Annual Report 2021

SFI Digital Food Quality

DigiFoods

• Photo/cc: Anne-May Johansen/Nofima

Tatiana Ageeva measures texture on salmon with a force meter.

Colophon
Multiple authors (2022).
Annual Report 2021.
SFI Digital Food Quality – DigiFoods.
Ås: Nofima, eds.
Design: Raquel Maia Marques at Vitenparken Campus Ås.

Contents

1. Overall progress and summary for 2021

DigiFoods was kicked off in December 2020 as a Center for Research-based Innovation, funded by The Research Council of Norway (RCN) and the partners. DigiFoods will develop smart sensors for effective food quality assessment directly in the processing lines and in field.

The intention is that massive assessment and digitalization of the essential food qualities throughout the value chains will be used for optimization of processes and value chains and make the food industry more efficient and sustainable. This research is in the very exiting intersection of food technology, sensor development, process control, robotics and data analysis and gives rich opportunities for innovation at different levels. Already after our first year we can see concrete innovation in the making.

In this annual report we present the main work and results achieved in 2021. In addition, we get to know some of the people who are important contributors to the progress of DigiFoods. Brian Marquardt, founder and CEO of MarqMetrix, shares his views on how to create value based on state-of-the-art Raman spectroscopy. We meet Bijay Kafle, a PhD-student from Nepal, who is working to take FTIR spectroscopy closer to in-line use in the food industry. And we get to know post-doc Samuel Ortega Sarmiento who uses his background from hyperspectral imaging in the medical field to develop new methods for quality differentiation of seafood. Finally, we give a status of what the agricultural robot Thorvald did the last year and what he most likely will do in the future.

The year of 2021 was strongly affected by the Covid-19 pandemic which also limited the progress in the centre. An important part of the planned work was to be done in the food processing lines, but the food companies were not accessible for such work most of the year. Communication in the centre was based on Teams, but a digital meeting place is not sufficient to release the potential of a large consortium full of ideas and competence. It was therefore of great value that we managed to arrange a physical annual meeting in November with more than 70 participants. This meeting felt like the real kick-off and it was an important event, inspiring and energizing for all of us. Despite the pandemic, a lot of interesting research has been carried out. Our working plan is structured into ten research projects, spanning topics from sensor and application development to robotics and process analysis. The main activities and results from these projects are presented in this report.

We have established that Raman spectroscopy is suitable for measuring food quality at high speed, for instance the determination of the fatty acids EPA and DHA in whole salmon fillets on a conveyor belt. There is great interest in the aquaculture industry for this application. Hyperspectral imaging in the near-infrared (NIR) does also work well, and two technology partners in the centre are aiming at commercialising this technology. Based on NIR, we can also distinguish so-called mushy halibut (poor quality) from normal blue halibut, and this can become an important application for quality sorting and sustainable capture. FTIR and IR spectroscopy offer some interesting opportunities for detailed chemical characterisation of fat and proteins, and we have started the development of two different and potentially low-cost and portable technologies.

Photo/cc: Stine Thøring Juul-Dam/Nofima

In November 2021 the DigiFoods Consortium met for their first physical annual meeting at Hellerudsletta.

Within robotics we have started to study how an autonomous robot can use sensors to evaluate strawberry quality, as well as how a robot can control a Raman probe in a process line. The integration of robotics and smart sensors is exciting! During the short time slot in October – November with reduced pandemic restrictions, we managed to install and calibrate a NIR instrument at HOFF for in-line monitoring of dry matter in potato strips before frying. This is the first installation of its kind and in 2022 we will study how such measurements can be used to possibly control and improve the process.

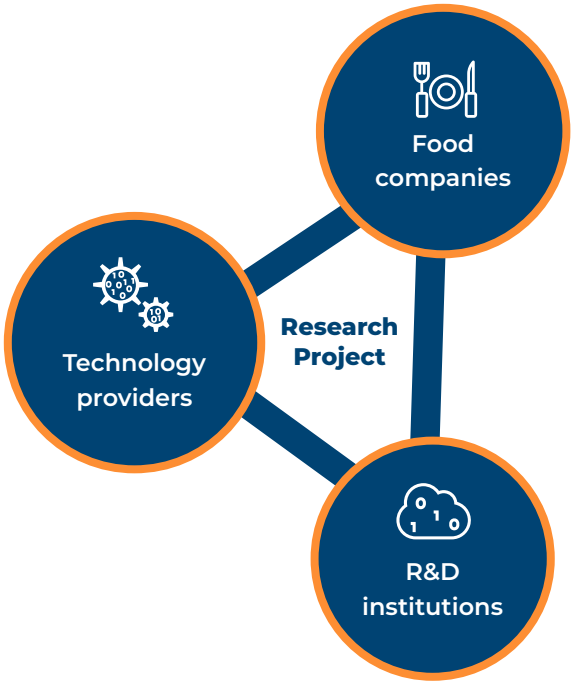
We have got off to a good start with collecting process data from several of the food companies and exploratory analysis of these is underway. The long-term goal is to develop data-driven solutions for process, product, and value chain optimisation. In the coming years it will be important for DigiFoods to collect large scale data from smart sensors in process that will be combined with other process data.

