorption properties of different milk ingredients (a picture of the setup is shown in the project description for Handheld and portable IR on page 30). In general, DigiFoods provides a partner network and an excellent basis and opportunity to discuss, develop and push innovative ideas towards the market. Our key person contributing in DigiFoods is Markus Naegele, who is the head of our analytics department.

Digital platforms, software and analytics

Aspen Technology, Inc. is a global software leader helping industries at the forefront of the world's dual challenge meet the increasing demand for resources from a rapidly growing population in a profitable and sustainable manner. AspenTech solutions address complex environments where it is critical to optimize the asset design, operation and maintenance lifecycle. Through our unique combination of deep domain expertise and award-winning innovation, customers in asset intensive industries can improve their operational excellence while achieving sustainability goals. The DigiFoods Research Centre will address the current knowledge and technology needs to achieve a successful digital transformation of the food industry. This is consistent with the strategies of our organization, where part of our goals is bringing insights from science-based industrial analytics into daily operations. Through the DigiFoods partnership, we will gain valuable insight that will help us guide the development of our solutions so they best fit the needs of the industry. Our key contact contributing in DigiFoods will be Leslie Euceda Wood.

IBM is a leading global technology company engaged in 170 countries and is becoming an open hybrid cloud platform and AI capabilities company. For our clients, these tools and technologies help them improve and work in smarter ways, improving production and operations, and gaining competitive advantage. We conduct research and development in the field of digitalization and blockchain technologies for the area of food production and distribution. In DigiFoods, IBM will focus on enabling centre innovations and allow our partners to interface and integrate with the IBM Food Trust platform, and thus enable a value-add way to scale up innovations for a global market. In addition, IBM can, if needed, engage in the utilization of largescale quality measures, where large data volumes are collected and analyzed to produce actionable insight for end users. We will then engage with relevant skills and technology and the IBM cloud platform, development tools, AI and blockchain technologies can be used to develop and test new, innovative technical concepts and solutions. Our key personnel contributing in DigiFoods will be Chief Technology Officer, IBM Norway Loek Vredenberg and IBM FoodTrust Europe colleagues.

Maritech is the world-leading provider of seafood software, enabling full traceability, data flow and process support from sea to table. From catch and landing, through production, processing, packing, sales, and logistics. Since the 1970s, Maritech has been a trusted advisor and technology partner to many of the biggest seafood producers in the global market. Today, more than 70% of all fish exports from Norway are traded through Maritech. Since 2019, all their new software has been built in Maritech Cloud; implemented and supported by employees in Iceland, Norway, and North America. In addition to business systems, packing solutions, data, and IoT, Maritech has specialized in hyperspectral technology. Using Maritech Eye™, seafood companies can now run objective, automated quality inspection of red and white fish at industrial speed. "We believe that collaborations between the industry and research institutions are crucial for innovation. Our partnership in DigiFoods enables us to cooperate with partners that experience similar challenges in other food industries. Furthermore, we connect with people and companies who have experience with tools that can be applied to help us develop new decision-support solutions for our customers, and thereby increase the value of our portfolio". Odd Arne Kristengård, CEO.

Intelecy is an innovative SaaS company with a clear goal of enabling sustainable production within the industry. Intelecy's no-code Industrial AI platform is built for industrial data and made for industrial citizens. The easy-to-use tools enable engineers and operators to create, use and operationalize sophisticated AI algorithms without prior coding knowledge. By using Intelecy, a wide range of industrial companies improve resource utilization, prevent unplanned downtime, increase capacity, and minimize their environmental impact. The food processing industry faces a significant challenge in monitoring and ensuring product quality due to the high variability in raw materials. Traditional methods, such as lab testing, can be time-consuming and produce results only several hours after production. The DigiFoods project aims to address this issue using the Intelecy no-code industrial AI platform. The technology analyzes data to provide real-time predictions and helps to maintain quality and efficiency in the face of raw material variability. DigiFoods is a platform for Intelecy to expand its knowledge and test machine learning algorithms against conventional approaches. The Intelecy key personnel contributing to DigiFoods is Senior Machine Learning Engineer Harald Husum and Founder and CEO Bertil Helseth.

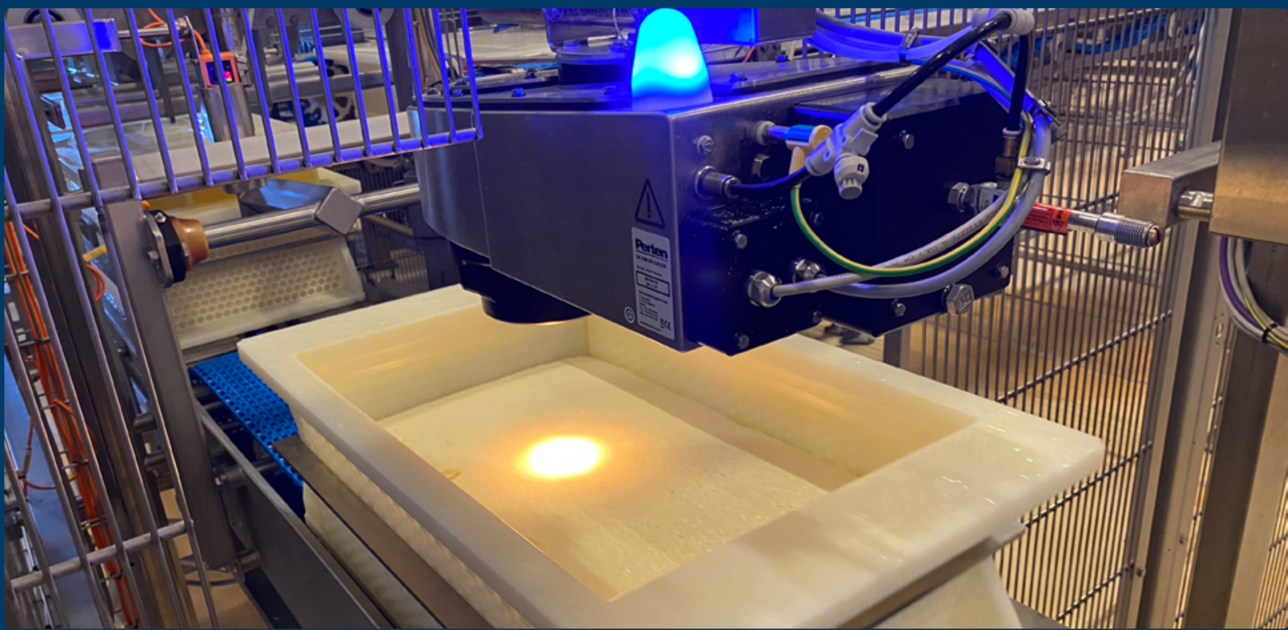
Idletechs AS was founded in order to stimulate the digitalization in the industry. We develop fundamentally new tools combining multi-channel sensors, transparent machine learning methods, and domain knowledge. In DigiFoods we intend to stimulate to deeper understanding, creative innovations and more robust in-line implementations of modern multichannel quality monitoring instruments, as well as to supply software for quality monitoring, deliver thermal and hyper-spectral software in the food production chain and simplify the integration of multichannel sensor data from various sources in the food production sector. DigiFoods will provide important market contacts and user feed-back for Idletechs and enable us to position us in the market.
Our key personnel contributing in DigiFoods will be CEO Andreas Wulvik and Project Manager Frank Westad.

Article

Working to ensure Norvegia cheese always tastes the same

by Wenche Aale Hægermark, Nofima

Everything is now in place to better understand the relationship between the quality of the cheese and the raw materials and processing conditions. Experts from TINE, Nofima and Intelecy are working together to advance the understanding of quality variations and process control further.



Photo/cc: Kjetil Jørgensen, TINE

NIR sensor on the processing line at TINE Jæren

The dairy TINE Meierier Jæren produces the majority of Norway's best-selling cheese – Norvegia. A NIR sensor has been installed on the dairy's production line, using light rays to measure the fat and dry matter contents of the passing cheese.

"Producing cheese with a consistent quality is a challenge, and there are several things that may cause the quality to vary. The contents of the milk used varies with the breed of cow, season, weather and feed, as well as lactation – that is, how long it has been since the cow calved. Processing conditions also have an effect – for example, we know that disruptions and stoppages affect the enzymes which leads to variations", says Kjetil Holstad, head of the R&D department at Tine Meierier Jæren.

From spot checks to measuring all cheese

"Previously, we only did spot checks where we manually sampled one in every 350 cheeses. The NIR sensor now enables us to measure all the cheeses directly on the production line and collect enormous amounts of data, which we use to gain insights into quality variations, including the nature of the variations, why they occur, and what we can do to ensure more consistent quality", says Kjetil Holstad.

“The NIR sensor enables us to measure all the cheeses directly on the production line and collect enormous amounts of data, which we use to gain insights into quality variations”

The NIR sensor evaluates the cheese at the end of the production cycle. The primary objective is therefore not to make changes to the final product, but to use the measurements to observe and understand how different manufacturing and raw material parameters affect its quality. The next step is to apply the results from the NIR measurements in the control system in order to make automatic adjustments in the process based on the milk quality.

Norway's best-selling cheese – and a market regulator

More milk is needed to make firmer cheese. It takes ten litres of milk in order to produce one kg of Norvegia. By comparison, Brie needs less, while Parmesan requires more.
Several thousand tonnes of Norvegia are sold every year, and the cheese plays an important role in regulating the milk market. More milk is available during certain times of the year, and more Norvegia is produced during these times of high milk production – resulting in the cheese spending a longer time in storage. "Storage time affects the need for dry matter. Norvegia becomes softer during storage as the protein is broken down, so more dry matter is needed for longer storage times. At the same time, we know that customers reject Norvegia that is too dry and firm," says Kjetil.

Comparing results from Nofima and Intelecy

A comprehensive dataset is needed to unravel the links between raw materials, processing conditions and cheese quality. In addition, expertise and investment in data management and analysis are also needed. TINE has therefore collaborated with both Intelecy and Nofima for several years, with the aim of gaining a better insight into the process.

Intelecy specializes in time-series analyses and provides a solution for "no code" industrial machine learning. They have focused on detecting patterns and insights from sensors with continuous data streams, for example on temperatures and pH values.

The collaboration with Nofima has focused on measurement technologies and multivariate data analysis, with particular attention on how combining data from both laboratory analyses, process sensors and processing conditions can provide a better understanding of the relationship between variables in the process.

"In the beginning, we kept these collaborations separate to compare the results. But even though Nofima and Intelecy have used slightly different data and methods, they came to several consistent conclusions," says Kjetil Holstad.

Long-term work

One of the results from the first phase was that more and better data on cheese quality was needed, and this was the reason for replacing spot checks with continuous measurements. Previously, the quality measurements were "laboratory data", but as the NIR sensor provides a constant data stream, it is now included as a time series in Intelecy’s system.

Using the DigiFoods research centre, TINE, Intelecy and Nofima work together to determine how the process can be improved to achieve consistent quality.

"The first analyses that include data from the NIR sensor are already underway, but it is necessary to collect data over a long period of time to account for variations in raw materials that change between seasons and from year to year. We also need to test the effect of different processing conditions by making controlled changes in, for example, temperatures and time spent in the different production stages. We are therefore fortunate to have the DigiFoods consortium, which makes it possible to have a long-term collaboration," concludes Senior Scientist Ingrid Måge at Nofima. She heads the research area “Utilization of large-scale quality assessments” at DigiFoods.

