SFI Digital Food Quality

ANNUAL REPORT 2023

• **Cover** Photo/cc: Jon Tschudi, SINTEF

• Photo/cc: Jens Petter Wold, Nofima

Measurement of meat content
in king crab by NIR spectroscopy.

Colophon
Multiple authors (2024).
Annual Report 2023.
SFI Digital Food Quality – DigiFoods.
Ås: Nofima, eds.
Design: Raquel Maia Marques at Vitenparken Campus Ås.

Contents

1. Overall progress and summary for 2023

DigiFoods is a Center for Research-based Innovation, funded by The Research Council of Norway (RCN) and the partners. DigiFoods is developing 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 science, sensor technology, 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 three years. Most activities are progressing well, and industry partners are active in the work. The centre is organized in four main activities (pillars) including

1. sensor development,
2. integration of sensors and robotics,
3. in-line implementation and testing, and
4. utilization of large-scale sensor data from foods.

In 2023 we saw that this organization clearly works as intended. New sensors developed in one pillar were incorporated in the research in other pillars. Novel in-line methods developed earlier years, were adapted, and used to collect large-scale quality data for process understanding and improvement. This kind of progress is very motivating and illustrates the added value of being a center rather than several stand-alone projects. It gives us the opportunity to think and act long-term and interdisciplinary.

The annual meeting with all partners was held in Hærland and Ås in June. We visited Nortura's large and impressive poultry processing plant and we also got to see the relatively new bioprocessing company Bioco, where they convert residual poultry waste into fats and proteins based on enzymatic hydrolysis. The latter is a quite complex process where DigiFoods has done much work based on NIR and FTIR spectroscopy to understand causes of product variation and how the process can be controlled. The annual meeting was important for sharing results, ideas and building the DigiFoods team.

2023 was a good year for DigiFoods. We conducted small and large measurement campaigns in the process lines. Some lasted a day, others took weeks. We 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 work was 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 we have contributed to real innovation in the companies.

Photo/cc: Wenche Aale Hægermark, Nofima

The DigiFoods consortium gathered for the 2023 Annual meeting at Nofima, Ås.

Fourier-transform infrared spectroscopy (FTIR) shows promise for measuring protein composition in peptide blends from enzymatic hydrolysis, and there is currently no industrial solution for such measurements. A portable FTIR instrument, both developed and built in DigiFoods, has now been tested with excellent results, enabling industry measurements, improving the understanding and control of these bioprocesses. We have continued our work on miniaturization of IR technology based on new types of LEDs (light-emitting diodes) and semiconductor lasers. This will allow for small handheld sensor systems for measuring chemical properties in foods throughout the value chain. Prototype systems will be evaluated on different foods in 2024.

In 2023 DigiFoods proudly delivered a doctoral degree in applied Raman spectroscopy for in-line analyses of foods. We have demonstrated that Raman is very suitable for determination of various food quality attributes of rather heterogenous foods directly in industrial processes. This work creates new opportunities that will be studied further.

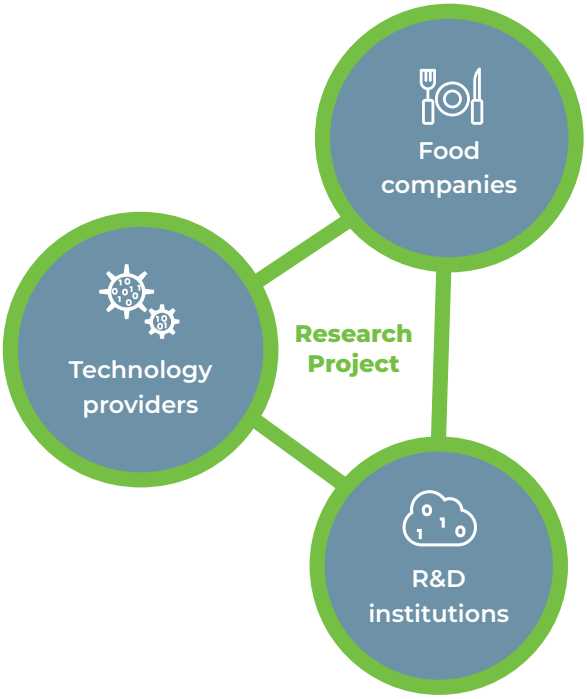
Hyperspectral camera technology has been developed for industrial measurement of fat, pigment, blood and melanin spots in salmon fillets and the technology will be put into commercial use in 2024. The technology is interesting for several different quality measurements on fish and meat.

We have developed a new NIR sensor for fast and non-destructive measurement of sugar in strawberries and tomatoes. This was tested on an autonomous robot and the concept will be developed further in 2024. The NIR sensor does also have a great potential in the seafood and meat industry, and a commercialization project has been started.

An important activity in the center is to conduct in-line measurements in industrial processes, and we have worked on the following cases: Dry matter in potatoes, dry matter in cheese, core temperature in fish cakes, fat content in sausages, fat and protein in poultry and salmon by-products, as well as quality attributes in salmon fillets. All these methods are novel and can significantly contribute to process improvement. The food companies learn about the process variations, leading to improvements in some processes, with the goal of reducing waste and achieving consistent final quality. In 2023 we collected in-line spectroscopic and other process data from TINE, Nortura, Norilia and Lerøy. This has given an increased understanding of the processes and quality variations, and for TINE, the strategy has produced lasting innovations that contribute to increased profitability and better utilization of incoming milk.

Scientific highlights have been many, the level of innovation in the research is high, and we have contributed to real innovation in the companies

Our students are well integrated in the different projects and contribute to many of the centre results and dissemination



DigiFoods innovation model: Each research task assigns 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.

In 2023 we had nine PhDs/post-docs connected to DigiFoods. We plan to recruit two post-docs within robotics in 2024. We also recruited 5 master students who started their work in early 2023 and contributed well to our work. 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 2023. Some interesting highlights from the research are presented in more depth. Linking fat marbling measured in-line at Nortura with consumer preferences indicates how we can use quality information all the way to the consumer to increase satisfaction and reduce food waste. And we inquire with Wiig Gartneri how they envision using in-line measurement of sugar in their packaging line for Norway's best tomatoes. We also provide insights into key center activities through some of our doctoral candidates.

We hope that you will enjoy the annual report 2023.

Jens Petter Wold
Centre Director, SFI DigiFoods

Article

Our mission is bridging the gap between research and industry

by Wenche Aale Hægermark, Nofima

These are the words from Silje Ottestad. She is a Hyperspectral Application Specialist at Maritech and head of the Innovation Advisory Board in DigiFoods.

The Innovation Advisory Board is made up of representatives from the industry partners Lerøy, Maritech, Norilia, Nortura, and Saga Robotics. Their aim is to ensure that DigiFoods' research results have concrete value, and that research is focused on the problems that the industry partners want to solve.

– We have monthly meetings in the Innovation Advisory Board where results from the scientific work are presented. The presentation is followed by a discussion on the innovation potential of the results. Quite often the results pave the way for new ideas, says Silje Ottestad.

DigiFoods aims to use spectroscopy to identify quality differences, increase efficiency and differentiate products.

Focus on innovation potential

– A common approach in the industry is to first identify a problem, then develop and test technological solutions. It is only after this that businesses consider how to create value and make the solutions profitable. However, we are trying to think about value creation earlier in the process to increase profitability, tells Silje Ottestad.

Another asset with the Innovation Advisory Board is that the members have different backgrounds and represents different industries, like food processing of fish, meat or byproducts, as well as from technology companies. They have different experiences, and sometimes a person from e.g. the meat industry can see new innovation potential for the meat sector, based on research done on fish or strawberries. This is rewarding and a benefit of being a large and multidisciplinary consortium.

Maritech Eye – a unique quality score for each fish

Maritech Eye is a hyperspectral imaging scanner that can measure and analyze whole fish directly on the conveyor belt. It can detect quality defects like blood spots, nematodes, gaping, black lining and skin residues in white fish and blood and melanin spots in salmon. In salmon it is also used to measure color, total fat and fatty acids. The fish can then be sorted directly into different quality groups. Silje is responsible for industrial testing, model development, system implementation and project management.

In the DigiFoods project, Maritech is working closely with Lerøy and Nofima to fine tune their technological solutions and create additional value. This collaboration has resulted in Lerøy Aurora purchasing a machine that is now in operation at their salmon processing plant in Skjervøy collecting a large amount of data every day. The next step is to determine how to best utilize this data to create value for their customers.

– Optimal utilization of the data is an important part for Maritech. We are mainly a software company that primarily sells solutions for sales and logistics to the fisheries and aquaculture industries. Our aim is to develop and implement cost savings solutions based on the data collected in the Maritech Eye scanning process and to merge this data with the sales and logistics solutions, says Silje Ottestad.

Meat industry – the next step?

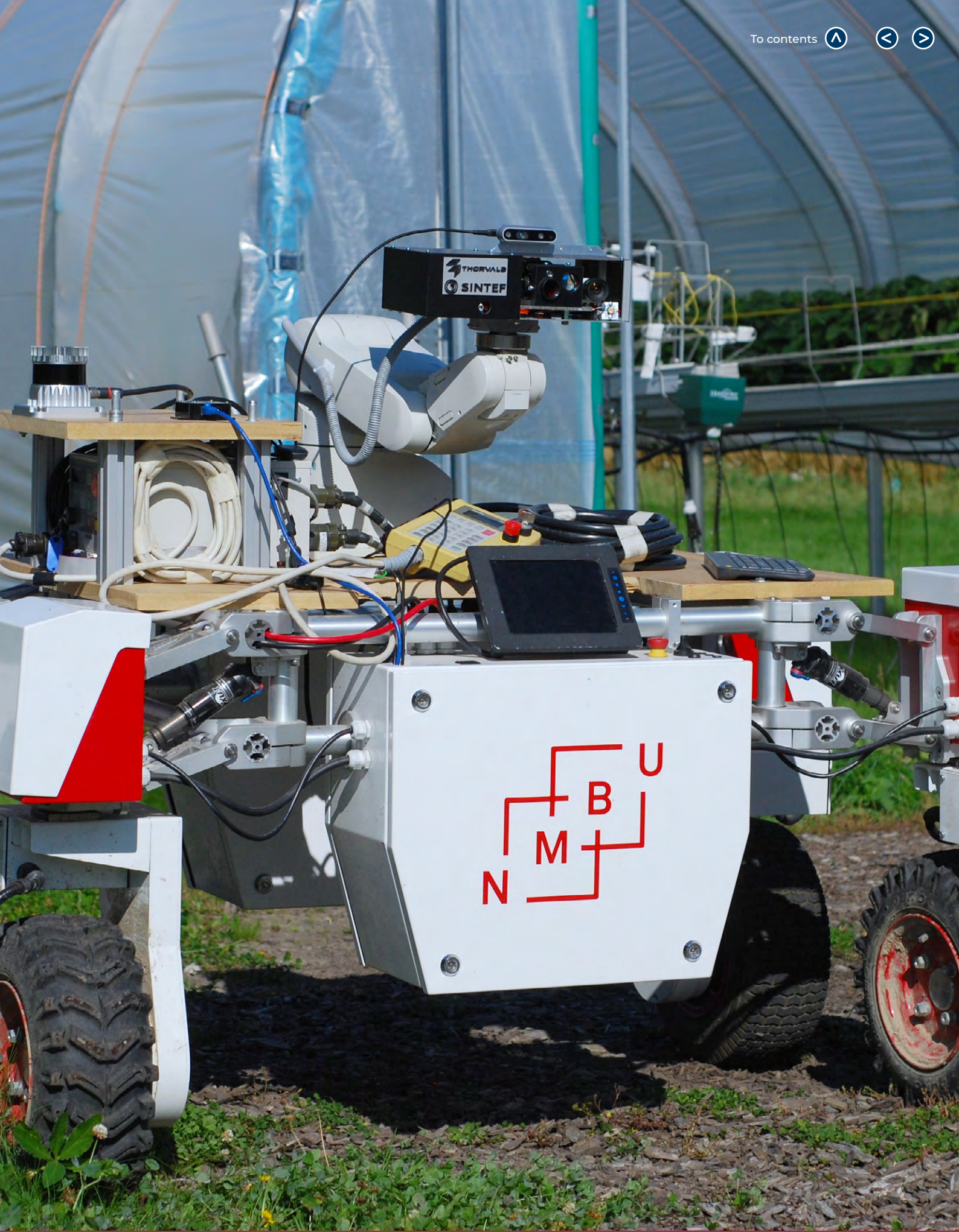
So far Maritech Eye is primarily aimed at the fisheries and aquaculture industries. However, since being a partner in DigiFoods, Maritech is now also looking towards other industries, such as the Meat Industry. In collaboration with Nofima and Nortura, Maritech Eye is testing a prototype that can identify the degree of fat marbling in whole beef loins. This can be used to differentiate the loins even before it is sliced, thus ensuring that consumers get exactly the beef they want.