All seven planned PhD-students and post-docs were recruited and operative within September. This was a major milestone for DigiFoods. Our students are well integrated in the different projects and contribute to many of the centre results and dissemination.

We hope that you will enjoy the annual report 2021.

Jens Petter Wold
Centre Director, DigiFoods

"All seven planned PhD-students and post-docs were recruited (...). This was a major milestone for DigiFoods"



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

Article

A technology optimist with respect for nature

by Wenche Aale Hægermark

Senior researcher Jens Petter Wold is the Centre Director of DigiFoods. He has been developing rapid measurement methods based on spectroscopy for more than 20 years. Several of the instruments he has been involved in developing are now in use in the Norwegian and international food industry.

There is a NIR scanner at Hitra that measures the meat content of brown crabs. This instrument makes it possible to sort the crabs so that you get the best possible yield from the raw material and ensure good quality in a demanding market.

"We measured the fat content in meat on a conveyor belt with near-infrared spectroscopy together with SINTEF, TOMRA and Nortura about 10 years ago", says Jens Petter.

This was a success for TOMRA, which has sold these systems worldwide. The fat content has a major impact on the quality and price of the meat and is therefore important to be able to measure and control.

Measurements both on the process line and in the field

So far it is mainly the industry that has benefited from these measurement methods. Developments in precision agriculture and robotics now mean that sensors and spectroscopic measurement methods will find their way to the fields. The robots will perform advanced tasks such as inspecting and harvesting fruit and berries. Then they need to be able to "see" – or measure – the quality of what they are to handle.

On pages 41 and 42 you can read about how researchers at DigiFoods contribute to the work of developing sensors for the agricultural robot Thorvald, so that Thorvald will be able to pick strawberries.

Increasingly detailed measurements

The possibilities for precise measurements have increased in line with digital developments, and this is also reflected in how accurately it is possible to measure. Ten years ago, one could measure, for example, how much fat there was in a raw material. Today you can measure the fatty acid composition.

An important driving force for Jens Petter is to help ensure that as little as possible is wasted, and that as much of the raw materials as possible is eaten.

"A lot of energy is spent on producing and distributing food. We must make sure that everything is eaten. Fighting food waste is very important", says the DigiFoods leader.

Sustainability more important than efficiency

There are many unfortunate examples of how nature and biodiversity has come in second-line.

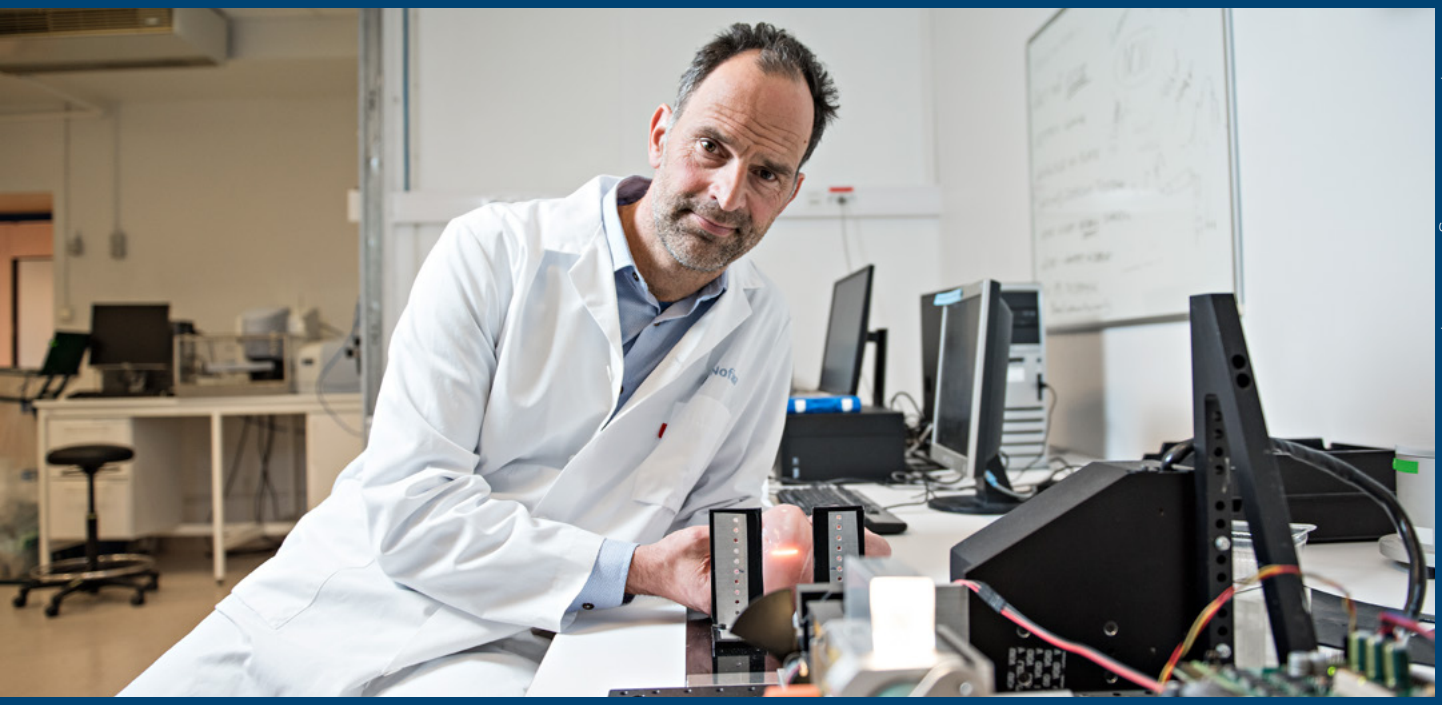
"We do a lot of things wrong. The Oslo Fjord is almost dead. The rainforests are being cut down. The Norwegian wild salmon stock has been halved in just a few years. The strategy of satiating as many people as possible, as cheaply as possible, has failed", Jens Petter points out.