4. Scientific activities and results

Pillar 1 Novel sensor systems and application development

In this Pillar, we focus on the development of new sensor systems that will enable inline measurement of food quality features. We explore solutions that are based on high-resolution spectroscopy, imaging sensors and low-powered spectral sensors. There are several industrial partners in DigiFoods that are at the forefront of developing in-line food measurement technology. In 2022, we focussed on the development of online applications using hyperspectral imaging, NIR, FTIR, Raman and IR, with involvement from technology providers such as Maritech, NEO, MarqMetrix, nanoplus and OptoPrecision.

Another activity in Pillar 1 is the exploration of new opportunities. In 2022, this included activities such as workshops, arranging the conference SensorDecade 2022, and developing a strategy for how DigiFoods will position itself in relation to the EU research programs.

Pillar 1 is led by Marion O'Farrell at SINTEF Digital. Key end-user industrial partners in this Pillar include Lerøy Aurora, Lerøy Norway Seafoods, Lerøy Havfisk, Nortura, Norilia, Biomega and TINE.

FTIR

FTIR spectroscopy is a technique that generates highly resolved, information-rich spectra. One of the intriguing aspects of FTIR is the possibility for characterisation of proteins, not only protein content, but also protein quality, like for instance protein structure, peptide size distribution, and even protein composition. Since water very efficiently absorbs infrared light, FTIR spectra of aqueous samples (like in food-based products)

Photo/cc: Katinka Dankel, Nofima

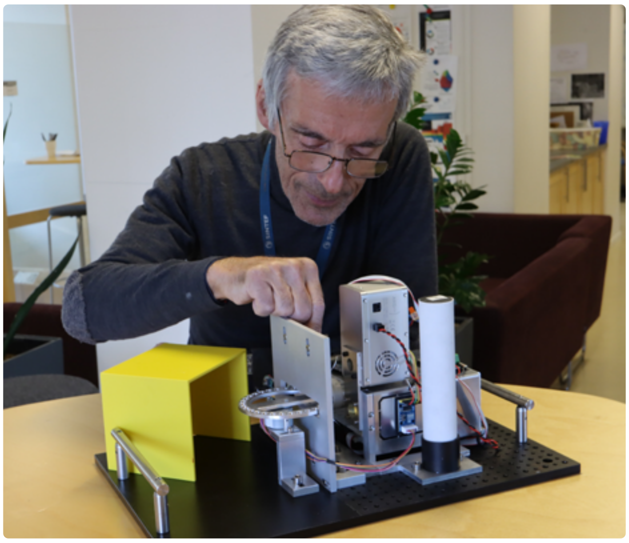
PhD student Bijay Kafle sampling hydrolysates at the Biomega processing facility

will often be dominated by water absorption. Dry-film analysis, on the other hand, has proven to increase sensitivity towards specific analytes compared to the direct analysis of liquids. Dry-film FTIR analysis is therefore particularly interesting related to protein characterization, since multiple protein-related infrared absorbances could be "buried" when water is present in the sample.

Application development is an important aspect of the project. A range of protein hydrolysates have been sampled from industry processes, both poultry- and salmon hydrolysates. All samples have been subjected to chemical and spectroscopic analysis at Nofima. The results show that FTIR can be used to predict average molecular weights of industrial protein hydrolysates, and this is the

"One of the intriguing aspects of FTIR is the possibility for characterisation of proteins, but also protein qualities"

Photo/cc: Jon Tschudi, SINTEF



Alain Ferber at SINTEF adjusting FTIR prototype

first time we show the applicability of FTIR to accomplish this. We have also worked on the optical sampling by comparing liquid analysis of the protein hydrolysates using Attenuated Total Reflection (ATR) – FTIR and dry-film FTIR. These results show that for salmon hydrolysates, results are similar when comparing ATR and dry-film analysis. For poultry hydrolysates, on the other hand, dry-film analysis works significantly better. This could be related to the increased complexity of protein composition in poultry hydrolysates compared to salmon hydrolysates. The results are important since they point at the industrial applicability of different sampling approaches, and a paper on these findings was published in 2022.

In 2022 we have also studied proteolytic activity and shelf-life measurements in milk. In collaboration with TINE, we have been part of a large study where the potential of FTIR analysis of milk to predict shelf-life has been investigated. From these results we see that dry-film FTIR can pick up subtle chemical differences in the proteins induced by proteolytic enzymes. A follow-up study will be finished in the spring of 2023. Here, specific micro-organisms will be used to induce changes in the protein structure and composition of the milk proteins. Subsequently, FTIR fingerprints of the milk samples will be linked to changes in protein characteristics during milk storage.

An important aspect of this research project is also to develop a portable FTIR system for dry-film measurements that can be brought close to industrial process lines, thus enabling industrially relevant measurements. This will be a technological solution that is not currently commercially available. In 2022, SINTEF in collaboration with the PhD student, Bijay Kafle, finished the optical design for the first version of such an FTIR system together with software for running the system. After this, the prototype has been travelling between SINTEF and Nofima for testing and subsequent hardware improvements. The final adjustments of the instrument are expected to be ready during the spring of 2023. The performance of the instrument will then be tested in industrial environments.

The work in the project has been performed in close collaboration with industry partners TINE, Biomega and Norilia.

• Photos/cc: Achim Kohler, NMBU

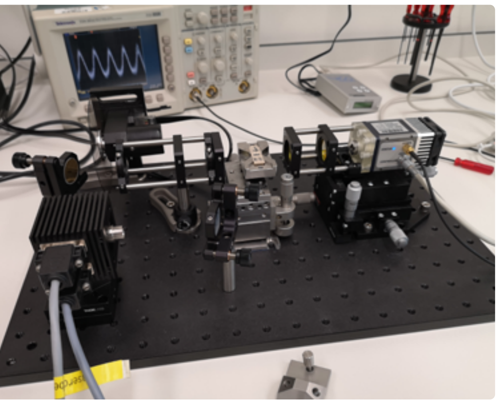


Fig. 1a: Laser-based infrared spectrometer with a MIR laser (quantum-cascade laser from nanoplus GmbH)

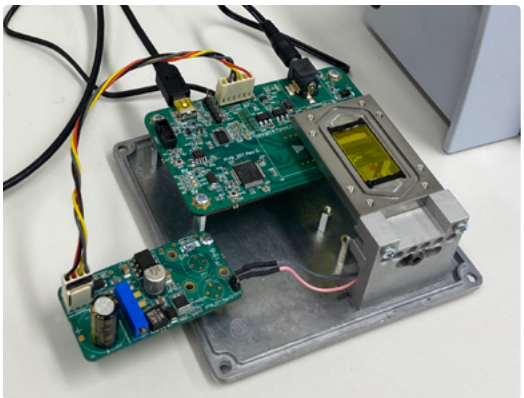


Fig. 1b: Two IC-LED-based devices are available for the project with an IC-LED (nanoplus) operating in the mid-infrared lipid region and in the protein region, respectively

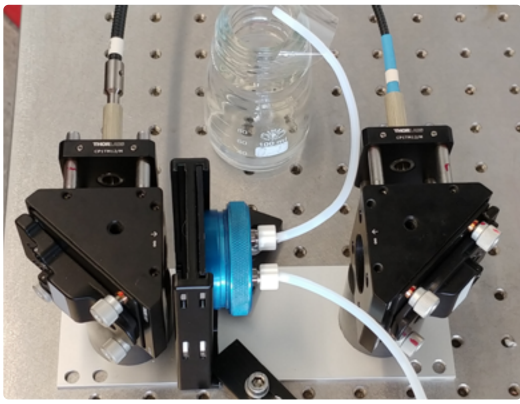


Fig. 1c: Milk measurement with laser-based device operating seven lasers that are couple into one optical fibre

Handheld and portable IR

n this project, new infrared solutions for foods quality measurements will be provided. The project has during the first period established three infrared devices: two based on novel lasers and one based on LEDs. The work was performed in close collaboration between NMBU, OptoPrecision GmbH, nanoplus and University of Ulm. All devices are built to be used in the field. The devices are currently in the prototype form, meaning they are established with the respective optical components on an optical table. The optical components are such that the laser-based setup can be transformed into a portable device, while the LED-based setup can be transformed into a smaller handheld device. One of the laser devices operates seven lasers provided by nanoplus with wavelengths in the range of 3 µm to 12 µm (Fig. 1c). The lasers are coupled into one optical fibre and the backscatter or transmission can be measured with a correspondingly sensitive MCT detector. The other laser device is presently operated at OptoPrecision who assembled the first prototype contains one laser (Fig. 1a). Right now, it can only be operated with one laser wavelength but soon this laser will be replaced by one that can provide 5–7 laser wavelengths in a wavelength region of around 100 wavenumbers. nanoplus is working with the development of this special laser. They have provided two LED light sources, with one around 3 µm (lipid region) and a second around 6 µm (protein region), which are currently adapted to an evaluation board using a linear variable filter for infrared spectroscopy (Fig. 1b). The LED-based system uses LEDs from nanoplus in the lipid and protein region, respectively. We have started to test the system for lipid analyses.

The new infrared devices provide spectral data of similar quality to an FTIR laboratory instrument, with a higher photon density of the lasers providing faster measurements and data with higher signal-to-noise ratio. Wavelength regions and laser wavelengths have to be selected to fit the respective application. Therefore, all systems are currently operated as open systems to be able to test as many food applications as possible.
To make fast sample analysis possible, the systems have been made in such a way that measurements can be made in the millisecond range. First measurements of milk samples have been performed with the laser system shown on Fig. 1c.

NMBU obtained interesting results for the data analysis of infrared data that covers specific wavelength regions or uses selected wavelengths. We found that when using a very narrow tuning of the wavelength of a laser around a centre wavelength, high-precision calibration models can be obtained. We are currently working with nanoplus to investigate if such a fine-tuning can be achieved by changing the laser current of single wavelength lasers.

RAMAN

The project RAMAN is studying how Raman spectroscopy can measure quality parameters such as fatty acid and protein composition in different foods. The focus of the project is on novel sampling strategies and the use of state-of-the-art technology to reduce sampling time and make Raman suitable for process measurements.

In 2022 we finished the evaluation of in-line Raman for rapid and non-destructive measurement of fatty acid features (EPA+DHA) in intact salmon fillets. This is of interest in the salmon industry for quality differentiation, efficient evaluation of feeding regimes, and for studies within breeding and genetics. It is possible to determine EPA+DHA with an excellent accuracy (R^2=0.96) based on Raman scans of only two seconds, indicating that in-line use is feasible. This work was coordinated with HYPERSPEC where the same samples were measured with high-speed hyper-spectral NIR imaging. PhD student Tiril Aurora Lintvedt has published a very interesting article, where these two methods are compared in terms of accuracy and practical use. The results were also presented at The SensorFINT conference in Izola, Slovenia, where she won the poster prize for this work.

The main focus in 2022 was to apply in-line Raman at Norilia (Bioco) for continuous monitoring of fat, protein, collagen and bone in the raw material entering the process. Calibrations for these components were based on Raman measurements in the lab. We then brought with us the MarqMetrix Raman system, mounted it above the grinder outlet, and collected in-line data over some days of production. The results are very promising, and it seems that it is possible to transfer Raman calibrations from lab to industry without too much adaptation. We will publish a paper on this in the beginning of 2023.

So far, we have demonstrated that, in spite of apparent limitations such as weak signals and small sampling areas, Raman spectroscopy is a very promising process control tool even for complex and heterogenous foods.

The work has been a collaboration between MarqMetrix, AspenTech, Norilia, Lerøy Aurora and Nofima.