You can read more about this test and the ongoing research in the article *NIR-sensor successfully sorting whole beef loins,* page 32–33.

DigiFoods aims to use spectroscopy to identify quality differences, increase efficiency and differentiate products

• Photo/cc: Knut Inge Evensen, Maritech

Silje Ottestad monitors the degree of fat marbling in whole beef loins with the MaritechEye NIR scanner.



• Photo/cc: Anders Hansen, SINTEF

Field studies with Thorvald and strawberry ripeness sensor FragoPro.

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.

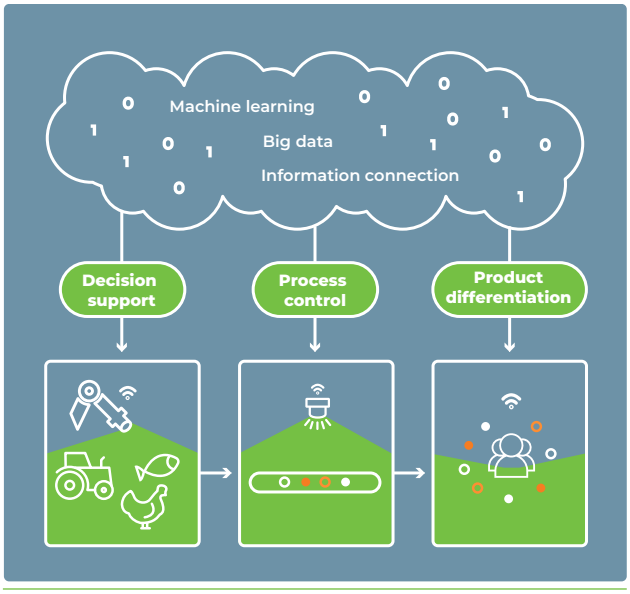
The **Primary objective** of DigiFoods is to develop digital solutions for food quality assessment as cutting-edge technological basis for optimal food value chains.

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.

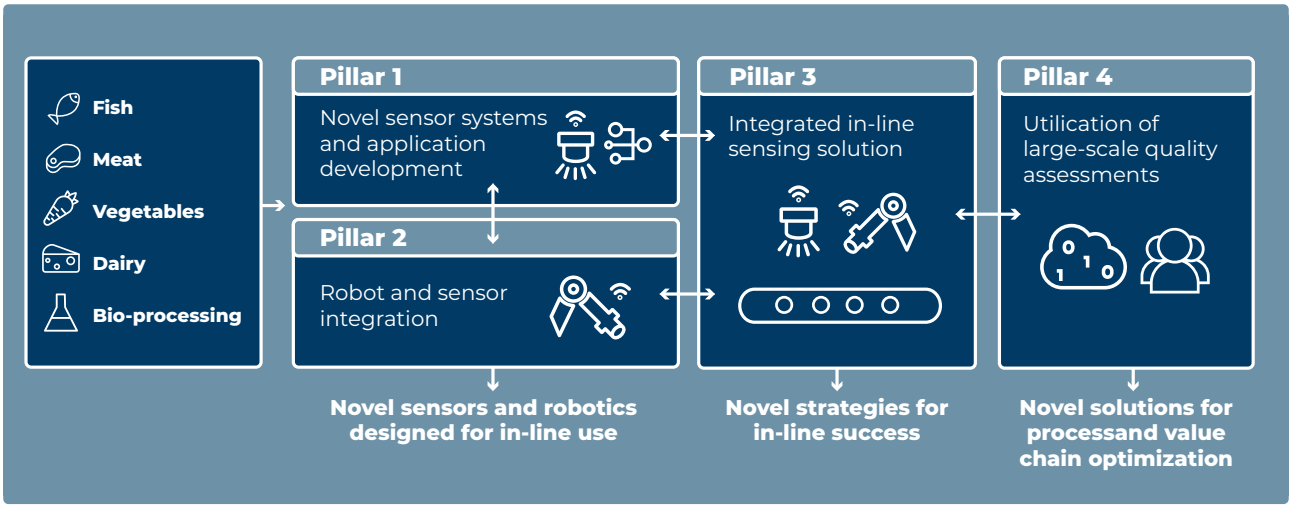
2. Research plan and strategy

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 are accomplished by combining basic and applied research. A major difference from traditional research in this area lies in the scientific method; prototypes are being 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 is developing novel sensor systems that address critical in-line challenges and industrial needs. Pillar 2 is designing novel integrations of robotics and sensors. Pillar 3 is developing strategies for successful implementation of in-line sensors in processes. In Pillar 4, the in-line food quality measurements are 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.



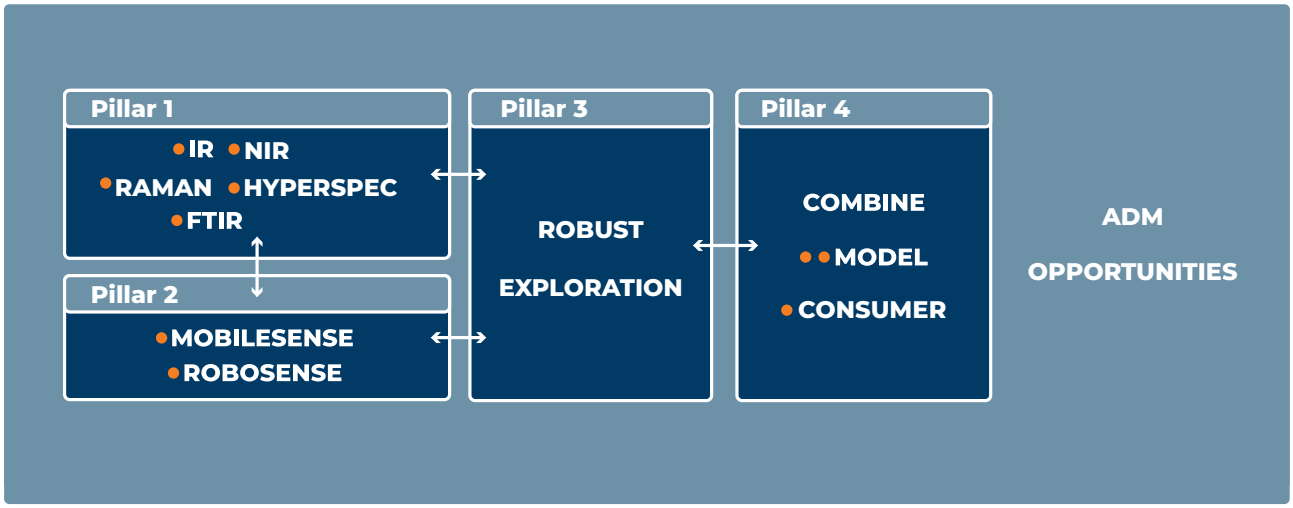
Partner companies representing the major food value chains will define relevant research activities for the four research pillars

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

All activities do as far as possible include participants from all three partner groups (food companies, technology providers and R&D institutions) to ensure practical relevance, interdisciplinary 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 we have divided the activities into research projects, twelve in 2023. 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

Just sweet tomatoes, please

by Wenche Aale Hægermark, Nofima

Norwegians love sweet tomatoes and are willing to pay a much higher price for these tomatoes. The sweet little Piccolo tomatoes grown by Wiig Gartneri in Jæren are exactly such a tomato variety, and Norwegian consumers have embraced it.

"For us, it is crucial that every Piccolo tomato gives customers exactly the taste experience they expect. At the same time, we are dealing with living plants, and we have suspected that the sugar content can vary, even on tomatoes that sit on the same cluster and have the same red color," says Frode Ringsevjen, production manager at Wiig Gartneri.

Measuring sugar content on whole tomatoes

The sweetness in tomatoes comes from the fruit sugar, and the concentration of sugar is measured based on a so-called Brix scale. The most common way to measure Brix on fruit, berries, and vegetables is with an instrument called a refractometer, which measures the sugar concentration in the juice. This means that the juice must be squeezed out, and the fruit, berry, or vegetable is thus destroyed.

Wiig Gartneri is now investigating whether rapid, non-destructive measurement methods can be the solution to ensuring that all Piccolo tomatoes are just as sweet as the customers expect. In the first instance, the tests are carried out at Nofima. Frode Ringsevjen sent the first 200 tomatoes, with varying degrees of maturity – from dark red overripe to green very immature, to Nofima in October.

The researchers then used a prototype of an NIR sensor and developed a non-destructive measurement method for sugar concentration.

"The purpose of these first tests was to investigate whether we can get good measurements of the sugar concentration inside the tomato without touching it. SINTEF has developed an NIR sensor that can measure them at a distance of 8 cm, and it was this we used in the tests. The results were very uplifting. We could measure sugar concentration with good accuracy," says senior researcher Jens Petter Wold who led the study.

Good calibrations require tomatoes with varying sugar content

The first 200 tomatoes were tested while lying still in their own plastic bowl. To ensure that the measurements of the sugar concentration are correct and accurate for each individual tomato, the researchers have made numerous adjustments and adaptations of both the measurement methods and the instrument.

"For us, it is crucial that every Piccolo tomato gives customers exactly the taste experience they expect"

Frode Ringsevjen
production manager, Wiig Gartneri

Photos/cc: Jens Petter Wold, Nofima

They look the same with similar redness, but the Brix value for these tomatoes increases from 5 to 9 from the left to the right.

Photos/cc: Tom Haga, Wiig Gartneri

I Wiig-gartneriet Frode og Kåre: Surrounded by tomatoes in the green house. From the left production managaer Frode Ringsevjen and gründer Kåre Wiig.

Among the tomatoes were green, yellow, orange, red, and dark red. The large range in maturity is necessary when researchers are to test the measurement methods they develop and to know that the sensor measures the real sugar concentration and is not affected by the colors. There turned out to be large variations in sugar content even among tomatoes that were equally red.

Thoroughness is a keyword in the work of developing solid measurement methods. In November, Frode Ringsevjen sent around 100 new tomatoes to Nofima. This time, all the tomatoes were in the spectrum from orange to red, and the researchers tested again whether the measurement methods held up. They then used the measurement results to place the tomatoes in eight different sweetness classes.

Correspondence between technology and human senses

In addition to the sensor measurements, the researchers made further quality checks. This time against the senses. Nofima's professional sensory panel, consisting of ten trained sensory assessors, tested tomatoes in the different sweetness classes and classified them based on flavour and odours.

"We were positively surprised by the correspondence between the classifications from the sensor measurements and from the sensory assessors. The differences were really tiny," says Jens Petter Wold.

Measurements on the packaging line are the next step

The good results from the first tests create optimism. Now the researchers are investigating how temperature can affect the measurements and how the fruit sugar is distributed in the tomatoes. This is to better understand what they are measuring.

The next step will be to develop measurement methods that can also measure the sugar content in the tomatoes in motion, i.e. while they are moving, for example, on a packaging line while still attached together in the cluster.

A very useful tool

"High quality and great flavours are crucial for customers to choose our Piccolo tomatoes. We therefore already carry out thorough internal quality controls. A measuring instrument that can effectively weed out tomatoes with lower quality and less sweet taste will further strengthen this work. It will be a good tool to ensure that our loyal customers get the quality and taste they expect, without individual tomatoes spoiling, Frode Ringsevjen points out.