He adds that technology can do a lot, but an understanding of nature must always be the basis. "Technology can make us more sustainable, but it should not be a goal just to be more efficient. We are efficient enough. The technology we develop will enable us to make the best possible use of the raw materials."

Real innovations are the goal

Norwegian companies are strongly represented in DigiFoods. All the food companies are Norwegian, as well as the majority of the technology companies. It gives them the opportunity to be at the forefront of technological development in the field, and to gain insights into the challenges faced by the food industry. Both are important to success.

"My goal is that the work done in DigiFoods materializes in useful instruments deployed in industry and agriculture"



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

Jens Peter Wold uses spectroscopy to control the quality of chicken breasts.

"My goal is that the work done in DigiFoods materializes in useful instruments deployed in industry and agriculture. We will also contribute to increased awareness that such solutions add value", says Jens Petter.

A challenge with developing fast measuring systems is that food raw materials are complex. They often contain many components and the variations can be large. However, it is possible to develop systems that are quite simple and at the same time very useful.

DigiFoods researchers are now in the process of testing measurements of dry matter in potatoes that will be turned into French fries. They envisage that the measurements can be used to control the frying process so that we get consistent quality and zero waste. Perhaps it also has other uses? The researchers will soon hear what opportunities the staff at HOFF see.

"It is really motivating when the magical combination of technology, knowledge, application and needs all meet – and bear fruit. This occurs in the form of solving challenges with the food companies and creating new business based on advanced technology", the Centre Director concludes.

• Video stills/cc: RobotNorge

The companies RobotNorge AS and Byte Motion AS are developing a new way of handling and sorting picked tomatoes. Piccolo tomatoes from tomato producer Wiig handled with robots from ABB, and vision and AI software Ocellus developed by Byte Motion. The project is expected to commence spring 2022.

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.

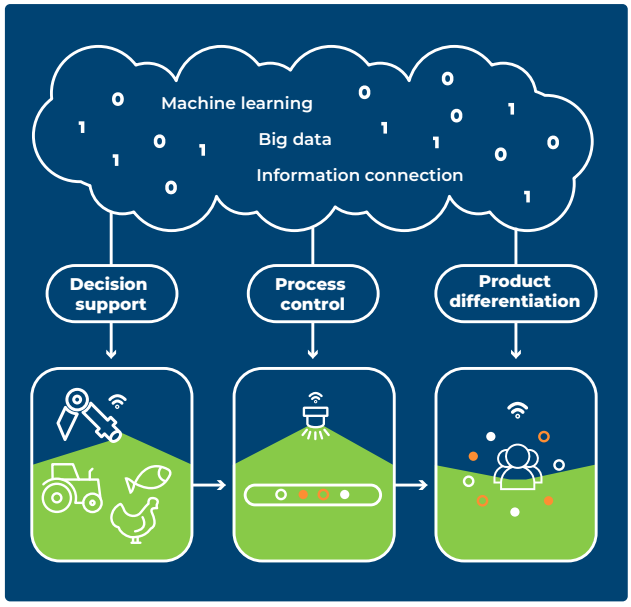
The **Primary objective** of DigiFoods is to develop digital solutions for food quality assessment as cutting-edge technological basis for optimal food value chains.