Photos/cc: Jens Petter Wold, Nofima

Tiril Aurora Lintvedt doing Raman measurements in-line at Bioco (left) and receiving a poster price in Slovenia (right)

“At the end of 2022, a discussion with Royal Greenland was initiated to start a spin-off project for automated identification of MHS”

HYPERSPEC

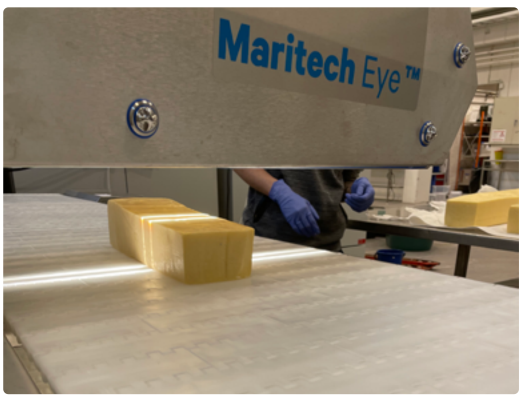
Maritech and NEO are active partners in HYPERSPEC along with Nofima, TINE, Lerøy Aurora and Lerøy Norway seafoods. Most activities were focused on developing and testing solutions based on the Maritech Eye and the hyperspectral cameras from NEO. Three specific applications have been addressed in 2022:

1. Detection of nematodes in whitefish fillets
2. Estimate texture properties maturation and chemical composition in cheese products. Analysis to be carried out in 2023.
3. Identification of blood and melanin stains in salmon fillets, as well as estimation fillet colour represented as SalmoFan values.

For salmon fillets, it is also of interest to combine “Estimation of fat content (and fat distribution)” with the solutions developed in the other activities related to salmon fillets.

Regarding the activities on “mushy halibut syndrome” (MHS), most of them were completed by the end of 2021 and the results have been published in two scientific articles.

At the end of 2022, a discussion with Royal Greenland was initiated to start a spin-off project for automated identification of MHS. Initially, a project with Royal Greenland and Nofima will be established. In this project a Ph.D. candidate from Royal Greenland, in collaboration with Nofima, will study the causes for MHS and validate/improve the solution developed for identification of MHS in halibut. Depending on this large-scale test at Royal Greenland a new spin-off project will be established with Nofima, Maritech and Royal Greenland as partners. The goal for that project will be to make a commercial solution for identification of MHS based on the Maritech Eye.



• Photos/cc: Samuel Ortega, Nofima

OPPORTUNITIES

This project centres on finding new opportunities and mange new ideas.

In 2022 we conducted several activities related to this project.

- In collaboration with CPACT, the Centre for Process Analytics and Control Technology, we held their second food related workshop, called Process Analysis and Control in Food Manufacturing on 16th June 2022, with approximately 100 delegates from industry and academia. The webinar comprised invited talks and a discussion panel. In 2023 we hope to follow up on this series of workshops, with a third workshop.

- From the 1st-2nd June, The Sensor Decade, an Oslo Science City event, was organized by SINTEF, the University of Oslo, NGI, Electronic Coast and StartupLab. The conference was aimed at companies that develop and deliver sensors and sensor solutions in Norway. Marion O'Farrell (SINTEF), who leads Pillar 1 in SFI DigiFoods, led the organization of the conference. In addition to technical talks and stands, there was also The Student Challenge to involve students and get them to think innovatively. SFI DigiFoods was well-represented at the event as follows:
  - Jens Petter Wold, from Nofima, presented "Design of spectroscopic smart sensors for quality assessment of heterogeneous foods"
  - Anders Hansen, from SINTEF, presented "Novel Sensors for Quality Classification of Strawberries in the Field"
  - NEO HySpex showcased their hyperspectral camera at a stand in the exhibition area.
  - Agrilives from NMBU submitted an entry to The Student Challenge based on computer vision and machine learning to help agri-robots to interact safely with their surroundings.

Ingrid Måge and Marion O'Farrell presented two talks at AgTech2022, 22nd November 2022, which was an event organized by the RCN, Innovation Norway and the Norwegian Agricultural Co-operative. The theme this year was data-driven developments for optimised food production and soil health. Marion and Ingrid presented DigiFoods

Jens Petter Wold presenting

Photos/cc: Kilian Munch

Trond Løke explaining their technology at the HySpex stand

from a data-creator (sensor) perspective and a data-user (modelling) perspective, respectively, and received positive feedback from the audience, who appreciated seeing concrete examples and gaining a better understanding of the full journey of data in digital food systems. They also partook in a panel discussion afterwards where we discussed the challenges in technology adoption, the importance of data quality, and the need for educating a new generation of young people that can straddle technology and domain competences.

In order to position DigiFoods at an EU level, we got involved in two strategic events.

- The Photonics21 Partnership organised a workshop to gather input for the Food and Agriculture chapter in the updated Strategic and Innovation Agenda (SRIA) for 2023. DigiFoods got the opportunity to present ourselves and provide input about challenges and required research as we see it, and these are now part of the working document that will be delivered in 2023.
- DigiFoods was also presented at the European Photonics Industry Consortium meeting on Photonics for Food and Beverage. After this event, EPIC, would like DigiFoods to host the next physical event for this in Norway, most likely in 2024.

Pillar 2 Robot and sensor integration

Robots and sensors are important in several different areas of the food industry. The rise of the agri-tech sector has shown a demand for robots and sensors to work closely together to increase the performance and accuracy of production both in outdoor and indoor systems.

In this pillar, we are looking at how robots can be used to enhance the performance of sensors by accurate positioning of sensors for optimal sample taking and measurements. We are also looking at how sensors can be used to increase the performance of robots and improve decision making and overall performance. We will develop fully autonomous robots and automatic sample preparation and enable in-line measurement of heterogeneous foods by robotic control of smart sensors.

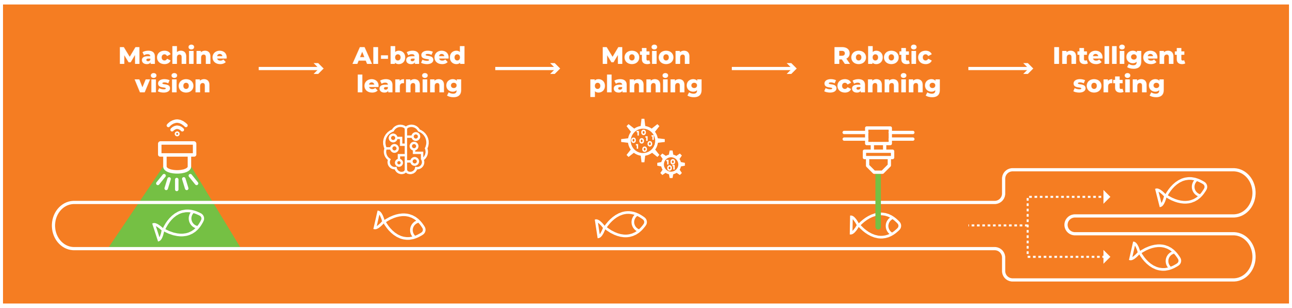
Long term, we will develop automatic sample preparation for high-throughput spectral finger-printing of biological liquid samples by FTR and Raman, which is closely related to the work done in the other pillars.

The research area is led by Pål Johan From at Saga Robotics/NMBU and divided into two main projects. Key partners in this pillar include Saga Robotics, RobotNorge, MarqMetrix, Lerøy Aurora, Nofima, SINTEF and University of Lincoln.

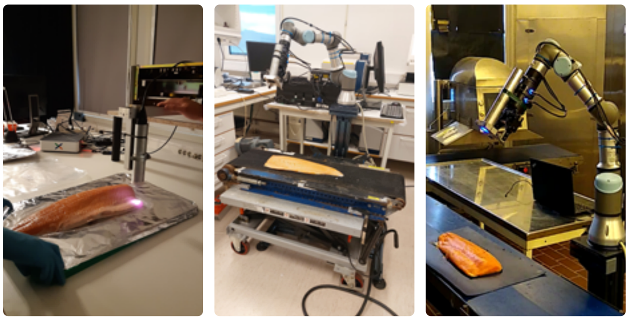
ROBOSENSE

ROBOSENSE enables robotic operations of smart sensors in processes, enabling accurate and effective in-line measurements of relevant parameters in heterogeneous foods. In 2022, the research team successfully achieved the goals and objectives initially planned for 2021: (i) design, implementation, and demonstration of a proof-of-concept (POC) for the robotic control of a Raman sensor in process for assessment of fatty-acid composition in salmon fillets; (ii) strengthen collaboration with research and industry partners (Nofima, MarqMetrix, Lerøy Aurora, RobotNorge, and Byte Motion) to generate basic/advanced knowledge, evaluate prototype solutions, and create results for innovation in the food industry; (iii) write a scientific paper, titled "Robotic Raman Spectroscopy for Assessment of Fatty Acid Content on Salmon Fillets", submitted to the 22nd IFAC World Congress, a highly-ranked international conference on control and automation, to be held in Yokohama, Japan, in 2023.

The POC demo uses a lightweight 6-axis industrial robot arm integrated with a MarqMetrix Raman probe and a Robotic wrist camera. A vision system detects the salmon fillet and identifies the inspection area. Then, a motion planning system generates a reference trajectory for the robot arm, that moves the Raman probe attached to its



Main steps in robotically controlled in-line sensing of foods



Photo/cc: Antonio Candea Leite, Nofima

Overview for the ROBOSENSE project activities in 2022: manual operation for salmon scanning; experimental proof-of-concept demonstration; robotic Raman spectroscopy validated on a laboratory scale

end-effector over the salmon's belly, measuring the fatty acid composition. A linear conveyor module is also integrated into the robotic system to simulate an industrial environment at the Nofima lab. The current vision system uses pre-trained image classification models of salmon fillets and has the capacity to track multiple salmons on a moving linear conveyor at about 80mm per second. However, the use of pre-trained models is unfeasible for industrial-scale robotic applications, as the process of training multiple images is time-consuming and error-prone. Thus, as real-time detection of salmon fillets is required to enable high-speed in-line measurement, AI/ML-powered solutions are mandatory. Byte-Motion has collaborated with NMBU providing the Ocellus vision system to detect salmon fillets and identify the scanning area for Raman measurements. Using the Ocellus AI cloud platform together with proprietary software tools, we can then detect the belly of a salmon fillet with a confidence interval of about 98%, with a 5% margin of error. The image dataset is collected in-house at Nofima using salmons from Lerøy Aurora. RobotNorge has also collaborated with ROBOSENSE, providing basic training on ABB RobotStudio software allowing researchers to operate the ABB collaborative robots in the future. Currently, the robotic Raman spectroscopy technology designed in ROBOSENSE is rated at TRL4, as it has been validated on a laboratory scale at Nofima through systematic testing for the measurement of fatty acid composition in salmon fillets. For 2023 it is expected to continue the technology development for the robotic operation of sensors in processes - towards the minimum viable product (MVP) – mastering the Ocellus vision system (Byte Motion) and integrating the externally triggered Raman system (MarqMetrix) with the ABB collaborative robots (RobotNorge).

MOBILESENSE

The purpose of this work is to develop fully autonomous robots for the automatic collection of large-scale quality data in agricultural areas. We will integrate a suite of sensors on the Saga Robotics's Thorvald mobile platform for exploration purposes in open fields. This will give large amounts of data over time and space and increase our understanding of how to collect and analyze data in the agricultural environment, particularly considering sparse plant distributions, different soil types, and irregular terrains. At the moment, the process of hiring a postdoc fellow has started for MobileSense and we plan to perform the first field work by the end of 2023.