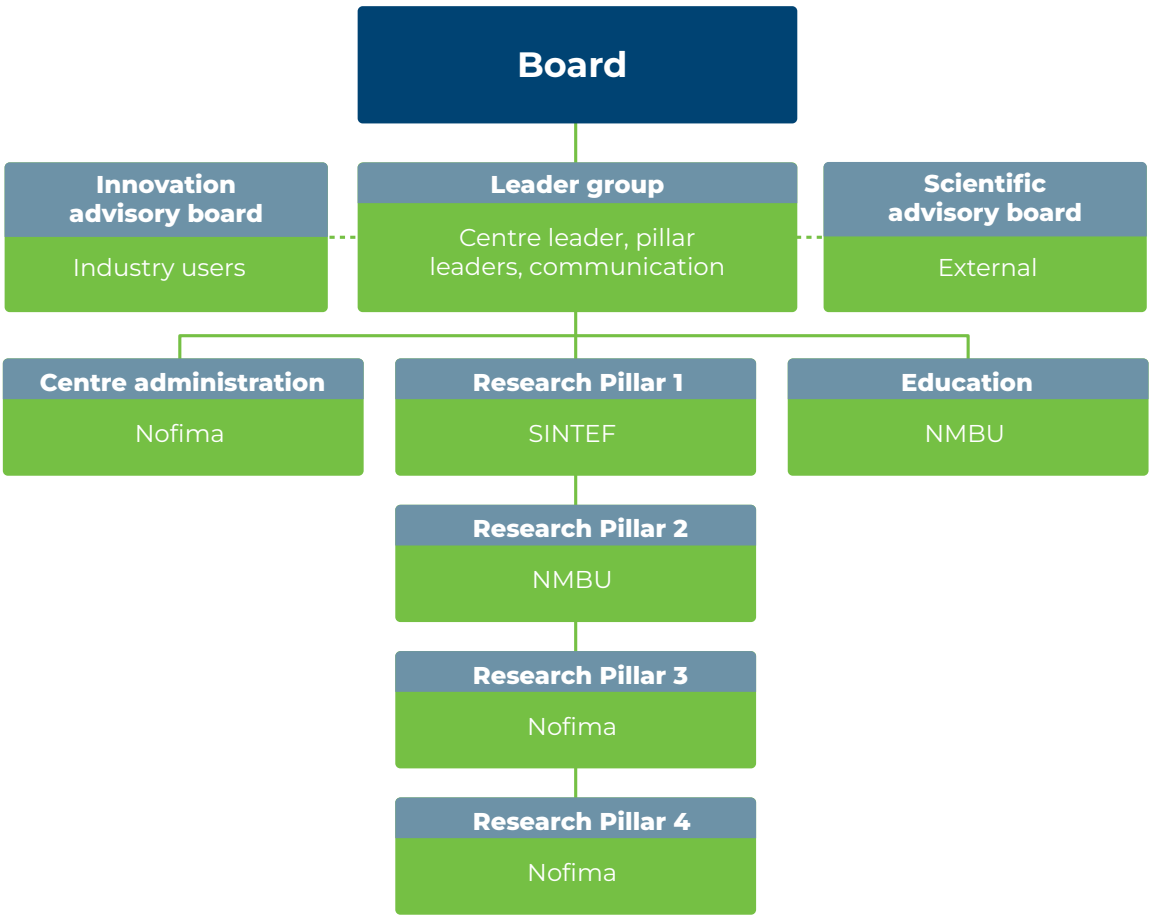
The production manager hopes for a measuring instrument that can be used both as a handheld device to take quality checks in greenhouses and mounted on a robot on the conveyor belt in the packaging plant.

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 2023, 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

Rune Hansen, Lerøy Norway Seafoods

Board Member

Silje Ottestad, Maritech

Board Member

Ellen E. Altenborg, BI (representing Saga Robotics)

Board Member

Mats Carlin, SINTEF Digital

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 Research Council of Norway, 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: Reidun Lilleholt Kraugerud, Nofima

The DigiFoods leadergroup, from left: Weria Khaksar, Marion O'Farrel, Ingrid Måge, Jens Petter Wold, Wenche Aale Hægermark, Anne Risbråthe, Stine Thøring Juul-Dam, Nils Kristian Afseth, Kristian Hovde Liland.

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
- Weria Khaksar (NMBU) – 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

The Scientific Advisory Board (SAB) for DigiFoods, consists 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 does also have 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.

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 members are:

- Silje Ottestad, NEO
- Marije Oostindjer, Norilia
- Per Berg, Nortura
- Roy Martin Hansen, Lerøy Norway Seafoods
- Ellen Altenborg, BI (representing Saga Robotics)

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 IAB (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. DigiFoods is also sharing news on Linkedin.

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 in agri-robotics. 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 Katherine James, Prof. Simon Pearson and Prof. Grzegorz Cielniak.

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, Anders Hansen and Trine Kirkhus, Researcher Tim Dunker and PhD student, Vilde Vraalstad.

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 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 og repetitive tasks. This is good for 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.

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 part of Thermo Fisher Scientific 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 polytunnels 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 know ledge 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.

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 CTO 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

NIR-sensor successfully sorting whole beef loins

by Wenche Aale Hægermark, Nofima

Researchers in DigiFoods have tested a NIR imaging scanner that can identify the degree of fat marbling in whole beef loins. This technology can be used to differentiate the loins even before they are cut into smaller steaks, ensuring that consumers get exactly the beef they want.

Photos/cc: Jens Petter Wold, Nofima

Packing of sliced beef loins after NIR scanning.

"The study found that consumers can actually taste the differences among different marbling levels, although there were almost no differenses in the actual liking"

Paula Varela Tomasco

– In the test, 29 whole loins were scanned with the Maritech Eye industrial NIR scanner, resulting in three different categories of marbling: low, medium, and high. The NIR sensor's ability to map the level of fat marbling in the loins was proven to be accurate when correlated to the assessment by Nofima's professional sensory panel, consisting of ten highly trained sensory assessors, says Jens Petter Wold, senior scientist in Nofima and director of DigiFoods.

The in-line sensor could be used to automatically sort the loins into three categories: low, medium and high marbling. – This is an interesting technology for quality differentiation that Nortura will assess, says Elin Hallenstvedt, quality manager in Nortura

Tender, ripe, juicy and meaty, please

For consumers, their ideal sirloin steak should be tender, juicy, with ripe and meat flavour. On the other side of the scale, i.e. the most negative characteristics are lean, sour, hard, dry and immature, tells Paula Varela-Tomasco, senior scientist at Nofima and responsible for the sensory and consumer study.

The scanning of the loins took place at Nortura Rudshøgda, and 110 internal consumers, all employed at Nortura and hence some knowledge of beef quality, participated in the study.

They were shown pictures of sirloin steak pieces with different degrees of marbling and were asked about their sensory expectations based on the marbling degree. The participants expected that beef with medium or high fat marbling would be juicy, tender and ripe, with a more prominent meat taste, and expected to be better liked. The leaner beef was expected to taste less fatty and milder- and healthier-, but also to be harder, dryer, less tender and more immature.

Steaks packed and ready for consumer test.

Differences in marbling can be tasted

– When tasting, the participants were able to differentiate the three levels of marbling, describing 10 attributes from meaty and juicy to bitter and grainy. Contrary to what the participants expected, the lean beef was perceived as with more meaty flavour than the medium and the high marbled beef and with no differences in perceived juiciness, says Paula Varela-Tomasco.

The tasting did, however, also show some expected differences in taste, that the lean beef was perceived as the most grainy and less fatty, as well as considered healthier by participants. The beef with the high fat marbling had the most intense taste and seemed somewhat more mature than the others, it was also perceived as most fatty, bitter and not as fresh as the other two options. The beef with medium fat marbling tasted fresh and was slightly more tender than the beef with the high fat marbling. On the downside, medium fat marbling beef was perceived as the most dry and metallic.

– All in all, the study found that consumers can actually taste the differences among different marbling levels, although there were almost no differences in the actual liking ratings between the three marbling types, in average, one could expect that some groups of consumers prefer tender beef, even if fattier, while those more driven by health would choose leaner pieces, explains Paula Varela-Tomasco. And now these can be differentiated in the production line, to be targeted to different consumer segments.

About NIR (near infrared):
NIR spectroscopy is a technique in which light is sent through a food product to measure how much light is absorbed at different wavelengths. This is a quick measurement method that is suitable for measuring various properties of food, such as fat, water, protein, carbohydrates and pigments. NIR is the most widespread on- and at-line technique in the feed and food industry.

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 2023, 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. Much of the activity has been moving the developed prototypes into the field for real-world testing, as part of Pillar 3.

Another activity in Pillar 1 is the exploration of new opportunities. In 2023, this included activities such as workshops, arranging the EPIC conference on food digitalisation at Nofima in 2024, and commencing the organising of The Sensor Decade 2024. We also continued our work for developing a strategy for the EU research programs. We attended the Photonics21 annual meeting in 2023 and are now part of the Extended Executive Board.

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) 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.

An important application of dry film FTIR is the characterisation of protein hydrolysates. In the project period, we have shown that dry film FTIR can be used as an analytical tool to characterise products from an industrial EPH process. In a large-scale designed experiment, frequent product sampling from the Bioco process with controlled variations in raw material composition and process parameters were performed. In six weeks, 463 protein hydrolysate samples were obtained and measured with dry film FTIR spectroscopy. In the same period, systematic variations in process parameters such as raw material composition, enzyme type, and water addition, were performed. FTIR spectra of all samples were obtained, and from a subset of samples, average molecular weights, low molecular weight constituents and collagen content were estimated. The FTIR fingerprints was subsequently successfully used both qualitatively and quantitatively to evaluate process variations, proving some of the potential of FTIR spectroscopy for in-process analysis.

Dry film FTIR spectroscopy also opens the possibility for protein characterisation of other food matrices, such as milk

Photo/cc: Katinka Dankel, Nofima

PhD-student Bijay Kafle bringing the portable dry film FTIR system for industrial testing at Bioco

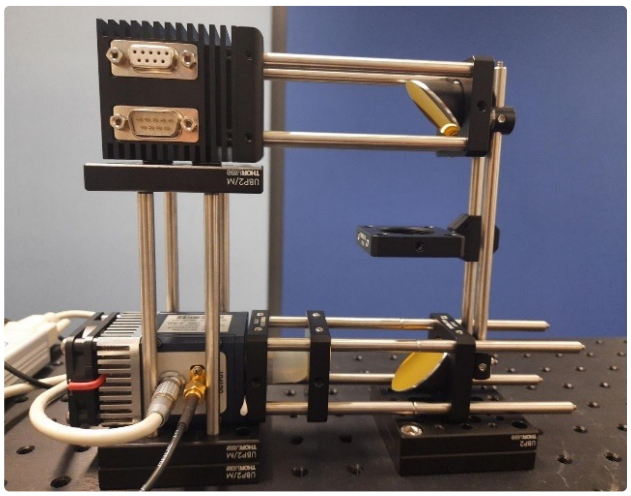
Dry film FTIR spectroscopy also opens the possibility for protein characterisation of other food matrices, such as milk. In collaboration with TINE, we have explored the possibility of using FTIR spectroscopy for quantification of protein fractions. This has been done through a large study where the potential of FTIR analysis of milk to predict shelf-life has been investigated. From the results of this study, we see that dry-film FTIR can pick up subtle chemical differences in the proteins induced by proteolytic enzymes. Moreover, detailed chemical analysis of the protein fractions shows that FTIR can quantitatively register minor changes in the protein composition. This application has potential use both on farms (e.g., disease detection) and in process (e.g., cheese making).

The final objective of the FTIR project is to develop a portable FTIR system for dry film measurements that can be used close to industrial process lines, thus enabling industrially relevant measurements. This is a technological solution that is currently not commercially available. In the project, such instrument has now been designed, build and tested, first in the laboratory, and finally in industrial environments. The latter was successfully achieved in the spring of 2023, when the portable dry film FTIR system was deployed in Bioco and protein hydrolysate samples were measured at-line in an industrial environment. This industrial testing involved building a calibration model for predicting average molecular weights, demonstrating low prediction errors as compared to benchtop FTIR measurements in the laboratory. Thus, testing of the portable system was successful, and the system will now be brought in the field for testing of other applications. A next natural step in the development of an inline system is the adaption of automation and robotic sample handling for automatic sampling from process streams. This would include automatically depositing samples on well plates, drying, and inserting into the FTIR system.