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 ndustry, technology and research
7. Disseminate knowledge to the industrial sector, the research community, and to the general public

DigiFoods will radically 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.

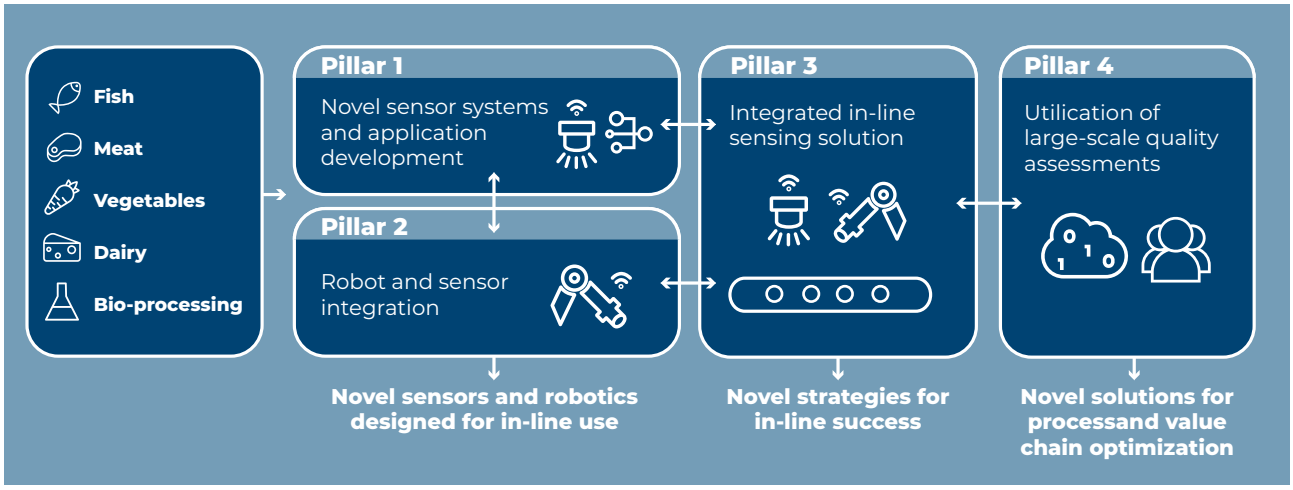
2. Research plan and strategy

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

The innovations in DigiFoods will be accomplished by combining basic and applied research. A major difference from traditional research in this area lies in the scientific method; prototypes will be tested at the end-users at an early stage, as part of the technology development. This includes large-scale trials in fields, onboard fishing boats and in industrial food process lines, and secures relevance and industry involvement from year one. 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 might over time progress from one pillar into another.

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

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



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

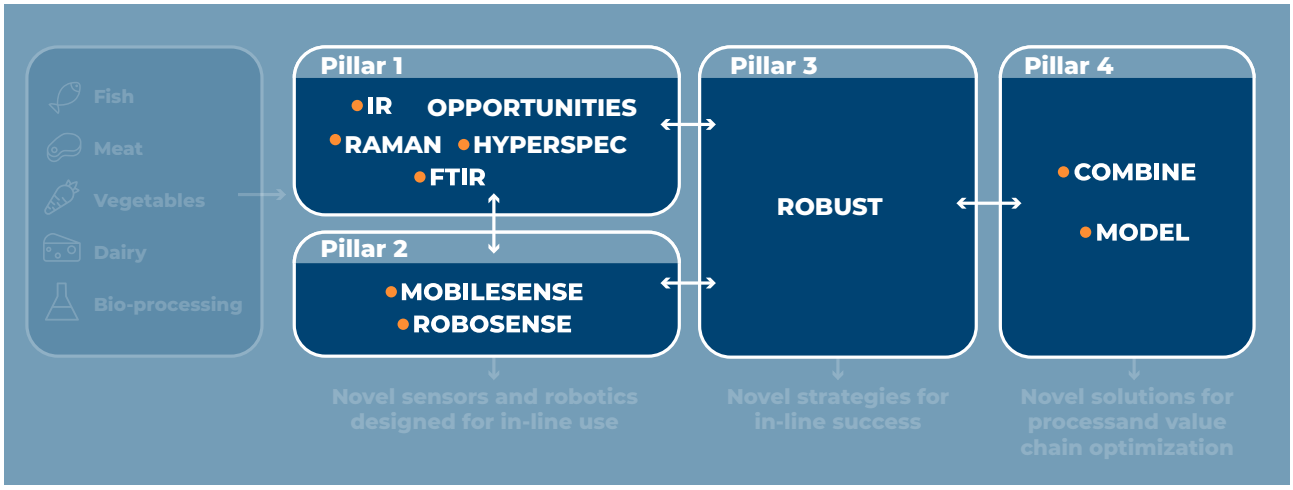
"The research activities are organized in four pillars, and involves value chains for fish, meat, vegetables, dairy and bio-processing"

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

In 2021 we started up ten research projects, which together are addressing the research that was proposed in the SFI application. The projects address the outlined goals and envisioned innovations, targeting gaps in knowledge and technology. All partners have been 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.