A target is now to develop a small low-cost spectrometer that can be used by Thorvald to measure and evaluate quality of strawberries and other fruits and berries. This work is done in collaboration with the RCN project Målbær. A main aim is that this sensor can be used by Thorvald to optimise picking of the strawberries as well as collect large scale data, which can be used to e.g., forecast time and size of harvest.

Photo/cc: (right) Katinka Dankel, Nofima, (left) Jens Petter Wold, Nofima

Researcher Petter Vejle Andersen (Nofima) doing NIR measurements in the strawberry field

Pillar 3 Integrated in-line sensing solutions

When a food sensor has been developed in a controlled environment, there is still a long journey to industrial implementation. Several commercial food sensors have failed because they were not robust towards the inherent bio-variability encountered in the processes and products. Thus, strategies that address the practical and theoretical considerations for sensor implementation are clearly needed for the instruments that are already used commercially, but also for techniques for which we have very limited industrial experience, such as FTIR, Raman and fluorescence spectroscopy.

In Pillar 3 we are developing and validating efficient solutions and strategies for successful sensor implementation in food production. In other words: We are making the sensors actually work in the food companies. We are developing the appropriate tools for robust calibration of real-time industrial sensor systems, enabling the sensors to provide the user with reliable quantitative outputs. This was the core research initiated in ROBUST for 2021 and extended into 2022. Since Covid-19 very effectively hindered site visits and industrial research, this work has been slightly delayed.

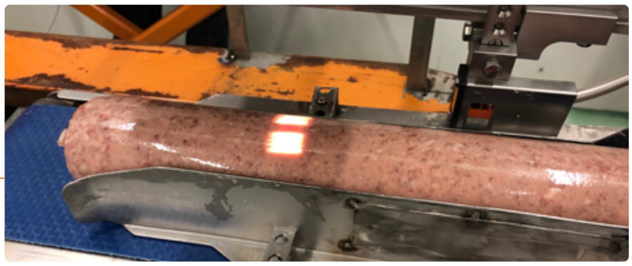
In DigiFoods, implemented sensors will also be used to explore and map variation in food processes over time. Many of the sensors proposed in DigiFoods will provide previously unavailable information from food processes. In 2022, we therefore also initiated the project EXPLORATION, where we are monitoring quality variations along processes and over time with in-line sensors, evaluating the potential for process improvements, real-time process control and product differentiation. This work has started together with Nortura in the process of making dry cured sausages.

Pillar 3 is led by Dr. Nils Kristian Afseth at Nofima. For 2022, key partners in this Pillar have included all food partners, NEO, AspenTech, MarqMetrix, Idletechs, SINTEF and NMBU.

ROBUST

A major bottleneck for industrial sensor implementation is to get from the measured signal to reliable estimates of food quality attributes. A robust calibration model needs to handle chemical and physical sample variations as well as harsh and changing surroundings. Spectroscopic sensor technology has many application areas in in-line food quality analysis. Some applications are well established, and robust calibration models can be purchased from instrument vendors. New or less standardised applications require development of new calibration models, which can be a timeconsuming and expensive task. Also, it is necessary to maintain models over time for both instrumental, environmental and process reasons.

In 2022, we reviewed calibration transfer techniques. There are many existing approaches, but little documentation on whether and when methods may work better than the alternatives. The focus here has hence been on addressing the circumstances under which methods may be expected to work. We have given a presentation on calibration transfer at the CAC conference (Chemometrics in analytical chemistry). We have also started a DigiFoods seminar series on calibration transfer where those in the consortium who are interested can join. This has been very fruitful.



Photos/cc: Jens Petter Wold, Nofima

Sausage being measured with NIR spectroscopy in process line

In ROBUST the main aim is to define strategies and methods for efficient and robust calibration and maintenance of in-line spectroscopic instruments. This will be based on collecting relevant calibration and process data from in-/on-line processes at selected industry partners. This got a slow start in 2021 due to Covid-19 restrictions, but in 2022 we got off well. At HOFF two NIR instruments have been mounted on the production line and we will follow this up in 2023 with calibration trials and process monitoring. We also did NIR measurements in process at Nortura Hærland with the aim of measuring core temperature in heat treated chicken. This is challenging but will most likely continue in 2023.

Finally, performance of models will be assessed over time in-/on-line at industry partners with the objective of improving the understanding of industrial processes both in terms of distributions and dynamics, but also in terms of relationships between processing stages.

Photos/cc: Jens Petter Wold, Nofima

Work at Nortura Hærland: Measuring core temperature in grilled chicken by the use of interactance NIR and thermal video. From left: Rugile Gasiunaite (Nortura), Erik Tengstrand (Nofima), Håkon Jarle Hassel (Idletechs)

EXPLORATION

A key challenge in many food processes is the missing knowledge about the actual quality variations. This information is crucial to gain insight into a given process to understand process behaviour over time. The knowledge about quality variation is usually based on sporadic or systematic measurements, maybe weekly or monthly. Process operators also possess valuable informal process knowledge based on personal experience and insight.

With smart sensors that measure and continuously monitor the critical quality features in a process, it is possible to document and map these variations along the processes and over time. The aim of EXPLORATION is to map exactly this variation and based on the results, figure out potential improvements, either in the final product or in the process itself.

In 2022, the project focused on fat content in dry-cured sausages. The motive for measuring fat in dry-cured sausages is that the fat content affects the quality and shelf-life of the final product, as well and the dry-curing process. We have measured sausages with in-line NIR spectroscopy both at Nofima and at Norturas factory in Sogndal. The measurements have been done both on the sausage stuffing and the actual sausages, during processing and the dry-curing process. At Norturas facility in Sogndal, we measured fat content in about 800 sausages without interfering in the process. This gives a very useful insight in the process variation. The work is done in collaboration with the RCN-funded project DigiSpek and gives very nice synergy effects for both projects. Better control of the fat content will give better and even more healthy sausages and much better control in the drying process.

In the coming year, this work will be followed up, and we will apply this exploratory approach to study also other processes in the DigiFoods consortium.

Pillar 4 Utilization of large-scale quality assessments

In this Pillar, we develop data-driven solutions for process, product, and value chain optimisation. The solutions are based on extensive food quality measurements, combined with other relevant data sources from farm, industry, and consumer. The solutions will be targeted at three application areas: Farming, food processing, and marketing.

There is a strong link between health and welfare of animals, fish and plants, and the resulting food quality. Decision support for farmers involves for instance optimised feeding, care, and time of harvest, as well as early detection of health and welfare threats. We will combine food quality measurements with data on environmental and husbandry factors to investigate how they affect quality and health. This knowledge can be used in either long-term production planning or in real-time decision support.

In-/on-/at-line food quality measurements can be used to monitor, optimise, and control production processes. We will develop solutions that transform the multitude of measured and registered data in a production line into meaningful information needed to adjust and stabilize the production or tailor-make specific end-product quality categories. As in farming, the information can be used in either long-term improvement work or real-time monitoring and optimisation.

Well-documented and tailored food products can contribute to increased consumer satisfaction and reduce food waste. We will investigate consumers' attitudes and willingness to pay for different quality categories, and from that develop communication and marketing strategies to target different consumer profiles. We will also investigate how the growing focus on food waste may impact food choice with respect to product quality.

Pillar 4 is led by Ingrid Måge at Nofima. Participating partners in 2022 were TINE, Nortura, Bioco, Biomega, Lerøy, HOFF, Intelecy, Maritech, IBM, NMBU and UPV.

"We will combine food quality measurements with data on environmental and husbandry factors to investigate how they affect quality and health"

COMBINE

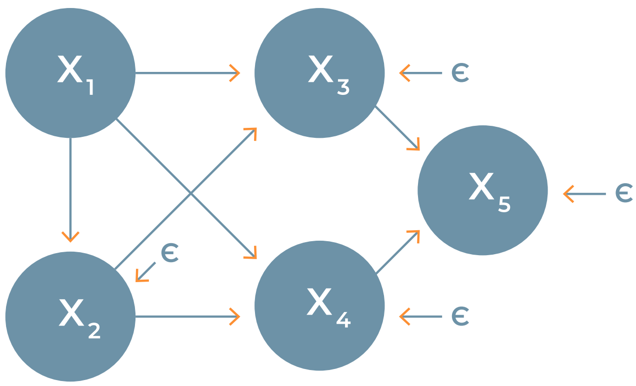
Data preparation is a crucial and resource-demanding part of any data science project, especially when we need to combine data of different types and from different sources. Data preparation includes operations such as cleaning, synchronising, aggregating, transforming, structuring, and validating data.

In 2021, we identified the main challenges for combining data in the food industry, and two of these were selected for further work in 2022. The first topic is inclusion of new data sources from the Manufacturing Execution System (MES) and laboratory database in Intelecy's implementation at TINE Meieriet Jæren. Until now, Intelecy has accessed time series data from a multitude of process tags, but the MES contains additional data needed to investigate potential causes for variation in cheese quality. Technical challenges and coordination with other data management initiatives at TINE has delayed the work slightly, so it will be continued in 2023.

The second topic is computational methods to identify lags between process measurements. This is a generic challenge when modelling data from continuous processes where the exact time lag between different sensors is not known. PhD student Marco Cattaldo has compared a broad span of methods, from classical correlation metrics, via more flexible machine learning methods to advanced optimization frameworks. The methods have been compared in a large simulation study and are evaluated on their ability to identify the correct time lags, their computation time, and their general ease of use. The methods have also been applied on data from the hydrolysis process at Bioco. The work has been presented at an international conference, and a scientific paper is in preparation.

MODEL

All data-driven solutions require some form of data modelling. In DigiFoods, the models will typically relate quality attributes to controllable and uncontrollable factors from farming or processing. In MODEL we will develop methodology for two types of models: causal modelling and real-time modelling.



Directed Acyclic Graphs (DAGs) is an increasingly popular framework for designing statistical models for estimating causal effects. A causal DAG is a graph consisting of nodes and arrows. The nodes represent variables one can measure, and the arrows indicate how the variables are causally connected. A DAG describes a theory or hypothesis about the system at study and should be based on domain knowledge and previous research results. It is important to test the validity of a DAG before it is used to estimate causal effects. PhD student Christian B.H. Thorjussen has developed a simple and flexible machine learning method to test conditional independencies inferred by a DAG. The method has been compared to alternative approaches in a simulation study, with good results. Christian is also trying to apply DAGs in cases from Nortura and Bioco. A scientific paper is in preparation.

Photos/cc: Katinka Dankel, Nofima

PhD students Marco Cattaldo (left) and Bijay Kafle (right) collecting samples at Bioco

The second type of model is intended for real-time monitoring, control, or decision support. In collaboration with Bioco, we have done initial analysis of inline NIR and other process data and identified potential cases for process monitoring and control. PhD student Marco Cattaldo has reviewed statistical methods for accounting for dynamics when modelling such multivariate time series, and further evaluation of these methods will continue in 2023. A huge data collection campaign has been performed at the Bioco factory in the autumn of 2022, which will be used to evaluate the dynamic modelling methods.

CONSUMER

Quality measurements open new possibilities for marketing and product development. To realize this potential, we need to understand how consumers will react to quality differentiation, how best to communicate/market such products, and how this may affect the value and consumption of different product categories.

A successful workshop was run in October 2022, focusing on mapping how the food companies in DigiFoods can utilize existing or future data on product quality for product development, shelf-life extension and/or marketing. From there, the newly started CONSUMER project will explore concrete case studies with some of the industrial partners in DigiFoods (TINE, Nortura, Lerøy, IBM) to bring those ideas into innovations. CONSUMER is led by Dr. Paula Varela, consumer researcher from Nofima.