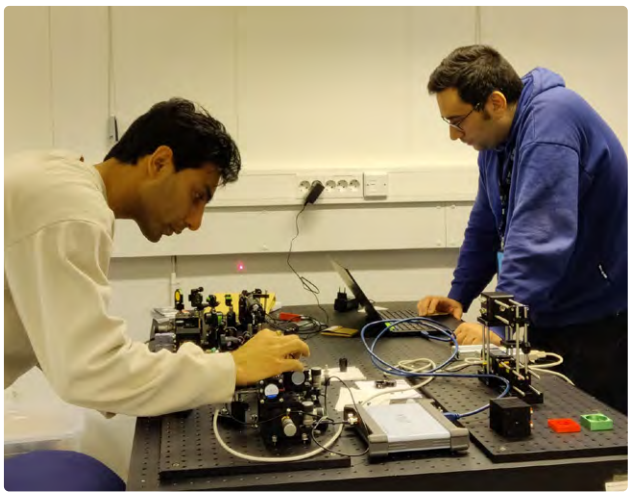
The work in the project has been performed in close collaboration with industry partners TINE, Biomega and Norilia.

Handheld and portable IR

This project aims at the development of new infrared devices that are not using Fourier Transform technology as most infrared measurements today do in food quality analysis. The advantage of these new infrared devices is that they can potentially be miniaturized and that measurements can be obtained very fast. Two different approaches have been followed. In the first approach, an infrared spectrometer has been established by using a linear variable filter which is in front of an infrared detector and analyses radiation coming from a thermal or narrower LED light source. This approach has been evaluated in the first part of the project for different chemicals and benchmarked with lab devices. The second approach uses new infrared lasers in the mid-infrared that emit either at a single wavelength or are tunable in a very narrow range. So far, the project focused on the development of the light sources, the optimization of different optical setups. A tunable laser was developed by nanoplus, that is tunable over a range of wavelengths in the protein region. This laser can be used for protein analysis in for example hydrolysates. In the next period of the project, the setups will be evaluated for different measurement situations, such as measurement of food samples with a single mode wave guide, in transmission thin film measurements and for measurements through a capillary. The measurement with a single mode wave guide allows to measure samples in contact and can potentially be integrated in a pipe or in a bioreactor. The focus here is on liquid milk samples or samples from hydrolysates.
The setup for measurements in transmission mode, may be used for analysis of hydrolysates. The measurement in a capillary, may be used for liquid samples as well. In this project NMBU works closely together with OptoPrecision GmbH, nanoplus and University of Ulm. All partners have been very active in the first period on the project that focused on the assembly of the setups and the development of the optical components. Further benchmarking of the setups will be needed. In the next period of the project, we aim at working closely together with food producers and test the devices with real food samples. We are working closely together with the FTIR project on the exchange of samples from Bioco, where the plan is to determine different process parameters by both FTIR system for dry film measurments and the tunable laser-based IR system.



Photos/cc: Pranish Karki, NMBU



Photos/cc: Michael Fenelon NMBU

To the left, a prototype of the device for dried sample measurements using a tunable laser in the protein mid-IR protein region is shown. To the right the PhD student Mehmet Can Erdem and the master student Pranish Karki working with the optical setups at NMBU.

Photo/cc: Food Analytics Conference 2023

Tiril Aurora Lintvedt presenting her work on Raman spectroscopy at the Food Analytics Conference 2023 in Copenhagen.

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 very promising evaluation of in-line Raman for rapid and non-destructive measurement of fatty acid features (EPA+DHA) in intact salmon fillets. This work was followed up by a study at NMBU, mapping the variation of the fatty acid profile within and between salmon fillets with gas chromatography, and studying the ability of IR,Raman and NIR hyperspectral imaging to quantify these.

A main focus in 2023 was to evaluate in-line Raman measurements at Norilia (Bioco) for continuous monitoring of fat, protein, collagen and bone in the raw material entering the process.

The results were very promising, and the scientific paper on this work crowned the PhD thesis of Tiril Aurora Lintvedt. She defended her PhD in May with a very entertaining and interesting disputation together with her opponents professors Astrid Aksnes (NTNU) and Roy Goodacre (University of Liverpool). So far, we have demonstrated that, despite 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. We will continue to evaluate Raman for in-line applications – study how to obtain stable measurements and how to pre-process the spectra in the best way. We will also compare the robustness of Raman with that of NIR spectroscopy with respect to variation in sample properties like structure and texture.

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

HYPERSPEC

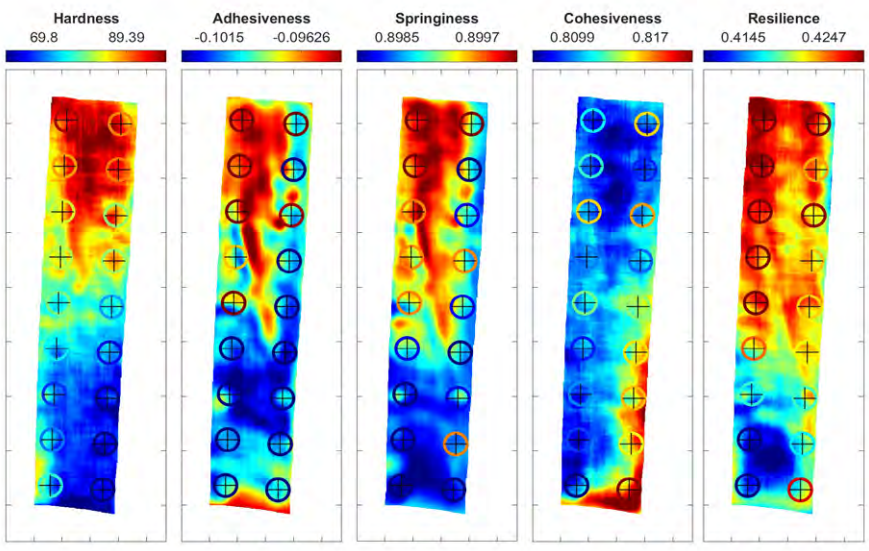
Maritech and NEO have been active partners as suppliers of technology within HYPERSPEC. Maritech has focused on the Maritech Eye instrumentation, while NEO has focused on their hyperspectral cameras. Maritech and NEO have also collaborated on specific tasks within HYPERSPEC. The most involved end-users have been TINE, Lerøy Aurora, Lerøy Norway Seafoods and Lerøy Havfisk. In 2023 several applications have been addressed. In February 2023, Rowan Romeyn started as a new postdoctoral researcher associated with DigiFoods. Rowan is based at Nofima Tromsø, working within the Department of Seafood and has a background in quantitative and applied data analysis. His PhD was completed at the Department of Geosciences at UiT with a focus on cryoseismology, i.e., the use of tremors and vibrations to measure physical properties of ice and permafrost.

With TINE the focus has been on analyzing data collected in 2022 to determine texture properties and chemical composition of cheese products. Together with Lerøy Aurora and Lerøy Norway Seafoods the focus has been identification of blood stains in fillets. In addition, at Lerøy Aurora better models for detecting melanin spots have been developed. The data was collected in 2022, and in 2023 the initial models were improved by including the simultaneous analysis of the spatial and the spectral information, and a method for visualization of where the defects are located as heatmaps both for blood and melanin. The results for these models were presented by Rowan Romeyn in the WEFTA (Western European Fish Technologists Association) 2023 conference.

Finally, solutions to identify several quality attributes based on one measurement. For whitefish fillets blood stains, blood level, nematodes, gaping and remaining shelf life can be identified based on data from the Maritech Eye. For the salmon industry (Lerøy Aurora) both melanin, blood stains, fat and color can be combined.

Lerøy Havfisk is involved in facilitating the on-board use of the Maritech Eye for blood detection through the skin and sorting fish according to species. In addition, initial tests were performed to sort cod according to texture using the Maritech Eye. This work will be continued in 2024.

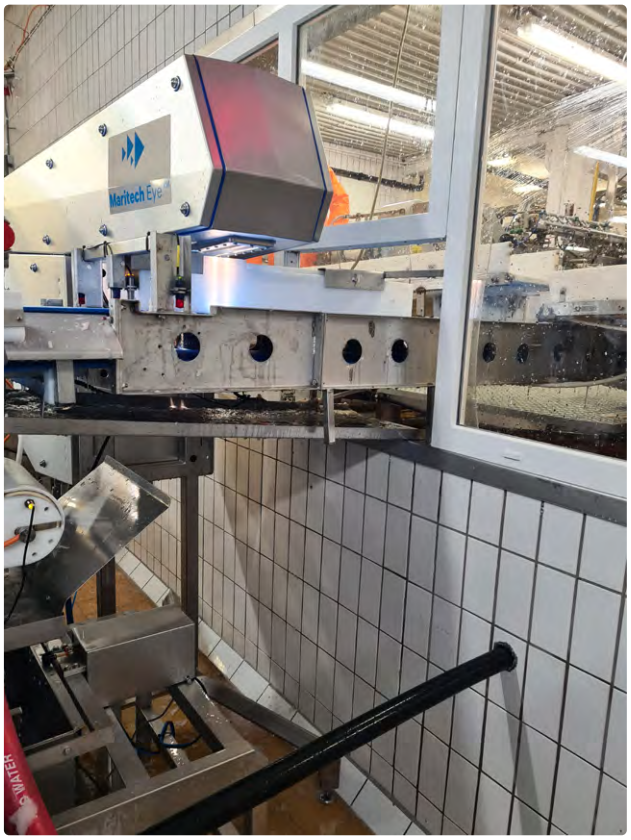
Photo/cc: Samuel Ortega, Nofima



Various texture characteristics of cheese such as hardness, adhesiveness, springiness, cohesiveness, and resilience were measured using a Texture Analyzer. Afterwards, the texture parameters were estimated from the spectral data, taking the reference information into account. An example of the texture prediction maps is presented in the figure above.

From an early-stage hyperspectral camera system to an industrial solution operating in both the whitefish and redfish sector

Photos/cc: Frank Gregersen, Nofima



Photos/cc: Maritech

Two spinoff projects will start in 2024 based on results developed in HYPERSPEC.

1. Nematode removal based on nematode detection using the Maritech Eye (Norwegian Seafood Research Fund (FHF)). Two solutions will be tested/developed in this new project. A waterjet setup delivered by Marel that already is used to cut the fillets into portions and to remove pin bones. The second solution to be developed and tested is in collaboration with NMBU, the leader of the ROBOSENSE project in DigiFoods.
2. Robust estimation of remaining shelf life for cod, both fillets and headed gutted fish (FHF). Previously, the solution has been developed and tested on homogeneous raw material. In this project fish landed from different fish vessels using different fishing gears will be included. Seasonal variation and storage conditions (air, ice, seawater, temperature) prior to estimating the remaining shelf life will be included. This project aims to improve the generalization of the current models available for shelf-life estimation based on the spectral information.

OPPORTUNITIES

This is a small project that centres on creating new opportunities and mange new ideas.

In 2023 we conducted several activities related to this project.

- We organised "Digitalisation in Food Production", a free on-line event, 09.11.2023, with an international audience, in collaboration with CPACT (cpact.com), IRTA Monells (irta.cat) and DigiFoods (digifoods.no).
- We set-up two summer internships (Lorentz Syslak and Arne Fredrik Adamsrød) at SINTEF as part of DigiFoods, and they worked on the FragoPro sensor platform for MOBILESENSE.
- We set up a masters project for our previous 2022 summer student, Vilde Vraalstad, on fundamental spectrometer characterization for applied use, and this led on to her starting a PhD with us in September 2023.
- In autumn 2023, we did some preliminary work on cherry tomatoes to get an understanding of the type of measurements we can achieve for this product. This will now form part of Vilde's PhD and was instrumental in obtaining Wiig Gartneri as a new partner in the SFI from 2024.
- NMBU, SINTEF and Nofima have spent some time going through commercialisation concepts around sample handling for dry-film FTIR, and this has resulted in a new commercialisation proposal which was sent in autumn 2023, and we will get an answer early 2024.
- Marion O'Farrell attended the EU Photonics21 annual meeting in Brussels and this led to Marion joining the extended Executive Board, which gives us good insight into potential calls within photonics and spectroscopy. We also provide further input to the Strategic Research and Innovation Agenda (SRIA)
- Marion O'Farrell and Jens Petter Wold attended workshops organized by ReThink Food, which focused on the digitalization of future food systems in Norway and on the possible effects of novel FoodTech the coming years, respectively.
- We started the work on organising a physical technology meeting in collaboration with the European Photonics Industry Consortium, EPIC, which will take place at Nofima, 24–25 April 2024 https://epic-assoc.com/events/epic-technology-meeting-on-photonics-for-agrifood-industry-enlightening-the-future-at-digifoods/
- We have started organising The Sensor Decade 2024, with the continued goal of building a sustainable sensor technology provider industry in Norway. Marion O'Farrell (SINTEF), who leads pillar 1 in SFI DigiFoods, will lead the organisation of the conference.