A Scientific Advisory Board (SAB) has been appointed for DigiFoods, consisting of researchers with competencies in the fields of research in the centre. An important task of the SAB is to advice during development of the annual plans.



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

- For all projects except "Opportunities" and "Robust", PhD or postdoc students will be affiliated.

Article

Quality assessment using hyperspectral light:

Promising results in new areas

by Anne-May Johansen

In his postdoctoral project, Samuel Ortega has achieved better estimates regarding the shelf life of cod, and the possibility of detecting the early stages of a syndrome that produces jelly-like and flaccid muscle in Greenland halibut. All using hyperspectral imaging.

New areas for the quality analysis of seafood using spectroscopy are constantly being uncovered in the Centre for Research-based Innovation (SFI) DigiFoods at Nofima.

"The preliminary results achieved in the DigiFoods project are promising, and suggest an improvement in the shelf life estimation of cod fillets", says Nofima's postdoctoral researcher Samuel Ortega, who happily adds:

"For the seafood industry, determining shelf life may lead to a more precise quality grading of the products."

Ortega defended his PhD at the University of Las Palmas de Gran Canaria in 2021. The PhD project titled 'Automatic classification of histological hyperspectral images: algorithms and instrumentation' dealt with the use of hyperspectral imaging for the analysis of medical data. His experience using hyperspectral imaging includes the use of instrumentation, experimental design and data analysis.

The scientist was recently awarded the 'PhD Extraordinary Award' in Engineering from his former university. He started as a postdoctoral researcher at Nofima in May, and the results are already looking good.

Less than a day's margin of error

In accordance with the goals of the Hyperspec sub-project in SFI DigiFoods and in his first year as a postdoctoral researcher at Nofima, Samuel Ortega has been focused on studying new potential ways of using hyperspectral imaging, which may be of great interest to the seafood industry. So far, he has concentrated on estimating the shelf life of cod, and identifying 'mushy halibut syndrome' – sometimes called 'jellyfish' by fishermen.

When analysing the shelf life of cod fillets, regression models – a quantitative analysis of relationships between a dependent variable and one or more independent variables – are applied to hyperspectral data from both whole fish and fillets of cod. The goal is to be able to estimate shelf life as accurately as possible.

"The reference values regarding shelf life were provided by a sensory panel, which has expertise in the smell, taste and texture of food. The actual analysis takes place using hyperspectral imaging", explains the scientist.

Previous studies conducted by Nofima suggested a shelf life estimation that had a margin of error of 1.6 days in cod fillets. Using the new method, this has been improved to a margin of error that is less than one day.

The estimate of shelf life in whole fish has not been evaluated before. It can now be done with a margin of error of 1.5 days.

Detecting mushy halibut

Mushy Greenland halibut that has a jelly-like consistency is a challenge for the industry that processes this species of fish. This challenge is also part of Samuel Ortega's postdoctoral project. He is now working to find out the extent to which hyperspectral imaging can detect Mushy Halibut Syndrome before the fish are processed.

"The Mushy Halibut Syndrome causes the muscles of the fish to turn jelly-like and flaccid, generally resulting in poor-quality flesh. Seafood producers risk receiving

In his postdoctoral project in Nofima Samuel Ortega is receiving promising results in new areas of using hyperspectral imaging in quality assessment on food.

Mushy Greenland halibut that has a jelly-like consistency is a challenge for the industry that processes this species of fish. Samuel Ortega is working to find out the extent to which hyperspectral imaging can detect Mushy Halibut Syndrome before the fish are processed.

Photos/cc: NOFIMA

complaints from customers if they deliver fish that have this syndrome. For this reason, it will be attractive for the industry to possess new technologies for early detection of this condition", the scientist points out.

So far in the project, more than 60 Greenland halibut – both normal halibut and 'mushy halibut' – have been examined using Maritech Eye instrumentation at Nofima.

"Different machine learning algorithms were applied to the spectral data with the goal of identifying Mushy Halibut Syndrome. Preliminary results indicate that early identification of normal halibut and those suffering from this syndrome is possible by utilising the spectral information of the samples", Samuel Ortega states.