Photo/cc: Paula A. Varela Tomasco, Nofima

CONSUMER workshop in IBM offices, Oslo, 8 Septermber 2022


TILGANG PÅ DATA


FORBRUKERNES BEHOV OG ØNSKER
+ SMAKSDOMMERE
DATA VI HAR ELLER ØNSKER OSS
SMAK!
SMAK
SMAK
KONSISTENS
Sensoriske egenskaper
UTSEENDE FARGE
Dyrevelferd
DYRE-VELFERD
DYRE-VELFERD
OPPRINN-ELSE
NORSK
NORSK
Kortreist
Jevn kvalitet
Trygghet (gifter)
HELSE
NÆRINGS-INNHOLD
Kvalitet
KVALITET
FETT-%
LAB-DATA
FETT PROTEIN TØRRSTOFF VANN
HELSE-KOMPONENTER (OMEGA-3)
LEVERANDØR
FISKER & FISKE-BÅT
OPPRINNELSE
Slakte-volum
Landings-volum
Fôr & medisin-bruk
HOLDBARHET - LANG - RIKTIG
Dynamisk holdbarhet
Holdbarhetstid
HOLDBARHET
FORPAKNING
Emballasje
ESG
IMPACT
BÆREKRAFT
klima-merker
ØKOLOGI
KONSISTENS?
TRENDDATA
PROSESSDATA
ENERGI-FORBRUK?
ENERGI
MSC ASC
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MERKE-VARE
TILLIT
ENKELHET
(For)bruker-grensesnitt
IDENTITET SKAM
NORMER
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PRIS
PRIS
UTVALG
pris
PRIS
KJØLE-KJEDE
Temperatur sporing (mht. holdbarhet)
CO2-utslipp
klimaavtrykk
Totalt klimaavtrykk
LAVT?
Utnyttingsgrad

The robot Thorvald at work

• Photos/cc: Matt Munro (counting left to right, up and down: photos 1, 2, 3, 4, 5, 6 and 9) and Kristoffer Skarsgård (photos 7, 8, 10, 11 and 12), Saga Robotics.

5. International collaboration

DigiFoods has established close collaboration with three excellent foreign research groups and three foreign high-tech technology providers who are important for carrying out the research and innovation work. The research groups take active part in the running projects and share supervision of PhD-students. It is an excellent base for exchange of PhDs and post-docs.

1. **University of Lincoln (ULin),** (UK), is represented in DigiFoods by Dr. Gregorz Cielniak and his research group at Lincoln Institute of Agri-food Technology. They are contributing with expertise in autonomous and long-term navigation of agricultural robots, sensor and implement integration and data gathering, management and analysis. The university has a research farm with more than ten of Saga Robotics' Thorvald robots that can be used for extensive testing in a realistic environment. They are taking active part in MOBILESENSE..

2. **Ulm University (UUlm),** (Germany), is represented by Professor Boris Mizaikoff, director of the Institute of Analytical and Bioanalytical Chemistry (IABC). UUlm has developed miniaturized mid-infrared sensing platforms based on thin-film semiconductor, oxide/nitride, and diamond waveguides that have already demonstrated their potential for analyzing e.g., secondary structure changes in proteins. UUlm participates in the project IR and develops this platform further for in-line measurement of protein, lipid composition in foods and dairy and bioprocess control.

3. **The Polytechnic University of Valencia (UPV),** (Spain), is represented by Professor Alberto Ferrer, group leader of the Multivariate Statistical Engineering Group. The group is devoted to research, development and innovation activities in the area of multivariate statistical techniques for quality and productivity improvement and mega-database analysis. Professor Ferrer participates in the MODEL project and provides joint supervision of PhD students and on data analysis and real-time process control.

Foreign technology companies are also partners since they offer technology of interest to the centre and Norwegian food industry:

4. **MarqMetrix,** (USA), provides modern, easy to use Raman instruments for rapid material analysis and process measurements. They are represented by Dr. Brian Marquardt, world leading in development of process Raman systems and very interested in novel food applications. He is contributing with knowledge and instrumentation in project RAMAN.

5. **nanoplus Gmbh,** (Germany), is represented by Dr. Johannes Koeth. They contribute by bringing in capabilities and related expertise in the field of Quantum cascade laser (QCL) and Interband cascade laser (ICL) technology. Nanoplus' main task is to support in combining QCLs with waveguide technology developed by UUlm for online measurement of complex structures and composition in food samples online, such as fatty acid composition. This is being explored in the IR project.

6. **OptoPrecision GmbH,** (Germany), represented by Dr. Markus Naegele, is a leading company in research, development, and production of high-quality optical sensing devices and contributes by developing laser-driver and detection electronics in conjunction with the corresponding embedded software to realize a dedicated analyzer platform in Pillar 1 and project IR.

6. Recruitment, education and training

DigiFoods is planning to have a total of nine PhD fellowships and three post-doctoral fellowships associated with our research over the lifetime of the centre. Many of the candidates have been employed and have started to work on their projects.

These candidates cover a large range of applications and instrumentations in the food industry. Their projects cover key areas from methodological and instrumental developments, optimal deployment and usage of sensors and analysis of process data collected with sensors.

At Nofima in Ås, Tiril Aurora Lintvedt is in the process of finishing her PhD work on in-line Raman spectroscopy aiming for representative sampling and modelling of heterogeneous foods. Christian Thorjussen is developing statistical path modelling approaches, aiming at better understanding of factors and mechanisms causing variation in food quality. Marco Cattaldo, enrolled at Universitat Politècnica de València, is developing statistical methods for process and product optimisation based on real-time measurements of food quality.

	Location	Candidate	Funding	Project	2020	2021	2022	2023	2024	2025	2026	2027
PhD-students	Nofima	Tiril Aurora Lintvedt	Nofima	RAMAN								
	Nofima	Christian Thorjussen	Nofima	MODEL								
	Nofima/UPV	Marco Cattaldo	RCN	MODEL								
	Nofima/SINTEF	Bijay Kafle	RCN	FTIR								
	NMBU	Andreas U.N. Persch	RCN	IR								
	TINE (Nofima)	Åse Riseng Grendstad	TINE	CONSUMER								
	SINTEF/Nofima	Vilde Vraaldstad	RCN	MOBILESENSE								
	NMBU	NN	RCN	ROBOSENSE								
Post-docs	Nofima	Samuel Ortega Sarmiento	Nofima	HYPERSPEC								
	Nofima	Rowan Romeyn	Nofima	HYPERSPEC								
	NMBU	Nageshvar Patel	RCN	IR								
	NMBU	NN	RCN	MOBILESENSE								

"Their projects cover key areas from methodological and instrumental developments, optimal deployment and usage of sensors and analysis of process data collected with sensors"

At Nofima and SINTEF, Bijay Kafle is building and testing an FTIR prototype system for analysis of dried liquid samples, combining development of new applications with industrial testing of the FTIR prototype.

Åse Riseng Grendstad started her Industrial PhD in 2022. She is funded by TINE and is working on consumer perceived quality of yoghurt as well as related spectroscopic properties.

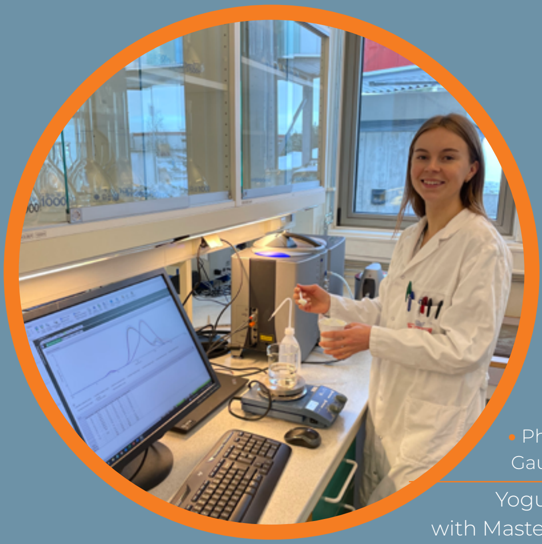
At Nofima in Tromsø, post doctor Samuel Ortega Sarmiento did work on strategies for combining Magnetic Resonance Imaging and other reference methods for robust industrial applications of hyper-spectral imaging, improving physical modelling and light interactions. Samuel has been hired now as a researcher at Nofima in Tromsø and a new post-doc, Rowan Romeyn, began in early 2023.

At NMBU, Andreas Persch started on a PhD on the development of a prototype hand-held IR instrument for food quality applications. Unfortunately, he terminated his work, but post-doc Nagesvar Patel took over in the spring of 2022. We attempted to hire a PhD within robotics in 2022, to work on control of sensors to be used in complex measurements situations. It has been difficult to recruit PhDs within robotics and we did not succeed. We aim to hire a person for this PhD position in early 2023 along with another PhD student to work on autonomous mobile robots to gather sensor data in field on ripeness and sugar content in fruit and berries.

A connection to the master programs in data science at NMBU has been established by offering relevant master thesis topics for students finishing their master education in 2023. DigiFoods has recruited two master students so far in 2023. Additionally, we have also recruited a student from Physics and Mathematics at NTNU for master work on sensor systems at SINTEF. The potential for further relevant master thesis topics, for students finishing in 2024 and beyond, is high.

Get to know

Åse Riseng Grendstad



• Photo/cc: Even Gausemel, TINE

Yogurt analyses with Mastersizer 3000

What do you do in DigiFoods?

I am working on an industrial PhD in collaboration with TINE, NMBU and Nofima. The purpose of the PhD project is to gain further insight into how the raw material composition and various process parameters affect the quality and shelf life of yogurt. In addition, it is important to develop expertise in sensory assessments at TINE.

The sensory qualities of yogurt are currently analyzed through a quality assessment by a trained panel. Objective measurements of the quality of yogurt are rarely carried out. There is therefore a need to develop solutions that can contribute to monitoring and controlling production in order to ensure that the yogurt achieves the desired quality. At DigiFoods, I use NIR measurements to assess the water-holding capacity of the yogurt, which serves as an indicator for the shelf life of the product.

Many consumers today throw away food that has passed the "best before" date. I will conduct consumer tests to investigate which quality defects result in customers throwing yogurt away. The project will potentially enable us to optimize the yogurt and extend shelf life so that the best before date is set in accordance with what the consumers consider to be acceptable in terms of quality.

Why did you choose this field of research?

Quality data can contribute to a reduction in the amount of food waste by assessing whether the shelf life can be extended and whether production methods and recipes can be optimised. The goal is to use quality data for product development in order to increase consumer satisfaction and reduce food waste, which will ultimately contribute to the achievement of the UN Sustainable Development Goal (12.3) of reducing food waste.

It is exciting to be able to carry out trials at NMBU and TINE SA's pilot plants, which are very effective at simulating industrial production conditions. It will also be interesting to use new analytical methods to identify properties that affect storage stability in yogurt. To date, there are very few studies in which NIR analyses have been used to identify water-holding properties in yogurt.

"The purpose of the PhD project is to gain further insight into how the raw material composition and various process parameters affect the quality and shelf life of yogurt"

Christian Thorjussen

Photo/cc: Mads Lillevold, Nofima

What do you do in DigiFoods?
I am writing a PhD in applied mathematics in the field of causal inference. Causal inference is an area of mathematical statistics that aims to estimate causal relationships. This involves everything from analysis of randomized trials and experiments to complex modelling of high-dimensional unstructured data.