Photo/cc: Marion O'Farrell, SINTEF

Marion had the pleasure of bumping into her PhD external supervisor from 20 years ago, Professor Anna Grazia Mignani, at the Photonics21 annual meeting.

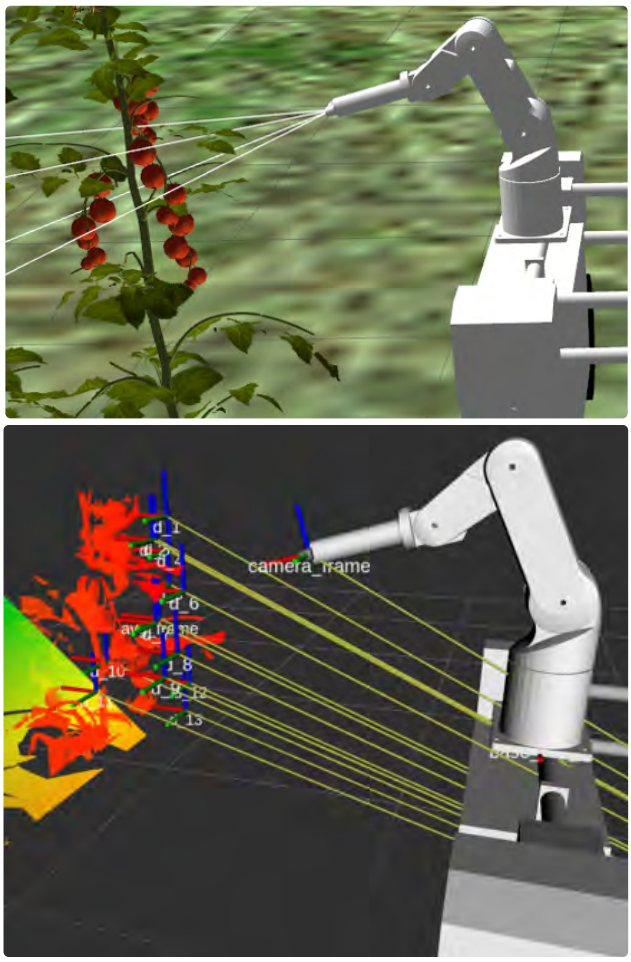
Pillar 2 Robot and sensor integration

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.

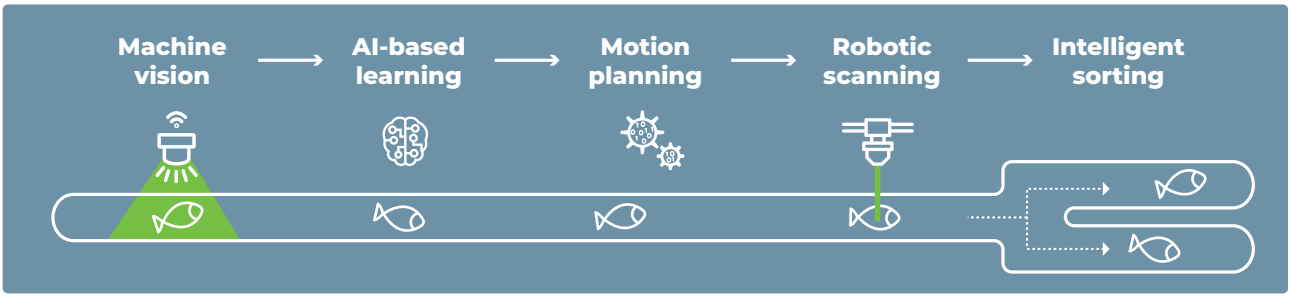
In this pillar, we are looking at how robots can be used to enhance the performance of sensors by accurate positioning of sensors for optimal sample taking and measurements. We are also looking at how sensors can be used to increase the performance of robots and improve decision making and overall performance. 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 FTIR and Raman, which is closely related to the work done in the other pillars.

The research area is led by Weria Khaksar at NMBU and divided into two main projects: ROBOSENSE and MOBILESENSE. Key partners in this pillar include Saga Robotics, RobotNorge, MarqMetrix, Lerøy Aurora, Nofima, SINTEF and University of Lincoln.

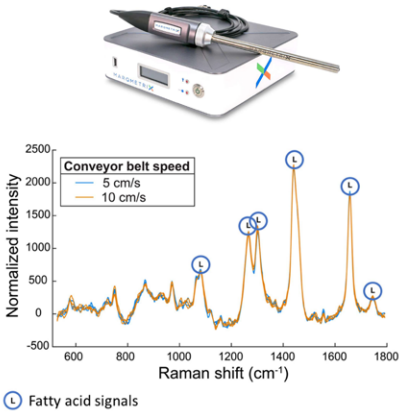


Positioning and handling sensors by a robotic manipulator placed on top of a mobile robot. This is one of the main focuses of the robotics pilar in DigiFoods.



The overall process of using in-line sensor technology handled by robotic solutions.

Photo/cc: Antonio Candea Leite, NMBU



ROBOSENSE latest results in 2023: a robotic Raman scanning system for fast and effective measurements of fatty acid composition in salmon fillets.

ROBOSENSE

ROBOSENSE enables robotic operations of intelligent sensors in industrial food processes, providing accurate and effective in-line measurements of relevant parameters in heterogeneous foods. The project aims to:

i. identify how to optimally collect spectral measurements from certain regions of complex food samples moving on a conveyor belt;
ii. develop an innovative and affordable concept for robotically controlled measurements;
iii. develop a robotic prototype for testing under realistic conditions expected in a food processing facility.

In 2023, the ROBOSENSE team successfully achieved the following goals and objectives:

i. publication and presentation of two scientific articles at prominent international conferences, one in IFAC World Congress 2023 (Yokohama, Japan, 9–14 July), another in IEEE CASE 2023 (Auckland, New Zealand, 26–30 August), promoting dissemination towards the scientific community, industry, commercial players, policymakers, and more;
ii. development of automatic triggering capability for autonomous control of the Raman spectroscopy system (MarqMetrix) via a robotic system using the ROS software framework, avoiding the need for a human operator during experiments;
iii. implementation of new motion planning algorithms with obstacle detection and avoidance capabilities for robotic Raman scanning of salmon fillets with dark melanin spots. This activity was developed by Daniel Glemminge last summer, as a DigiFoods/NMBU summer job.

In 2024, as next steps, the ROBOSENSE team aims to

i. collect a new image and video dataset of salmon fillets at Lerøy, with different colours, shapes, trims, and dark melanin spots to be used as input to the AI-based image processing algorithm, which finds the suitable Raman scanning area for the robot motion planning algorithm;
ii. write and submit 1–2 journal articles one on the robotic Raman spectroscopy for digital food quality assessment, another on dataset collection and analysis, and experiments;
iii. develop and validate a pilot-scale system and a minimum viable product (MVP) concept for robotic in-line scanning under relevant operating conditions, in collaboration with RAMAN project and industry partners;
iv. at NMBU, Daniel Glemminge and Abhaya Pal Singh will join the ROBOSENSE team respectively as a master's student and postdoctoral fellow to conduct R&D activities towards implementing and testing the MVP concept in a salmon fillet processing line.

MOBILESENSE

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.

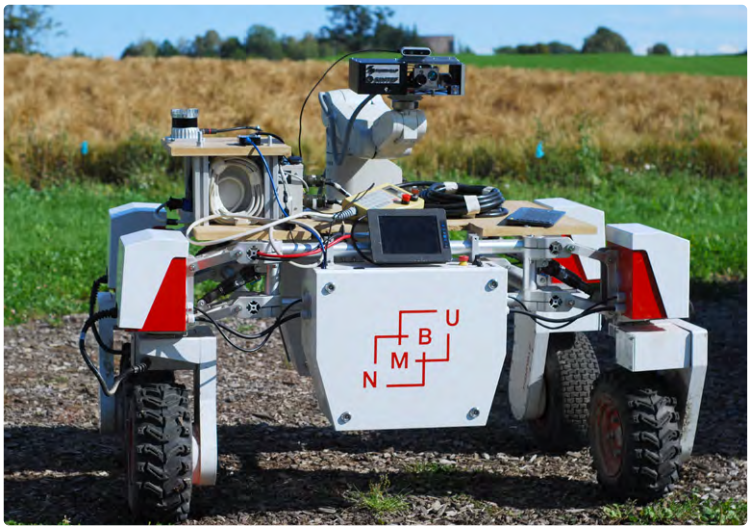
In 2023, SINTEF developed a fully self-contained sensor head, FragoPro, for integration on robotic platforms. FragoPro uses a spectrometer design that was demonstrated in the first years of the project, and includes a computer vision camera, an edge computer, and a wireless data antenna for low-effort hardware integration. Much of the sensor system development was carried out by summer students Arne Adamsrød and Lorentz Syszlak at SINTEF.

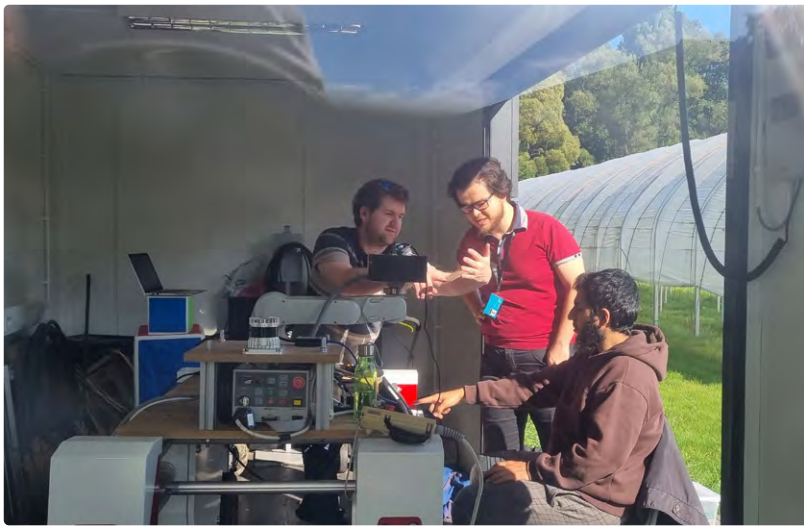
At NMBU, Gabriel Lins Tenorio joined the project as a researcher. He will continue as a post-doc in 2024, after completing his degree in Q2. He has started his contribution to MOBILESENSE with the development of a Gazebo robotics simulator, which will be used in 2024 for developing autonomous navigation methods. His focus in 2024 will be on first, to develop and implement deep learning solutions for individual fruit detection and segmentation and second, to design a machine-learning-based solution for optimal placement of the sensor in front of the targeted fruit to maximize accuracy and robustness.

A field test of FragoPro mounted on Thorvald was executed in late summer. The test used manual, open-loop robot control. In this way, the team gained operational experience with the features and limitations of the robotic platform. Sensor data from the test was analyzed at SINTEF, revealing several opportunities for improved design.

In 2024, the project aims to carry out a closed-loop field test, demonstrating improved sensor performance with autonomous robotic positioning.

Photos/cc: Anders Hansen, SINTEF





Summer 2023 test campaign with Thorvald and FragoPro.

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. In DigiFoods, implemented sensors are 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. As developments proceed in the sensor development work of Pillar 1, there will be a gradual increase in novel application work also in Pillar 3. Therefore, in 2023, process exploration work obtained using both FTIR and Raman spectroscopies could be presented.

Pillar 3 is led by Dr. Nils Kristian Afseth at Nofima. For 2023, key partners in this Pillar have included all food partners, NEO, AspenTech, MarqMetrix, Idletechs, SINTEF, NMBU and Nofima.