He still has more than two years left of his postdoctoral project and expects to progress significantly with the two projects he is working on, and also find other new areas where spectroscopic measurements can be utilised in an industrial context.

Light and tissue

Improving understanding of the interaction between light and tissue is one of the main goals.

"Understanding how light interacts with tissue can lead to improvements in the mathematical models that are used to extract the optical properties from the samples, which could potentially show the connection with their chemical composition", the scientist explains.

Another goal of the Hyperspec project is the combination of magnetic resonance imaging (MRI) with hyperspectral imaging in order to utilise the combination of both technologies.

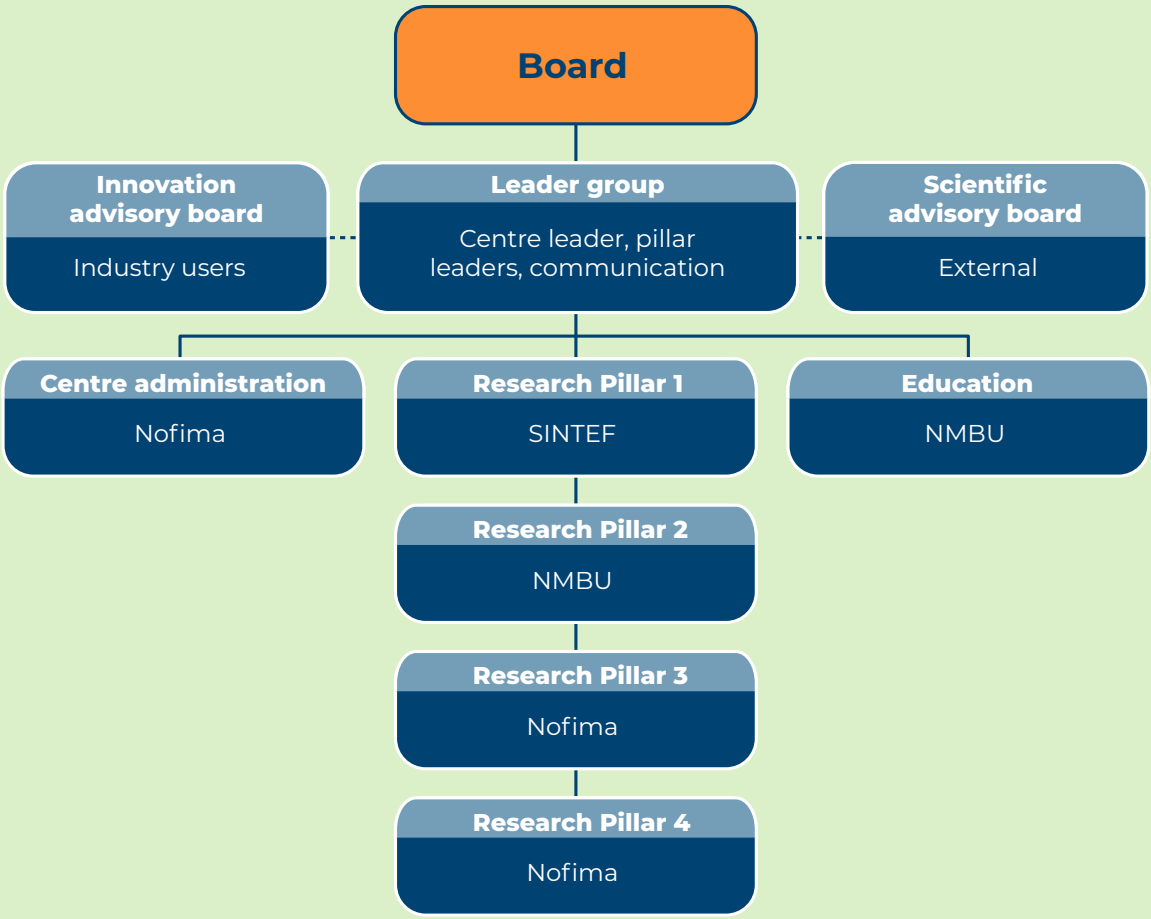
"We do this to improve modelling and further study the applicability of hyperspectral imaging for food quality assessment", says Samuel Ortega.

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 Nofima, NMBU and SINTEF have successfully worked together with industry and research partners, independent of their locations.

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 2021, the Board met for one digital and one physical meeting following the Annual meeting in November. The Board consists of the following elected members (see next page).



Chairperson of the DigiFoods Board

Anne-Cathrine Whist, TINE

Board Member

Anne Cathrine Gjærde, NMBU

Board Member and representing the host institution

Eva Veiseth-Kent, Nofima

Board Member

Ingvild Dalen
Lerøy Norway Seafoods

Board Member

Mari-Ann Akerjord, Prediktor

Board Member

Mats Carlin, SINTEF

Board Member

Odd Arne Kristengård, Maritech

The DigiFoods Board.