The article that I am busy finishing, proposes a procedure for evaluating statistical assumptions in a graphical causal model. These assumptions are important, because graphical models are often used as a basis for statistical modelling aimed at estimating causal effects. The current standard is that these assumptions are not tested in any systematic way. Existing statistical methods that can be used are mostly designed for other special cases and are often difficult to implement in general cases. My method aims to solve this by being flexible and relatively easy to implement and intuitive for researchers working with statistical modelling.

I will also work with data from Nortura to look at the effects of feed type and light on the prevalence of health and welfare indicators in chickens. My goal is to write an article that provides researchers – who are typically trained in conducting controlled experiments – with a guide on how to model causal effects. I believe this can be very useful for researchers who have a lot of data, but may lack expertise in working with causal inference.

In addition, I would like to extend the model testing to cases where the data is high-dimensional, and to write a program for model testing which will be made available to other researchers both at home and abroad.

Why did you choose this field of research?
I really enjoy working with statistical modelling, as it requires you to both be creative and try to capture the real world in models. Causal inference based on unstructured data has seen explosive growth in recent years. Proper analysis of observational data can provide new scientific insights, and it is important to generate more knowledge about how this is done. Going forward, it will be exciting to have another opportunity to sink my teeth into Nortura's datasets.

"The article that I am busy finishing, proposes a procedure for evaluating statistical assumptions in a graphical causal model"

Article

Examining salmon fatty acids with handheld sensor

by Georg Mathisen, NMBU

A simple scanner is all it takes to find out what is in a salmon. NMBU researchers are developing a tool that will make good food even better and more valuable.

If you already have a large laboratory with expensive equipment, you can work out the contents of salmon without any trouble. However, Nageshvar Patel, Boris Zimmermann and their collaborators are currently working on a simple gadget that does the same job but fits in your hand and which everyone who works with salmon can afford.

Healthy oils

It's all about what's in the salmon – especially the healthy and sought-after oils which contain those omega-3 fatty acids. The scientists can detect the proportions of these oils and how they are distributed in the salmon fillets.

"This will enable salmon producers to sort the fish by quality and charge more for the best and most optimal fillets and cuts," says Boris Zimmermann. "Different quality has different value," adds Nageshvar Patel.

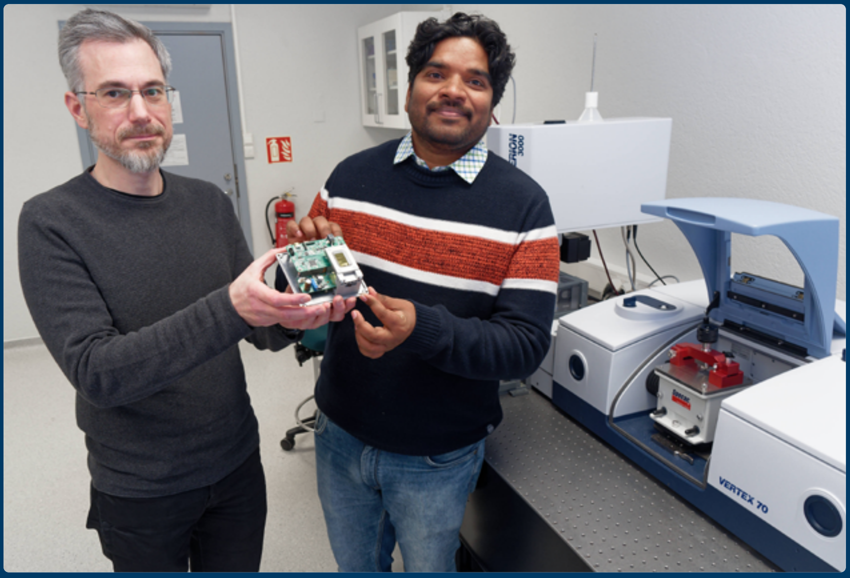
The two are, respectively, scientist and postdoctoral researcher at NMBU, and working at the DigiFoods research centre, where Nofima, NMBU, SINTEF and a number of other Norwegian and foreign companies and universities are collaborating to develop smart sensors for measuring food quality.

Adding value

"Today, both trained operators and machine vision are used to assess the quality of salmon fillets," explains Zimmermann. He is referring to the factory production lines where everything must happen very quickly. However, not everything can be seen or detected with either the naked eye or a regular camera.

"The composition of fats is one such property. If we are able to measure that with a fast sensor, we can gain so much more information about the quality", explains Zimmermann. He points to the Salma brand and other ultra-fresh fillet products that are of such high quality that it is possible to charge a premium price for them.

The scientists use spectroscopic measuring methods to find out more about the salmon. In simple terms, this means light or other electromagnetic rays that show what substances the meat contains.



Photos/cc: Georg Mathisen, NMBU

Boris Zimmermann (left) and Nageshvar Patel are working on the prototype for a handheld scanner. The small device they are holding will be replacing the large machine to the right in the picture

“This will enable salmon producers to sort the fish by quality and charge more for the best and most optimal fillets and cuts”

Big, slow, and expensive

"Spectroscopic sensors are so sensitive that we do not need to cut into or penetrate whatever we are testing, and often we do not even need to touch it," says Zimmermann.

At the Faculty of Science and Technology laboratory at Ås he has sensors and instruments that can analyse the fish in great detail. The problem is that this equipment is large, expensive and slow.

Patel and Zimmermann will develop and evaluate a new type of sensors that are so small they can be placed on any assembly line at any salmon processing facility – or so small that they fit in your hand and are able to take quick measurements. The sensors will be based on infrared spectroscopy.

"They should be easy to install in process lines where they can measure different quality characteristics of fish, meat, milk, vegetables or fruit during different stages of production. A key part of our work is to lower the cost of these sensors, preferably to a degree where small-scale producers can also afford them", he says.

Just the right amount of info

The traditional, large sensors provide an abundance of information. The trick is to only capture what is needed. A sensor that does not measure unnecessary data can be made both cheaper and smaller in size.

"The market is huge. Just consider the sheer number of people who take omega-3 as a supplement", says Zimmermann.

"We will not only be able to detect the composition of the fish, but also where in the fillet the various substances are located," Patel explains.

Such a sensor can also assess the residual biomass from the salmon – that is, the parts of the fish that are not used directly as human food. And also be used for example to measure the fat quality of lard from pork and provide useful information about its properties.

From large to small devices

In recent years, sensors have undergone a global revolution where they have become smaller, faster and cheaper – not only in development at Ås. However, in order for the new sensors to be used on salmon, the scientists must first use the larger sensors in the laboratory to obtain the reference data required to calibrate the smaller sensors correctly.

“The work we do in the laboratory is costly and takes a lot of time. However, we are currently busy with spectroscopic measurements and have almost finished analyzing the reference data. This year we will work on determining the specifications for the smaller sensors, which will enable us to develop them further in collaboration with our partners from the University of Ulm, OptoPrecision and Nanoplus”, says Nageshvar Patel.

Feed and supplements

The sensors will not only be used to find the best and healthiest pieces of the fish and make them even more valuable:

"There are a lot of other parts of the fish in addition to fillets, such as belly fat and residual biomass that are sold to be used, among other things, in animal feed. When we know what these products actually contain and how they can be sorted, we can extract more value out of them, whether as dietary supplements or animal feed," says Boris Zimmermann.

The sensors can also be used to find out if the farmed salmon actually utilizes its feed.

”The aquaculture industry is working on finding alternative feed sources. It is of no use if the new feed contains oils if the fish are not able to absorb them. The fact that the feed contains healthy nutrients does not necessarily mean that they will be found in the fish later”, he says.

Processing-line sensors

The sensors can be used as quality control all the way from feed to the finished food product.

"You can keep track of what happens if you change feeds, and you can observe seasonal differences. Some manufacturers use large sensors in their factories, but our plan is to build the sensors into small, handheld scanners to allow them to be used at all stages of production, including in at the fish farm and the slaughterhouse", says Patel.

7. Communication and dissemination

In DigiFoods, the purpose of the communication is to present inventions and know-how from DigiFoods research as well as network development and knowledge exchange.

Our priority target groups are:

- Industry: Food and bioindustry, technology companies
- Scientific community: scientist and students
- The Public, including funding bodies and policymakers

External communication

During 2022 there were 46 news articles in the press about DigiFoods. The SFI was presented in both trade magazines like Kjøttbransjen and Mat & Marked, and more public media like NRK, Nationen and Forskning.no

The press release *Kjemien i perfekte jordbær er nøkkelen når roboter skal lære seg å plukke dem* was most widely spread, to a total of 26 medias, including NRK, Bergens Tidende, Nationen and Gartneryrket.

Two chronicles were written to trade magazines.

- *Innovasjon krever samarbeid* (Kjøttbransjen)
- *Raske og effektive målinger av fettsyre-sammensetning i laks* (Norsk Sjømat and Forskersonen)

DigiFoods participated at Arendalsuka, in the seminar debate *Klimaendringer, krig og konflikter truer matsikkerheten. Forskning kan bidra med løsninger.* The other participants in the debate were Miljøpartiet De Grønne, Arbeiderpartiet, Nærings- og Nytelses-middelarbeiderforbundet and Norges Bondelag.

DigiFoods had nine peer-reviewed publications accepted that have all been published now.

• Photos/cc: Wenche Aale Hægermark, Nofima

Besøk Wiig Gartneri (up), Annual meeting (left)

• Photo/cc: Wenche Aale Hægermark, Nofima

In September, The Minister of Agriculture and Food, Sandra Borch visited Nofima, and tested sweetness in strawberries

Dissemination within the project

Three newsletter editions were produced in April, September and December. They were distributed to the partners and funders by e-mail.

The annual meeting took place in Sandnes in June, with 49 participants. Company visits were made to TINE Meieriet Jæren, Wiig Gartneri and RobotNorge. In addition, results were disseminated while needs and challenges were discussed.

Article

The juggling act of making compact and mobile sensors

by Jon Tschudi & Marion O'Farrell

SINTEF and Nofima want to make instruments that are smaller and mobile so that they address new ways of sorting of food, earlier in the value chain, before reaching the factory floor. This can play a part in the bigger goal of DigiFoods, to reduce waste, increase quality and increase margins.

Photos/cc: Jon Tschudi, SINTEF

Non-contact measurements being made on clipfish. The measurement point (green) is surrounded by an illumination ring

SINTEF and Nofima have spent many years developing and commercializing inline instruments that measure the quality of food moving on conveyor belts. In the MOBILESENSE project, they are taking a different approach, and addressing applications where you need to move the sensor to the food product and make it handheld or robot mounted. This requires a much smaller sensor that needs to handle a more unpredictable measurement environment.

One application being explored in MOBILESENSE, is the use of sensors for robotic harvesting of strawberries. Based on the percentage of red over the surface, the sensor chooses which berries to pick. If the sensor can also probe deep into the strawberry, without contact, and measure the sugar content and sweetness of the strawberry, this could help optimize sorting earlier in the value chain, which can reduce waste. Today, strawberries that would perfectly suitable for jam are wasted at a later stage due to unsatisfactory color or sweetness.

"This kind of sensor technology could be used in a variety of potential applications in the food, agriculture and bio-industries. There are still industries where people use basic manual methods to determine quality and where conveyor sorting systems are not viable, for example, determining meat content in king crabs or water content in clipfish. In these cases, someone must squeeze or bend the product to literally get a feel for the quality, since it is not obvious from looking at the surface," Research Manager and pillar leader Marion O'Farrell at SINTEF says.

"By making it possible to measure inside the product, we will not only contribute to reducing food waste and increasing quality, it can also take the subjectivity out of how products are graded for pricing, and this can make trading and negotiations run more smoothly," she continues.