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 time consuming and expensive task. Also, it is necessary to maintain models over time for both instrumental, environmental and process reasons.

In 2023 we have continued the work on calibration transfer techniques. Having reviewed existing techniques in 2022, we have been focusing on approaches to address the question of when and why different techniques may solve the issues in transferring models between instruments. We expect to continue this work in 2024 and plan to continue the seminar series initiated in 2022. As for 2022, in 2023 we have had invested in building valuable industrial datasets for the study of robust models, in particular in the collaboration with Hoff. This involved a calibration campaign in April along with in-line measurements during May/June and also since December. After Covid-19, electricity price surges and the havoc wrecked by the storm Hans, we hope that in 2024 this work will follow more smoothly. As mentioned in other projects, a collaboration with Bioco has continued in 2023 and has over the years resulted in a valuable industrial dataset that will also be relevant for work

Photos/cc: Lars Erik Solberg, Nofima

Work at Hoff during the calibration campaign in April: measuring dry matter in French fries using both interactance and reflectance NIR spectroscopy. The Perten instrument (to left in image) is currently measuring spectra continuously. The three bottom images are close-ups of measurement spots of the three instruments – Perten, Prediktor, QVision.

Photos/cc: Jens Petter Wold, Nofima

Idletechs and Nofima during measurements of core temperature in fish patties, with one example patty to the right. (Lars Erik Solberg, Håkon Jarle Hassel, Frank Westad, Tom Johannessen).

in Robust. 2023 included a preliminary study with Lerøy of fish patties where models for core temperature were attempted based on NIR spectroscopy by Nofima and infrared imaging by Idletechs. Results were presented and discussed with Lerøy who were interested and positive to pursuing this work further.

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. This is a long-term goal which will continue in 2024.

Photo/cc: Erik Tengstrand, Nofima

Equipment for automatic handling of raw materials prior to sausage production.

A key challenge in many food processes is the missing knowledge about the actual quality variations

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 and 2023, 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 at Nofima and twice 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 1500 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 (NRC no. 327946) and gives very nice synergy effects for both projects. Better control of the fat content will give less variation, better control of the drying process, better yield and more healthy sausages.

Sausage being measured with NIR spectroscopy in process line.

Sausages ready for dry-curing.

Photos/cc: Erik Tengstrand, Nofima

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 2023 were TINE, Nortura, Bioco, Biomega, Intelecy, NMBU and UPV.

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. TINE and Nofima have developed routines for manual data export followed by synchronisation and aggregation in the MATLAB software. The aim was to implement similar routines in the Intelecy software, to have access to combined data in real time and avoid manual work. Technical challenges and coordination with other data management initiatives at TINE has delayed this work, but a workaround with manual import of the combined data has been implemented in the Intelecy software. This makes it possible for TINE to explore and model their historical data directly in the Intelecy software.

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

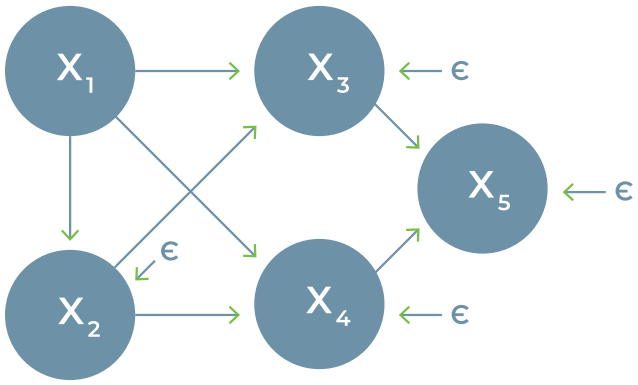
All data-driven solutions require some form of data modelling

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. Based on this work, we recommend applying the metrics *Distance Correlation* and *Maximal Information Coefficient*. The methods have been used to estimate lags in the hydrolysis process at Bioco. The work has been presented at two international conferences, and a scientific paper is submitted.

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 develop methodology for two types of models: causal modelling and real-time modelling. We also apply different types of modelling methods in processes at industry partners.

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.

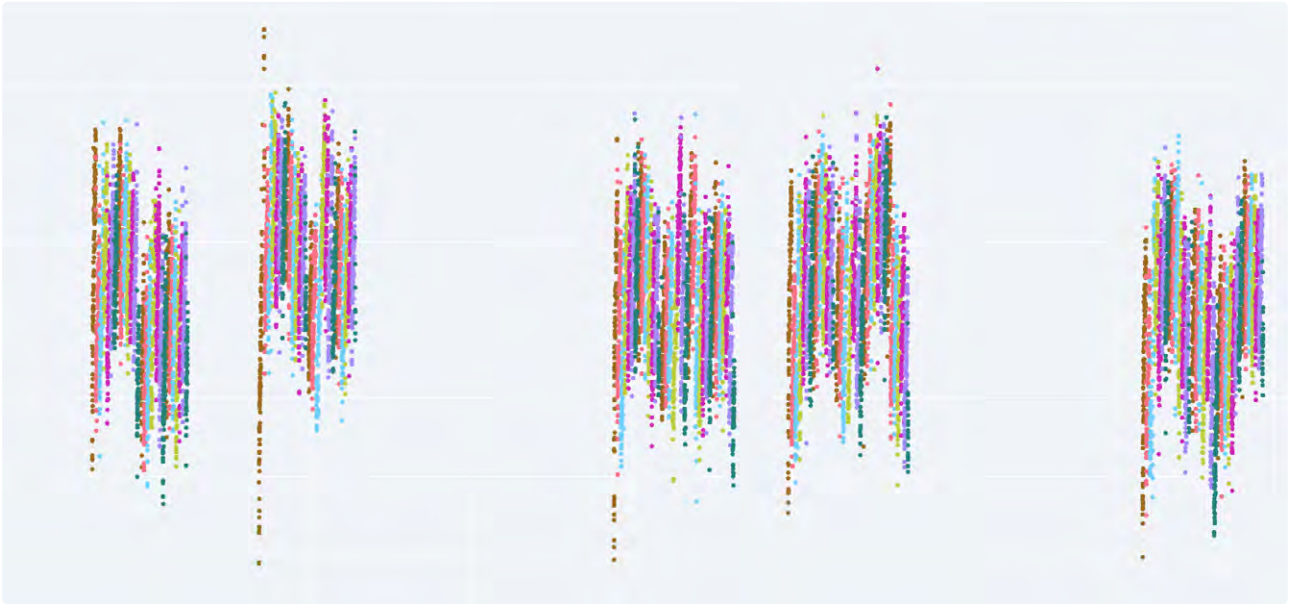


The method has been presented at an international conference and a scientific paper is submitted. Christian is applying this framework in a case study with Nortura, to estimate the causal effect of feed on a chicken health parameter. Preliminary results have been presented at a conference, and a scientific paper is in preparation.
The second type of model is intended for real-time monitoring, control, or decision support. PhD student Marco Cattaldo has proposed a new method for modelling process dynamics in cases when the data comes from both spectroscopic sensors and other process measurements. The new method is based on the multiblock method SO-PLS and Dynamic inner PLS (DiPLS). A manuscript is in preparation, where this new method is compared to alternative modelling strategies.

We have also modelled process data from both TINE and Bioco, with the aim of understanding relationships between raw materials, process parameters and end-product quality. In TINE, this is done in collaboration with Intelecy who are developing a new feature in their software for investigating quality variations. This work has already led to adjustments in the cheese production process at TINE Jæren, and data collection and modelling will continue in 2024.
At Bioco, a huge data collection campaign was performed in 2022/2023 where different enzymes and raw material compositions were tested.
We found that both raw material quality (measured by NIR) and enzyme dose and type affected important product attributes. In 2024, two master students will investigate further the potential benefits of using inline NIR to adjust process parameters at Bioco.

Photo/cc: Camilla Gjetvik, Intelecy

Bertil Helseth (Intelecy) and Magne Aase (TINE) at Tine Meieriet Jæren.



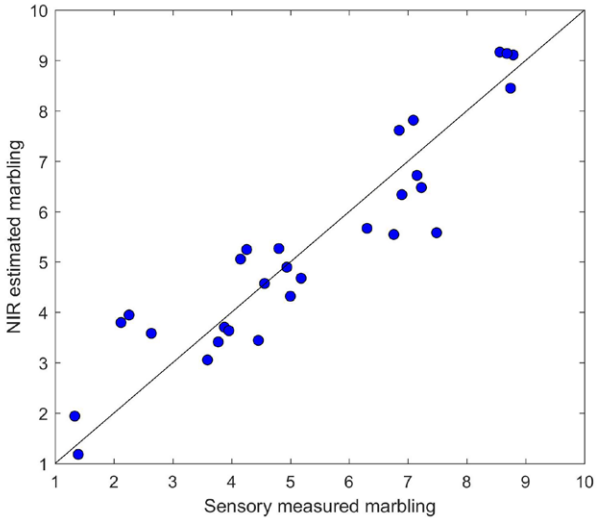
Screenshot from the Intelecy software, showing time series of dry matter in fresh cheese measured by NIR. Each dot represents a block of cheese, and colours represent different batches.

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. How could the food companies in DigiFoods utilize existing or future data on product quality for product development, shelf-life extension and/or marketing?

After a mapping workshop in late 2022, the CONSUMER project has run a successful case study together with Nortura during 2023, on meat marbling and sensory quality perception. Meats with different marbling levels were classified with use of on-line spectroscopic measurements and measured with Nofima's trained sensory panel. Consumers tasted the samples and rated their expectations and liking. On-line measures were successful for classifying meats that could potentially be targeted to consumer groups or different markets (e.g. restaurant vs supermarket). An industrial PhD candidate at Tine (Åse Riseng Grendstad) is working within the CONSUMER project on yogurt quality to avoid food waste. Åse has presented her project in Næringsmiddeldagene 2023 and a poster in Pangborn Sensory Science Symposium 2023 (Nantes, France).

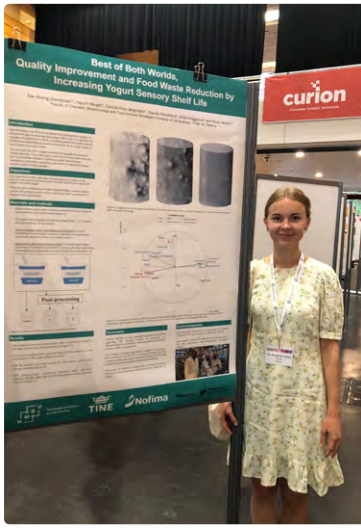
CONSUMER is led by Paula Varela, consumer researcher from Nofima; the project will continue exploring concrete case studies with other of the industrial partners in DigiFoods to bring ideas into innovations.



Correlation of NIR measurements with marbling as measured by the trained panel.

Photo/cc: Karoline Lyngstad Skjerve, G.O. Johnsen

Photo/cc: Susanne Enholm, TINE



Åse Riseng Grendstad (TINE) at Næringsmiddeldagene (16–03–2023) and Pangborn Sensory Science Symposium (23–08–2023).

• Photo/cc: Kristoffer Skarsgård, Saga Robotics

Thorvald in vineyard in Santa Maria.

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. 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.

	Location	Candidate	Funding	Project	2020	2021	2022	2023	2024	2025	2026	2027	2028
PhD-students	Nofima	Tiril Aurora Lintvedt	Nofima	RAMAN									
	Nofima	Christian Thorjussen	Nofima	MODEL									
	Nofima/UPV	Marco Cattaldo	Nofima	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	Mehmet Can Erdem	NMBU	IR									
Post-docs	Nofima	Samuel Ortega Sarmiento	Nofima	HYPERSPEC									
	Nofima	Rowan Romeyn	Nofima	HYPERSPEC									
	NMBU	Nageshvar Patel	RCN	IR									
	NMBU	Gabriel Lins Tenório	RCN	MOBILESENSE									
	NMBU	Abhaya Pal Singh	RCN	ROBOSENSE									
	Nofima	Tiril Aurora Lintvedt	Nofima	RAMAN									
	NMBU	Maren Anna Brandsrud	RCN	IR									

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

At Nofima in Ås, Tiril Aurora Lintvedt defended her PhD work on in-line Raman spectroscopy aiming for representative sampling and modelling of heterogeneous foods in May 2023. She is now hired as a post-doc within the same field of research. 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. 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 PhD in 2022. She is funded by TINE and is working on consumer perceived quality of yoghurt as well as related spectroscopic properties. Vilde Vraalstad started her PhD work in September 2023 and she will study opportunities and limitations in the design of well working miniature NIR sensors for food applications where measurements in depth is essential. She sits at SINTEF and collaborates closely with Nofima.