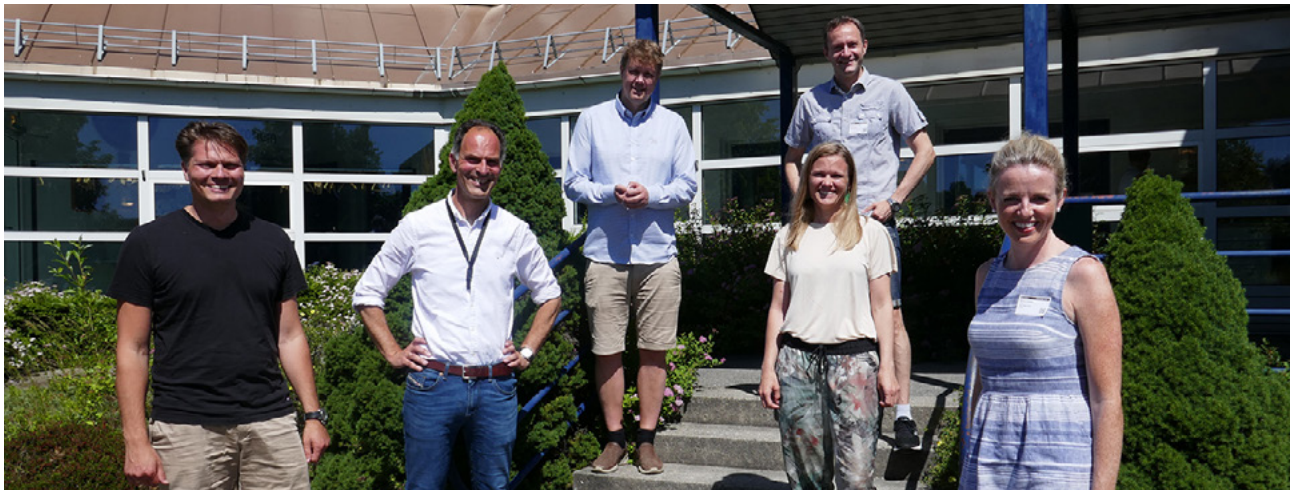
In addition, Mona Gravningen Rygh, the contact person for DigiFoods at the Research Council of Norway, will be an observer at the Board meetings.

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: Wenche Aale Hægermark, Nofima

The Centre Director and Pillar Leaders, from left Pål Johan From, Jens Petter Wold, Nils Kristian Afseth, Kristian Liland, Ingrid Måge og Marion O'Farrel.

The leader group consists of:

- Jens Petter Wold (Nofima) – Center Director, overall scientific and administrative leader
- Marion O'Farrel (SINTEF) – Scientific Manager of Pillar 1
- Pål Johan From (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

An external Scientific Advisory Board is appointed and will annually review results and research plans and participate at the annual centre meetings to assist in ensuring scientific quality and industrial and societal relevance. The members are:

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

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

The members are:

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

DigiFoods will be 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 will be involved in the planning of experiments, execution and discussion of results. Research will be conducted in the end-user process lines and require 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), and thematic or project level (as required). In addition to physical and digital meetings, DigiFoods has an internal SharePoint site with a news feed where centre participants can post e.g. news, links to documents, research plans, results, pictures and videos. In addition to a formal news channel, the SharePoint will also act as a social media, thus contributing to build the DigiFoods team spirit.

• Photos/cc: Anne-May Johansen/Nofima

Engineer Amanda Karlsen prepares salmon samples for tear tests to measure texture.

Partners Research partners

Nofima is one of Europe's largest institutes for applied research within the fields of fisheries, aquaculture 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 foot prints. 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, Pillar 3 Lead Dr. Nils Kristian Afseth, Pillar 4 Lead Dr. Ingrid Måge, Dr. Karsten Heia, Dr. Lars Erik Solberg and Dr. Paula Varela. A group of about 16 scientists and technicians will also take part in the research.

University of Lincoln has established an international reputation for the quality of its research and teaching. Two of the University's leading research centres will participate in DigiFoods, namely the Lincoln Centre for Autonomous Systems Research (L-CAS) and the Lincoln Institute for Agri-food Technology (LIAT). L-CAS specialises 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 will be Dr. Grzegorz Cielniak.