Industries like king crab and clip fish are surprisingly large and international markets. Norwegian exports of clipfish in 2021 were 91,100 tons, with export value of NOK 4.5 billion. Norwegian export of king crab in 2021 was 2,300 tons, with an export value of NOK 999 million[1]. To put this in the context of well known, large markets; the total salmon and cod exports for the same year were NOK 81.4 billion and NOK 9.8 billion, respectively.

Reduce the size, not the performance

As part of MOBILESENSE, the goal is to squeeze the high performance of an existing instrument, SmartSensor, into a much more compact form factor, Mini SmartSensor. The original Smart Sensor was novel because it could measure non-contact, sub-surface quality measurements of complex foods. However, to make it mobile, size suddenly moves up on the critical design parameter list, and a new design is required.

"SINTEF's role is to compress the size as much as we can, while not compromising too much on performance. In many applications we don't have the luxury of reducing to pocket-sized devices at the cost of performance," O'Farrell says.

1 https://en.seafood.no/news-and-media/news-archive/record-high-norwegian-seafood-exports-in-2021/

"The goal is to squeeze the high performance of an existing instrument, SmartSensor, into a much more compact form factor, Mini SmartSensor"

"In the field of photonics, there is a big push to reduce the size of spectrometers – smaller, smaller; micro, nano – and while this has its place when simpler surface measurements suffice, it becomes a greater challenge if you want to measure deeper into the product," Senior Research Scientist Jon Tschudi at SINTEF adds. He is the researcher behind the design of SmartSensor technology.

–The farther the photons, which are particles of light, travel into an object, the more information they gather along the way and the weaker the light gets. To measure this weaker, hard-working light instead of light that has bounced off the surface, you need to get plenty of photons into the object and help the maximum number of photons get back into the detector, he explains. More photons mean a stronger and cleaner signal, and the general rule of thumb is that the smaller the instrument, the fewer photons can get through at a given time.

A cost-effective sensor in the making

It is crucial not only to make the Mini SmartSensor small enough, but also cost effective and power efficient. This is why SINTEF has been involved in many detailed technical discussions with photonics manufacturers on the availability and potential availability of suitable optical components and spectrometers. SINTEF has sourced several spectrometers, which have been adapted to their needs, and they have designed new efficient light sources, which are being tested in different combinations. A self-contained unit including batteries, electronics and a display can be made similar in size to a standard hairdryer. However, in the case of a measurement head that is mounted on the end of a robotic arm, it can be made much smaller.

"SINTEF can, if needed, develop our own core spectrometer, as we have done in SmartSensor. However, there is lot of development going on in the photonics industry, and it is important to understand and test off-the-shelf technology first, before going down that more extensive development track," Tschudi says.

The research is still ongoing and there are several unanswered questions to be explored.

"How far can we push the compactness of our designs before we compromise too much on performance? To which degree should we adapt the design of the instrument to each application so that it is commercially viable? How can we help a lay-person or robot use this instrument as well as a trained expert," Marion O'Farrell asks and concludes:

"We believe in the market potential of this concept and have already set in motion some steps towards further securing funding to continue developing the concept towards a commercial product".

Publication and dissemination

Peer-reviewed publications

Afseth, N.K., Dankel, K.R., Andersen, P.V., Difford, G.F., Horn, S.S., Sonesson, A., Hillestad, B., Wold, J.P., Tengstrand, E. (2022). Raman and near Infrared spectroscopy for quantification of fatty acids in muscle tissue – A salmon case study. Foods. 11(7), 962. DOI: 10.3390/foods11070962.

Anderssen, K.E., Kranz, M., Syed, S., Stormo, S.K (2022). Diffusion Tensor Imaging for Spatially-Resolved Characterization of Muscle Fiber Structure in Seafood. Food Chemistry. 380, 132099. DOI: 10.1016/j.foodchem.2022.132099.

Anderssen, K.E., McCarney E.R (2022). Mechanisms of transverse relaxation of water in muscle tissue. Food Control. 132, 108373. DOI: 10.1016/j.foodcont.2021.108373.

Jansen, J.J., Måge, I. (2022). Report of Path Modelling Workshop, Zaandam, The Netherlands, 25–26 April 2022/ Meeting report, Journal of Chemometrics. Journal of Chemometrics, abstract. e3430. DOI: 10/1002/cem.3430.

Kuchta, M., Wubshet, S.G., Afseth, N.K., Mardal, K.A., Liland, K.H. (2022). Encoder-decoder neural networks for predicting future FTIR spectra – application to enzymatic protein hydrolysis. Journal of Biophotonics. 15(9). DOI: 10.1002/jbio.202200097.

Wold, J. P., Solberg, L.E., Gaarder, M.G., Carlehøg, M., Sanden, K.W., Rødbotten, R. (2022). In-Line Estimation of Fat Marbling in Whole Beef Striploins (Longissimus lumborum) by NIR Hyperspectral Imaging. A Closer Look at the Role of Myoglobin. Foods. 11(9), 1219. DOI: 10.3390/foods11091219.

Kafle, B., Böcker, U., Wubshet, S.G., Dankel, K., Måge, I., O'Farrell, M., Afseth, N.K. (2023). Fourier-transform infrared spectroscopy for characterization of liquid protein solutions: A comparison of two sampling techniques. Vibrational Spectroscopy. 124, 103490. DOI: 10.1016/j.vibspec.2022.103490.

Lindtvedt, T.A., Andersen, P.V., Afseth, N.K., Heia, K., Lindberg, S.K., Wold, J.P. (2023). Raman spectroscopy and NIR hyperspectral imaging for in-line estimation of fatty acid features in salmon fillets. Talanta. 254, 124113. DOI: 10.1016/j.talanta.2022.124113.

Ortega, S., Ofstad, R. Syed, S., Kranz, M., Heia, K., Anderssen, K.E. (2023). Characterization of vasskveite (water halibut) syndrome for automated detection. Applied Food Research. 3(1). DOI: 10.1016/j.afres.2022.100250.

Presentations (oral or poster)

Afseth, N.K. (2022). FTIR spectroscopy as a future bioprocess monitoring tool – Characterisation of hydrolysed proteins and peptides. 19th European Conference on the Spectroscopy of Biological Molecules (ECSBM 2022), Reims, 29.08.-01.09.2022.

Afseth, N.K. (2022). Exploring multi-step protein hydrolysis strategies for tailored poultry hydrolysates. Seminar – Enzymatic protein hydrolysis and Bioactive peptides, Nofima Ås, 26.04.2022.

Afseth, N.K., Kristoffersen, K.A., Kafle, B., Böcker, U., Måge, I., Wubshet, S.G. (2022). FTIR spectroscopy as a future bioprocess monitoring tool – Some examples from enzymatic protein hydrolysis. CPAC Rome Meeting 2022, 21-23.03.2022.

Cattaldo, M., Riquelme, A.F., Måge, I. (2022). Methods for variable time-delay estimation in industrial data. ENBIS: European Network of Business and Industrial Statistics, Trondheim, 26.-29.06.2022.

From, P.J. (2022). 4th International Strawberry Congress, Antwerpen, Belgium, 21.–24.09.2022.

Hansen, A. (2022). Robotic Sensors for in-the-Field Quality Control of Strawberries. Norwegian Electro-Optics Meeting, 09.09.2022.

Hansen, A. (2022). Novel Sensors for Quality Classification of Strawberries in the Field. Sensor Decade, 01.06.2022.

Heia, K. (2022). Automatisering I hvitfisknæringa – Fra en forskers perpektiv. Workshop – automatisering i hvitfisknæringen, Tromsø, 02.11.2022.

Heia. K. (2022). Using hyperspectral imaging and machine learning for identification of several quality attributes simultaneously. 50th WEFTA conference, Rotterdam, 17.-21.10.2022.

Lintvedt, T.A., Lindberg, S-K., Andersen, P.V., Afseth, N.K., Heia, K., Marquardt, B., Wold, J.P. (2022). Raman Spectroscopy for In-line Estimation of Fatty Acid Features in Salmon Fillets. The international SensorFINT conference, Izola, Slovenia, 10.–12.05.2022.

Måge, I. (2022). DigiFoods: sensordata for bedre matproduksjon. AgTech 2022, Oslo, 22.11.2022.

Måge, I. (2022). Industrial bioprocessing – an amusement park for chemometricians and analytical chemists. Chemometrics in Analytical Chemistry (CAC2022), Rome, 29.08–02.09.2022.

Måge, I. (2022). Statistics in food industry – applications and challenges. Trondheim Symposium in Statistics, Orkanger, 29.10.2022.

O'Farrell, M. (2022). Food and agriculture research at SINTEF. Photonics21 Work Group Meeting "Agriculture & Food", Digital, 01.12.2022.

O'Farrell, M., Tschudi, J., Wold, J.P. (2022). Optimisation of sensor design for measuring complex food products. AgTech 2022, Oslo, 22.11.2022.

Ortega, S., Lindberg, S-K., OAgeeva, T., Heia, K. (2022). Estmation of shelf-lifeof Atlantic cod using hyperspectral imaging and machine learning. 50th WEFTA conference, Rotterdam, 17.–21.10.2022.

Thorjussen, C.B.H., Solberg, L.E., Måge, I. (2022). On the use of Directed Acyclic Graphs (DAGs). Path modelling workshop, Zaandam, Netherlands, 25.–26. 04.2022.

Wold, J.P (2022). In-line NIR spectroscopy for quality assessment of heterogeneous foods. The international SensorFINT conference, Izola, Slovenia, 10.–12.05.2022.

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8. Administration

Key personnel

Postdoctoral researchers with financial support from the Centre budget

Name	Period	Topic
Samuel Sarmiento Ortega*	2021–2022	Hyperspectral imaging applied to food quality analysis
Antonio Candea Leite*	2021–2022	Robot and Sensor Integration

*To be replaced

PhD students with financial support from the Centre budget

Name	Period	Topic
Bijay Kafle	2021–2024	Dry-film FTIR spectroscopy for in-process food quality measurements.
Andreas Ulrich Nicolas Persch**	2021–2022	Portable IR-spectroscopy for food quality measurements
Tiril Aurora Lintvedt	2020–2023	Raman spectroscopy for in-line food quality sensing
Nageshvar Patel**	2022–2026	IR Instrumentation

** Patel replaced Persch in 2022

PhD students with financial support from other sources

Name	Funding	Period	Topic
Åse Riseng Grendestad	TINE	2022–2026	NIR & Consumer studies
Christian Thorjussen	SLNF	2021–2024	Path modelling in agriculture and food industry
Marco Cattaldo	RCN – basic funding	2021–2024	Data fusion and process optimization/control