At Nofima in Tromsø, post doctor Rowan Romeyn began early in 2023. He works 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.

At NMBU, Mehmet Can Erdem, member of the Biospectroscopy and Data Modeling (BioSpec) group, started his PhD in April 2023. He is working on the design and implementation of infrared optical devices and instrumentation. We attempted to hire a PhD within robotics in 2022 and 2023 to work on control of sensors to be used in complex measurements situations. It has been very difficult to recruit PhDs within robotics, but we have now succeeded in hiring two post-docs who will start in 2024. Gabriel Lins Tenório started allready in the summer of 2023 and will include DigiFoods work in his PhD. His post-doc will be focussed on how to operate sensors on mobile robots in the field. Abhaya Pal Singh will start his post-doc in May 2024 and study robotic control of sensors at conveyor belts.

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 and three more in 2024. Additionally, in 2023 we recruited a student from Physics and Mathematics at NTNU for master work on sensor systems at SINTEF and she is now a PhD-student. The potential for further relevant master thesis topics, for students finishing in 2025 and beyond, is high.

Article

Optical sensors can measure ingredients in foods

by Wenche Aale Hægermark, Nofima

Nofima research fellow Tiril Lintvedt has investigated whether it is possible to carry out detailed quality measurements of raw materials directly on the production line. Her research shows that measurements with Raman spectroscopy offer many interesting possibilities.

More specifically, she has investigated whether it is possible to use Raman spectroscopy to measure fatty acid composition in salmon fillets or fat, protein, bone and collagen in residual raw materials from chicken and turkey.

Tiril defended her PhD in May 2023 with a very entertaining and interesting disputation together with her opponents professors Astrid Aksnes (NTNU) and Roy Goodacre (University of Liverpool).

Technological development opens up new opportunities

The technological development gives the food industry far better opportunities for process control and product differentiation, quality control and sorting of raw materials. Optical sensors, used in spectroscopic measurement methods, are becoming faster, less expensive, and more precise.

There are several different rapid and non-destructive spectroscopic measurement methods. They are suitable for different raw materials and measurement needs.

Detailed measurements directly on the production line are challenging

"Raman specctroscopy, which I have studied, has become both more affordable, better and more stable. It is now possible to make exact measurements over larger areas than before, but there are still challenges associated with measuring at exposure times low enough to keep up with the speed of, for example, conveyor belts. In addition, the measurements can be affected by large variations in working distance as a result of varying thickness and volume of raw materials," says Tiril Lintvedt.

The challenges she mentions relate to how long measurement time is needed to capture the necessary details in the raw materials. If one is to measure, for example, salmon fillets while they move on

"We have seen that Raman measurements can indeed be used in-line at quite high speed"

Tiril Lindvedt

Photo/cc: Jon-Are Berg-Jacobsen, Nofima

Tiril Aurora Lintvedt tests to use Raman spectroscopy to measure fatty acid composition in salmon fillets.

Photo/cc: Wenche Aale Hægermark, Nofima

Celebrating Tiril Aurora Lintvedt well executed Public Defence. Back from the left Achim Kohler, Nils Kristian Afseth, Kristian Hovde Liland (committee coordinator), Jens Petter Wold, Tiril Aurora Lintvedt, Astrid Aksnes (2nd opponent), Roy Goodacre (1st opponent)

the production line in normal production, the Raman instrument that was used in Tiril's experiment must measure both very detailed and precise – and quickly.

"There are as far as we know very few in-line Raman solutions in the food industry today. Current spectroscopic solutions in use, such as NIR, can measure larger areas and deeper in the samples, but these solutions cannot measure with the same chemical richness and detail as Raman. We have seen that Raman measurements can indeed be used in-line at quite high speed, but for single samples with weak signals the method may be better suited for rapid measurements alongside the production line. Such measurements can also be of high value to the industry. They provide opportunities for frequent feedback on quality, and as of today there are few such solutions," Tiril points out.

From laboratories to industrial production

Very detailed measurements are needed, right down to the molecular level, to map fatty acid composition in salmon fillets or fat, protein, bone and collagen in residual raw materials from chicken and turkey. Raman spectroscopy is particularly suitable for such measurements.

"Raman has been used in laboratories in the development of expensive products such as medicines. Better and cheaper instrument solutions open new opportunities for industrial use, also in food production. It is this potential that I explored in my PhD, and the results show great potential for the development of new Raman applications in quality documentation, sorting, process analysis and real-time process control in the food industry," says Tiril.

After completing her PhD, Tiril has continued as a postdoc in DigiFoods, and will continue the work of developing Raman applications for the food industry.

Interesting aspects to investigate now is the robustness of the method towards sample variation in structure and texture, as well as variation in distance between sample and instrument. We will compare the robustness of Raman with that of NIR spectroscopy, since it is well known that NIR is rather sensitive to such properties.

Facts about the doctoral degree

Tiril Lintvedt defended her thesis on 11 May 2023. The title of the thesis is Raman spectroscopy for in-line food quality characterization. Supervisors were Professor Achim Kohler (NMBU), senior scientists Jens Petter Wold and Nils Kristian Afseth (both at Nofima).

Article

Pushing sensor limits to improve measurements under challenging conditions

by Vilde Vraalstad

Food is complex, and some products and properties are particularly challenging to measure, especially in the "real world" outside of the lab.

Through my PhD-work, I will explore the fundamentals of applied spectral measurement solutions, to get a better understanding of the overlap between the instrumentation, sample properties, and data analysis, so that we can further push the limits of what can be measured, even under more demanding conditions. This enables digitalisation and optimisation of applications that previously have been considered too challenging.

My first encounter with DigiFoods was through a summer job at SINTEF in 2022. SINTEF and Nofima have spent many years developing instruments for food quality assessment based on spectroscopy. As a physicist specialized in optics and instrumentation, who spends much of my spare time cooking and baking, this felt like the perfect match. I had an amazing summer taking part in this work and was fortunate to continue within DigiFoods, first through my master's thesis in 2023, and now as a PhD student.

In the spring of 2023, I finished my master's degree in applied physics, with specialization in optics, from NTNU. My master's thesis was conducted at SINTEF and focused on developing methods for the characterisation and comparison of spectrometer performance. Such understanding of the instruments is needed for us to better understand our data, and to select the optimal instrument for a given application.

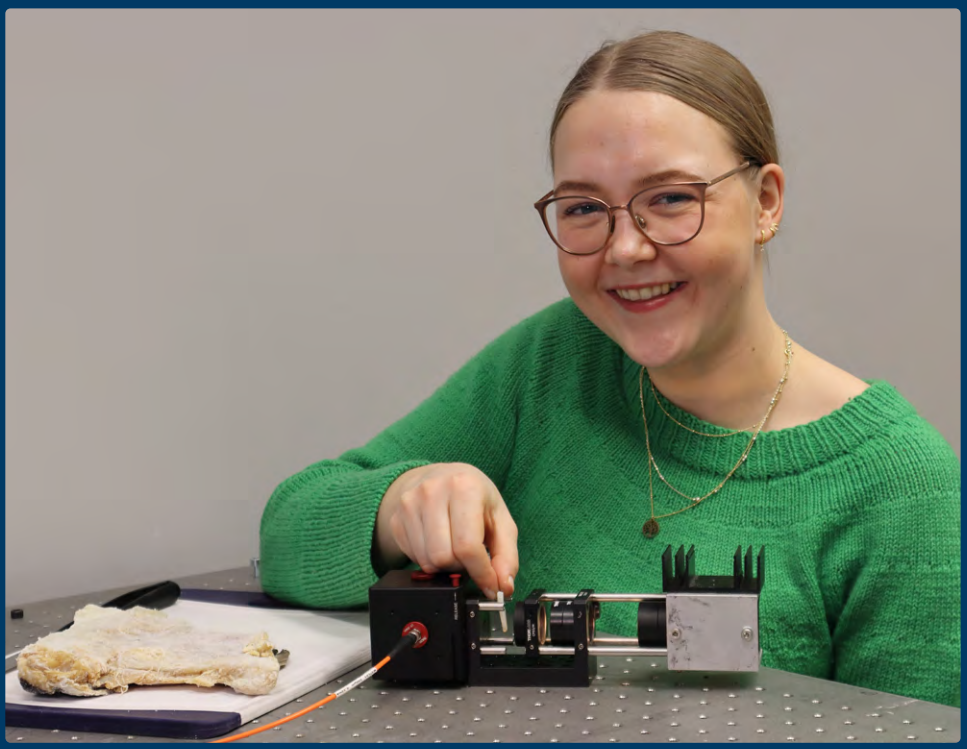
This was the perfect buildup to my PhD, which started in September 2023. The overall goal of the PhD is to increase the understanding of applied spectral measurement solutions, both in terms of instrumentation, sample properties and analysis, as this will help us improve our measurements.

Sufficient performance when pushing the limits

Developing instruments for demanding applications is all about pushing the limits of the instrument design. We need to push what is achievable in terms of size, speed and cost, while still having good enough performance and robustness. It all boils down to a compromise between these properties, as all application-specific requirements must be met for the instrument to be usable.

Our focus is on measuring properties related to the quality of particularly demanding food products, such as water content of clipfish (dried salted cod) and sugar content of strawberries. These products are heterogeneous, and we need to measure the inside of the product – beneath the clipfish salt layer and into the core of the strawberry. Not only do we aim to do this, we also aim to do it non-contact. Our solution, near-infrared (NIR) spectroscopy with interactance measurements, gives weaker signals, which places more demands on the instrument performance to achieve the required signal quality.

We want to push the limits even further, and develop sensors that are handheld and robot mounted, and still able to measure demanding food products. They need to be compact, which reduces the signal quality, as less light can get through and be measured. They also need to handle the "real world" and its unpredictable measurement environment. For example, when mounted on an agricultural robot in the field, a variety of different disturbances may disrupt the data. Daylight not only blends with the signal you want to measure, making it harder to detect a clear signal. It may also change very fast when a cloud moves over the sun, so that it is harder to separate the signal from the ambient light. When measuring for example strawberries on the plant, light that is reflected from other berries or leaves may disturb the measurement. These leaves or berries may also block the view to the berry you want to measure, making it harder for



Photo/cc: Jon Tschudi, SINTEF

The overall goal of the PhD is to increase the understanding of applied spectral measurement solutions

Using an integrating sphere setup, originally developed for spectrometer performance characterisation in my master's thesis, to measure transmission of clipfish slices.

the robot to find and measure the berry. Also temperature variations may change the signal. All these challenges, and many more, must be overcome for the sensor to have the required performance for measuring demanding foods.

Interdisciplinarity is the key to success.

The key to successfully pushing limits of measurement solutions lies in interdisciplinary fundamental understanding across the domains of instrumentation, sample properties and data analysis. My PhD will be about addressing the overlap of these domains, and getting a better understanding of the compromise between different instrument requirements for design optimisation.

My current focus is a study of using light to measure complex, highly scattering food products. We want to build a better understanding of their physical and chemical properties, how they affect the signal, and how this in turn affects the results from the multivariate calibration models. Through a collaboration with KU Leuven, we will measure the bulk optical properties of clipfish, a highly scattering medium. In the end, we hope our increased understanding of the sample will guide us in how to optimally measure the fish.

Later, I will study the impact the "real world", with demanding conditions and non-optimal instrument properties, has on the data. While it is quite straight-forward to see how different design choices and environmental conditions affect the raw signals, the effect on the multivariate models is not as well-known. In a controlled manner, we will introduce disturbances that are difficult to avoid in the real world, like motion, background light (e.g. sunlight), and non-optimal sensor placement, while changing instrument properties such as resolution and sensitivity. From this, we hope to gain a better understanding of what disturbances are the most important to minimise when designing new applied instruments.