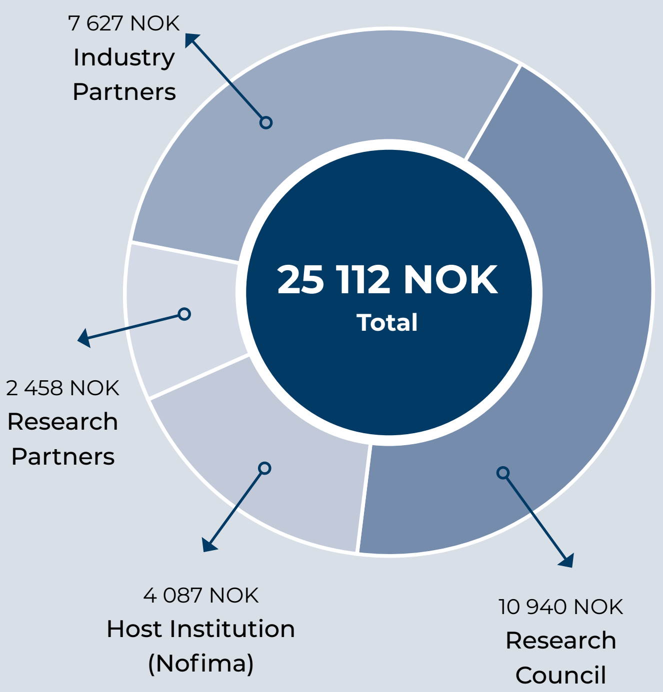
Key researchers

Name	Institution	Pillar	Main research area
Jens Petter Wold	Nofima	1,2,3	Applied spectroscopy and food science
Karsten Heia	Nofima	1	Applied spectroscopy
Kate Anderssen	Nofima	1	Applied spectroscopy
Petter Andersen	Nofima	1	Applied spectroscopy and food science
Samuel Ortega	Nofima	1	Hyperspectral imaging applied to food quality analysis
Shaheen Syed	Nofima	1	Data analysis
Sileshi Gizachew Wubshet	Nofima	1	Analytical chemistry
Stein-Kato Lindberg	Nofima	1	Applied spectroscopy
Svein Stormo	Nofima	1	Applied spectroscopy and chemistry
Nils Kristian Afseth	Nofima	1,3	Applied spectroscopy and chemistry
Erik Tengstrand	Nofima	3	Applied spectroscopy and chemometrics
Lars Erik Solberg	Nofima	3,4	Data analysis
Ingrid Måge	Nofima	4	Multivariate data analysis
Paula Varela	Nofima	4	Sensory and consumer science
Valérie Lengard Almli	Nofima	4	Sensory and consumer science
Achim Kohler	NMBU	1	Applied spectroscopy and physics
Boris Zimmermann	NMBU	1	Applied spectroscopy and chemistry
Valeria Tafntseva	NMBU	1	Spectroscopy
Volha Shapaval	NMBU	1	Spectroscopy and biotechnology
Antonio Candea Leite	NMBU	2	Robotics
Nils Bjugstad	NMBU	2	Agricultural technology
Pål Johan From	NMBU	2	Robotics
Weria Khaksar	NMBU	2	Robotics
Kristian Hovde Liland	NMBU	4	Data analysis
Kari Anne Hestnes Bakke	Sintef	1	Optical measurement systems and smart sensor systems
Tim Dunker	Sintef	1	Optical measurement systems and smart sensor systems
Trine Kirkhus	Sintef	1	Optical measurement systems and smart sensor systems
Anders Hansen	Sintef	1,2	Optical measurement systems and smart sensor systems
Gregory Bouquet	Sintef	1,2	Optical measurement systems and smart sensor systems
Jon Tschudi	Sintef	1,2	Optical measurement systems and smart sensor systems
Marion O`Farrell	Sintef	1,2	Optical measurement systems and smart sensor systems
Simon Pearson	Uni. Lincoln	2	Agricultural robotics
Boris Mizaikoff	Uni. Ulm	1	IR spectroscopy
Alberto J. Ferrer-Riquelme	Uni. Valencia	4	Process modelling and control

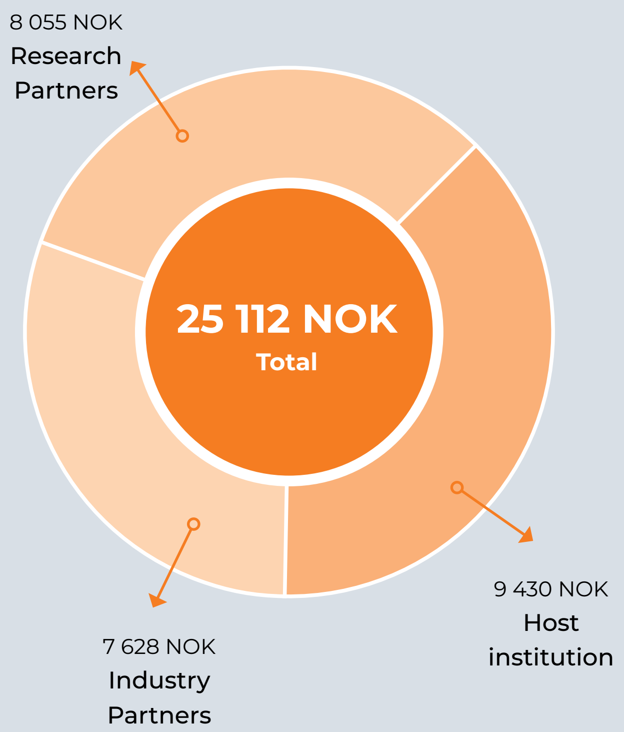
Annual accounts

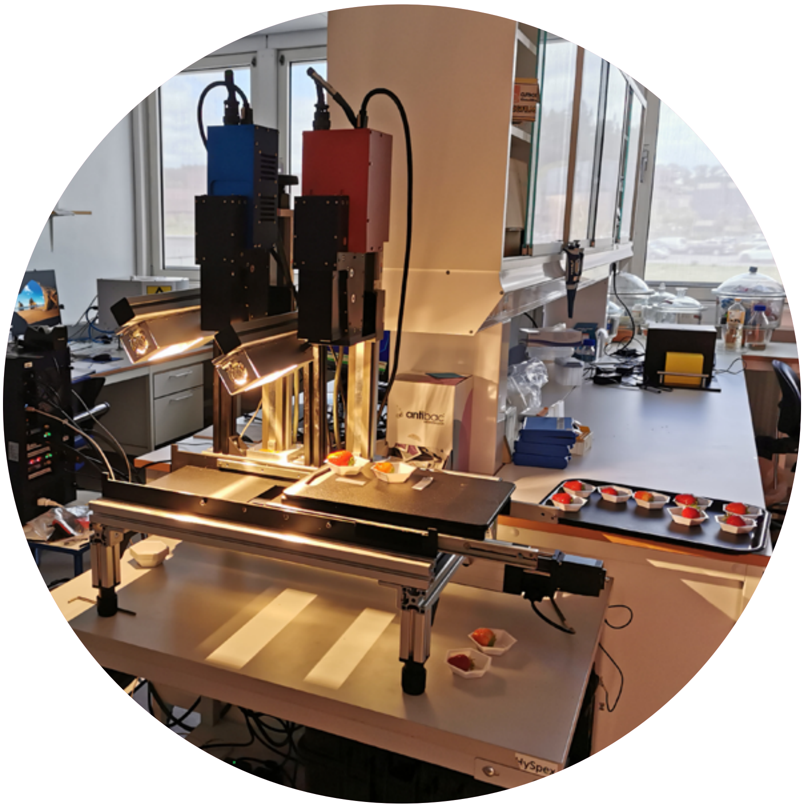
The total budget for SFI DigiFoods is 188 mill NOK over eight years. The financing of SFI DigiFoods is based on contribution from the RCN and cash and in-kind from the Industry Partners and the Norwegian Research Partners.

Funding



Costs

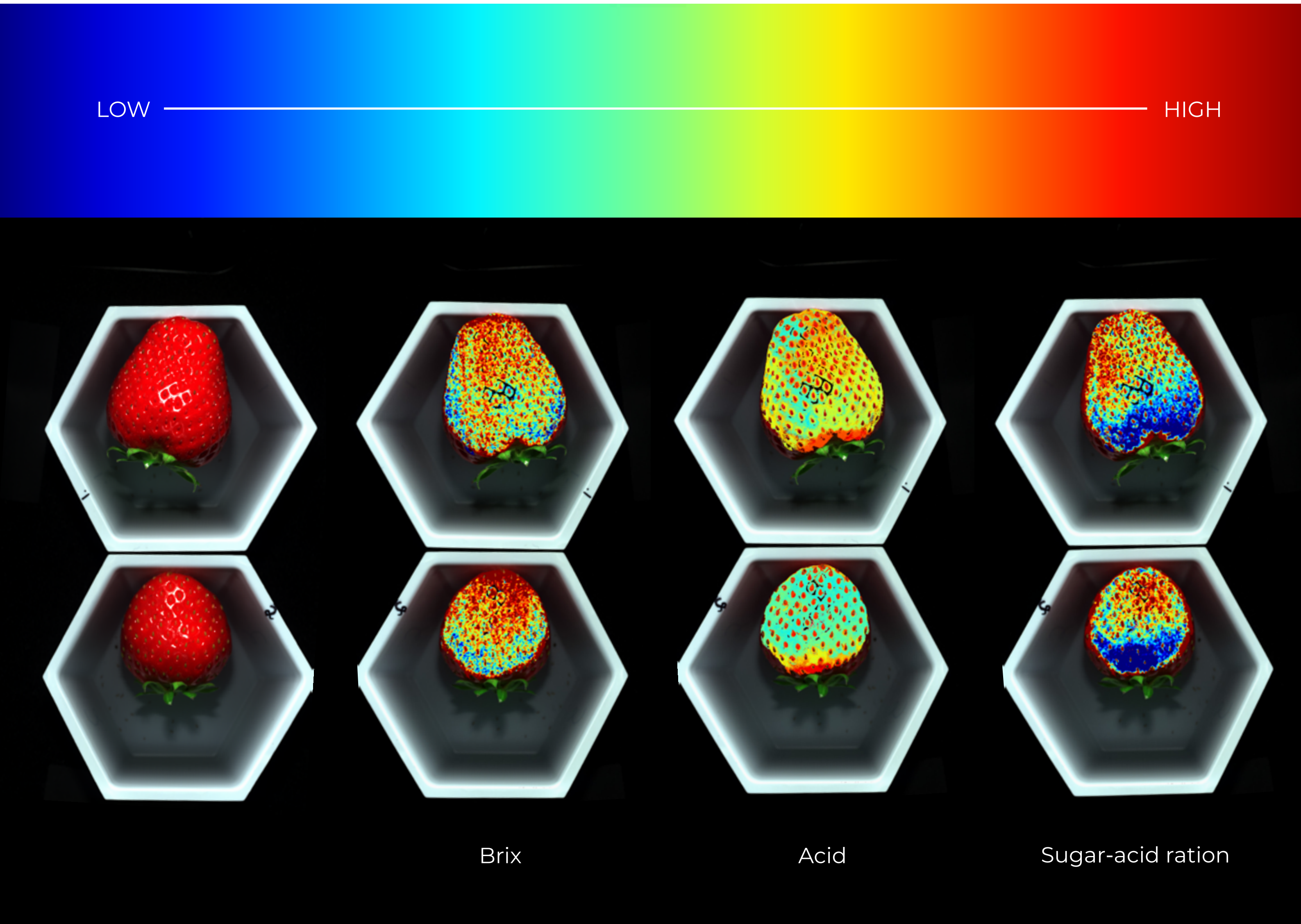




• Photos/cc: Na Liu, NEO

Setup for hyperspectral imaging of strawberries. Two of NEOs cameras were used: HySpex Classic VNIR 1800 (Blue) and HySpex Classic SWIR 384 (Red)

The strawberry images show how the spectral information can be used to map det distribution of chemical properties on the berries. Sugar (Brix), acid and the sugar-acid ratio. The latter is closely related to sensory sweetness. Note that the berry is sweeter at the apex



Senter for forskningsdrevet innovasjon

Norges forskningsråd

SFI Digital Food Quality (short named DigiFoods) is a centre for research-based innovation (SFI) with the purpose of developing smart sensor solutions for food quality assessment directly in the processing lines, throughout the food value chains.

digifoods.no