Finally, I will also explore how we can improve multivariate calibration through combining with the knowledge of instrument, sample properties, and measurement disturbances that is obtained from the other projects. Such hybrid modelling combines "the best of both worlds" from physics and data driven modelling, and we hope this will make the models more stable and robust against biological variation and demanding conditions.

Hopefully my PhD work will contribute to the realization of food quality assessment for new and demanding applications. I am grateful to take part in this important work, pushing the digital transformation of the food industry even further.

7. Communication and dissemination

The primary objective of DigiFoods is to develop smart sensor solutions for food quality assessment directly in the processing lines, throughout the food value chains. The obtained food quality information will be used for optimization of both processes and value chains and make the food industry more efficient and sustainable.

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

55 news articles in the press

34 of these in the Norwegian press

15 peer-reviewed publications published and **37** presentations held

External communication and dissemination

During 2023 the media outreach in DigiFoods has resulted in 55 news articles in the press. 34 of these where in the Norwegian press, both trade magazines like *Ny Teknikk, Gartneryrket* and *Fiskeribladet*, and more public media such as *Nationen* and *Forskning.no*. Internationally there were for instance nine articles in both Japanese and English and four in Spanish.

The director of DigiFoods Jens Petter Wold participated in a webinar for the members in *Kjøtt- og fjørfebransjens Landsforbund*, talking about among other things SFI DigiFoods.

In September, several of the professionals in DigiFoods organized and led a three-days spectroscopy course at Nofima for around 30 young scientist from different European countries, sharing results from DigiFoods and other relevant projects.

DigiFoods had 15 peer-reviewed publications accepted and all are now published and held 37 presentations and poster-presentations in 2023.

Dissemination within the project

Two newsletter editions (in March and September) have been produced and distributed via e-mails to the partners and funders.

The annual meeting took place at Nortura Hærland and Nofima Ås in June. At Hærland, there was tour at both the Nortura and the Bioco facilities. At Ås there were tours both to NMBU and at Nofima. In addition, results were disseminated and needs and challenges discussed. 52 persons from the different partners participated.

Photo/cct: Jens Petter Wold, Nofima

The young European researcher attending the spectroscopy course at Nofima, did also get to take part in how sensors can be used to measure sweetness in strawberries. And as Maria Tarapoulouzi, post.doc at the University of Cyprus, said “This is the future of food research, a robot that can also measure components”.

Screenshot: Nofima

In October, among others, The Minister of Agriculture and Food, Geir Pollestad and the mayor of Ås municipality Bent Nøst-Klemmetsen visited Nofima, and senior scientist Ingrid Måge told them about DigiFoods.

Article

Finds the fingerprints of the molecules, faster and easier than before

by Wenche Aale Hægermark, Nofima

Smaller, faster and easier. When researchers and industry work together, they are able to create completely new instruments that find out exactly what food and drink contains.

Milk, salmon or residual raw materials – infrared radiation, chemistry, spectrum and optics. There is a lot to be seen in context when Mehmet Can Erdem and Pranish Karki create the instruments of the future to analyse what the food contains.

"Our goal is to develop something that is cost-effective while being smaller and measuring precisely"

Mehmet Can Erdem

The goal: cost-efficiency

The two are researchers at NMBU. Erdem is working on his doctorate. Karki is pursuing a master's degree. It's all part of the DigiFoods project. Together with the German partners from the University of Ulm, Nanoplus and OptoPrecision, they are developing completely new devices for measuring fats, proteins and other substances in food and beverages.

"Now the equipment available for infrared spectroscopy is either large and space-consuming, too expensive, or it does not provide measurement results that are accurate enough. Our goal is to develop something that is cost-effective while being smaller and measuring precisely," says Mehmet Can Erdem.

Infrared

When handling a sample from a food or beverage product, they send light of a very specific wavelength into the sample. These are not wavelengths that the eye can see – they work with radiation that lies in the middle of the infrared spectrum. That is, wavelengths from 2.5 micrometers, which is far more than the visible light, and up to just over 12 micrometers.

When the sample reflects the light, some wavelengths have disappeared. You can compare it to a black field midway between the colors of a rainbow: the substances in the sample absorb certain specific wavelengths. Different substances suck up different wavelengths. When those working in the lab look at what kind of light passes through the sample, they also see exactly what substances are contained in it.

Fingerprints of the molecules

"We get a molecular fingerprint," Erdem explains. "That way we can find out what kind of fat is in milk or salmon.

"We have our own guide to the wavelengths. Based on the signals from our detector, we can analyse how much fat the sample contains, for example," says Pranish Karki. When they find out exactly what kind of fatty acids are in the milk, they also know more about how long it can be stored.

But researchers have to tailor to make the instruments good enough. In each case, they must use light of the right wavelength, and they must use the correct optics. As they try to make their way, they report back to the German industrial partners how the instruments need to be changed to become even better.

Skin and bone

Right now, for example, they're looking at which remains from chicken and turkey that can become human food. Bioco is a part of Norilia, which is also part of the DigiFoods collaboration, and working to find out how this residual raw material can be utilised.

"Bioco has a facility where bones, skin, fat and other residues are turned into protein-rich feed ingredients with enzymatic hy-

Photos/cc: Georg Mathisen

Mehmet Can Erdem (left) and Pranish Karki are working on what will become completely new instruments for measuring fats, proteins and other substances in food and drink.

drolysis," says NMBU researcher Boris Zimmermann. Enzymatic hydrolysis means that enzymes cause the raw material to be split into smaller particles.

"Thesearehighlynutritiousproducts. Nofima, NMBU and SINTEF are collaborating to develop smart sensors that will measure the quality of their products. Our role is to measure their content quickly and efficiently and evaluate whether production is optimal or not," he explains.

"For example, production can provide some types of products that humans and animals are unable to break down so easily. Then we need to turn them into more liquid form. Eventually, we get a number of substances, and we'll figure out how our system can measure all of that," Zimmermann said.

Smaller instruments

When the researchers are finished, their goal is to have made instruments that are much more compact than what exists today. Thus, the factory or the farmer does not have to go to a laboratory to check everything that needs to be analyzed:

"We can also make this so that the analysis can be done at the industry or on the farm. They can buy the equipment themselves instead of sending the samples to a laboratory," says Karki.

The plan is also to be able to make the measurements fast enough so that the instruments can be placed on a production line and check each individual product while it is on its way through the factory.

"If we achieve a certain level of automation, this can also be integrated into robots for industrial use," says Mehmet Can Erdem.

Prototype this year

Once he has figured out exactly what kind of light and what kind of optics are best for each measurement, it is also possible to combine several measurements in one place. "Proteins, fatty acids and carbohydrates all need a variety of light sources. But we can imagine a general-purpose machine that measures a number of different components simultaneously. What determines what is measured is what the user needs," says Boris Zimmermann.

During the year, the intention is to have a prototype in operation with different settings intended to measure different substances, such as milk from Tine and protein products from Bioco. "Since this is a completely new type of instrument, it's hard to say how well it will deliver. We have to test on different samples and correct mistakes," he said.

"DigiFoods has major contributions from the industry, and consequently developing commercial products is an important part of this. The project deals with data, sensors and robotics. The three can be used separately, but they can also be integrated and used together," says Zimmermann.

Publication and dissemination

Peer-reviewed publications

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Operators at Bioco monitoring process parameters and raw material flow during the production process.

Photo/cc: Sune Eriksen, Norilia

8. Administration

Key personnel

Postdoctoral researchers with financial support from the Centre budget

Name	Period	Topic
Rowan Romeyn	2023–2026	Hyperspectral imaging for food analysis
Gabriel Lins Tenorio	2024–2027	Synchronized Navigation and Manipulation
Abhaya Pal Singh	2024–2026	Integration of sensors with robotics
Tiril Aurora Lintvedt	2023–2026	Applied Raman spectroscopy
Maren Anna Brandsrud	2025–2026	IR Instrumentation

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.
Mehmet Can Erdem	2023–2027	IR instrumentation
Tiril Aurora Lintvedt	2020–2023	Raman spectroscopy for in-line food quality sensing
Christian Thorjussen	2021–2024	Path modelling in agriculture and food industry
Marco Cattaldo	2021–2024	Data fusion and process optimization/control
Åse Riseng Grendstad	2022–2026	NIR & Consumer studies
Nageshvar Patel*	2022–2023	IR Instrumentation

* Nageshvar Patel terminated his post-doc position at NMBU spring 2023. He will be replaced in 2024.

PhD students with financial support from other sources

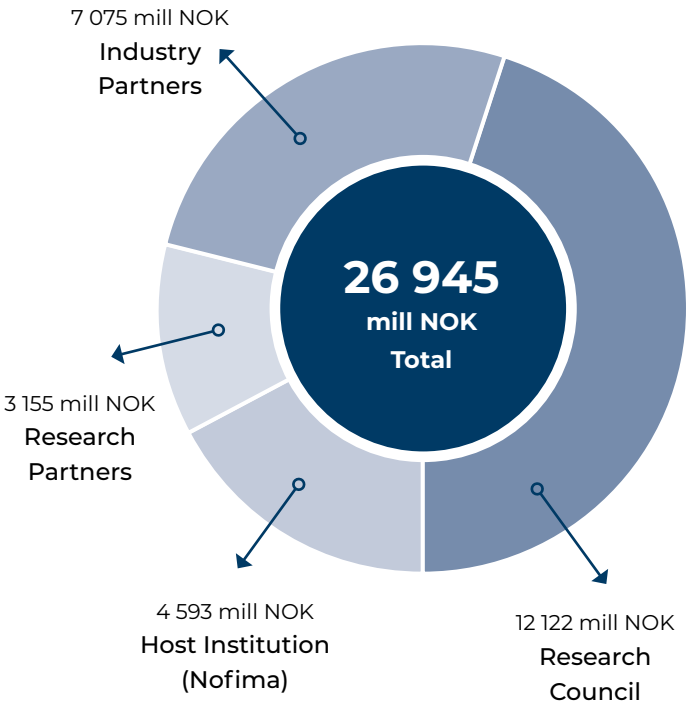
Name	Funding	Period	Topic
Åse Riseng Grendestad	TINE	2022–2026	NIR & Consumer studies

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
Sileshi Gizachew Wubshet	Nofima	1	Analytical 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
Grzegorz Cielniak	Uni. Lincoln	2	Agricultural robotics
Boris Mizaikoff	Uni. Ulm	1	IR spectroscopy
Alberto J. Ferrer-Riquelme	Uni. Valencia	4	Process modelling and control
Boris Mizaikoff	Uni. Ulm	1	IR spectroscopy
Alberto J. Ferrer-Riquelme	Uni. Valencia	4	Process modelling and control

Annual accounts

Funding



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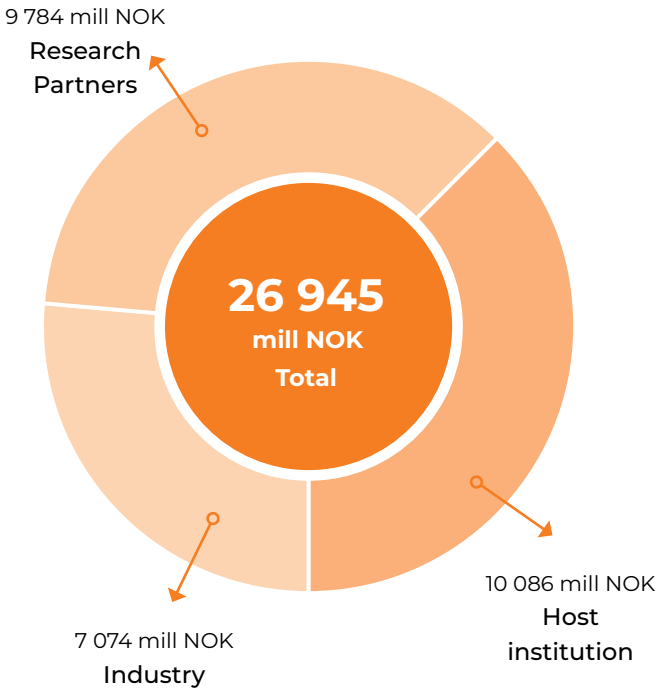

• Photo/cc: Nofima

NIR interaction measurements in potato.

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

Norwegian Centre for Research-based Innovation