Ulm University (UULM) is among the leading 'golden age' universities ranked #3 in Germany, and #18 in the world (Times Higher Education Ranking). The Institute of Analytical and Bioanalytical Chemistry (IABC) operates the Elemental Analysis Center and the Focused Ion Beam Center UULM for Micro/Nano Fabrication/ Characterization. IABC provides ample laboratory infrastructure (1,000+ m2), and operates analytical instrumentation including FTIR. IABC has been leading several national and international projects specifically for developing advanced vibrational spectroscopic sensing concepts for industrial, medical, environmental, and food safety applications. In DigiFoods, we will provide our 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 will develop miniaturized mid-infrared sensing platforms based on thin-film semiconductoran d diamond waveguides for analyzing relevant food constituents and pathogens. We anticipate that this collaborative effort will result in the submission of join publications and the development of furthe collaborative research projects. Our keypersonnel contributing in DigiFoods will be Professor Boris Mizaikoff.

NMBU's mission is to contribute to the well-being of the planet. Our interdisciplinary research and study programmes 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 will contributes with the development and application of novel handheld and portable infrared devices for quality measurements of food. The Robotics group will contribute with competence in robotics, in particular agricultural robotics, and will develop robots for automation in food processing and sampling. The Biospec group and the Robotics group collaborate on combination Infrared sensors and robotics. The two research groups have employed one PhD student who will work on novel infrared sensors for food quality measurements and one post-doctoral fellow who has worked on robotics within the projects Robosense and Mobilesense. Associate Professor Kristian Hovde Liland from the department of Data Science 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 that are designed for measurement in the industrial process and adapting existing scientific instrumentation to industrial sites for process characterisation measurements. SINTEF will work closely with the PhD students in Digifoods so that they have a greater understanding of the theory behind the sensor prototypes, and make modifications as required. Our key personnel contributing in DigiFoods will be Pillar 1 Lead Marion O'Farrell, Senior Researchers Jon Tschudi, Kari Anne Hestnes Bakke and Trine Kirkhus, and Researchers Anders Hansen and Tim Dunker.

The Universitat Politècnica de València (UPV) is the only Technical University in Spain in the top 500 world's most prestigious universities based on the Academic Ranking of World Universities 2018. It is particularly relevant in the areas of Engineering and Sciences and a national leader in patent license income and start-up creation. The Multivariate Statistical Engineering Research group was established with the aim of offering the scientific community and the business & technological enterprises a working environment in which to develop research, development and innovation (RDI) in the area of multivariate statistical techniques for quality & productivity improvement. The group is active in Data Analytics, Six Sigma, Process Analytical Technology (PAT), Multivariate Image Analysis (MIA), Process Chemometrics and Statistical Methods for Knowledge Discovery. Our experience working with industry and research-based innovation can be very valuablefor Digifoods. On the other hand, getting involved in DigiFoods will provide us an excellent opportunity to be exposed to the needs of the high-tech food industry opening new research lines to get involved. UPV will provide joint supervision of at least one PhD student on data analytics and real-time process control & optimization. Our key personnel contributing in DigiFoods will be 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 specialised 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 tomake 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. We are organized as a cooperative, owned by 17 700 Norwegian farmers that supply raw material to our customers and factories. Nortura slaughters, cuts, refines and develops meat and egg products that are sold to food-services, retailers 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 30 research projects. In DigiFoods we will concentrate our work on our poultry 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 even better products in the future. Our key personnel contributing in DigiFoods will be Research Director Per Berg and Development Director Atle Løvland.

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 senor 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 hydrolysis 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 Norwegian biorefinery we turn food-grade fresh salmon raw materials into premium feed and food-grade ingredients. Sophisticated biorefining 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 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.

Lerøy Norway Seafoods is Lerøy's quality brand for sustainable whitefish 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 worldwide. 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.

Sensor & Robotic

Prediktor Instruments develops and delivers advanced sensors and associated software for industrial applications. Our instruments are based on Near Infrared spectroscopy and designed for in-line mounting for the purposes of continuous monitoring, process control and optimization. Important customer segments are food, feed and dairy industries, with common needs for controlling their processes, minimize the expenses and achieve optimal product quality. In DigiFoods, Prediktor will actively take part in the research activities, and we will also contribute with relevant equipment (sensors) for the field trials. We foresee that being part of a long-term research center together with the research organizations, food companies and other technology providers will be of great value for our business development in general; through networking, increased understanding of the customers' needs and challenges, and opportunities for collaborations and sharing of experiences with a wide range of technology suppliers. Our key personnel contributing in DigiFoods are CPO Mari-Ann Akerjord, CSO Terje Karstang and CSO Dag Martin Romslo.

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 the SFI 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 spectros copic 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. Our key personnel contributing in DigiFoods will be Executive Chairman Atle Rettedal and Chief Software Developer Tommy Jonsson.

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

MarqMetrix offers a simple, stable and powerful Raman spectroscopy platform built for field and process applications at a performance leve 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 knowledge and experience in the DigiFoods partner network and see this as a good basis and opportunity to discuss innovation ideas.
We will also offer an autonomous robot for field trials with sensors. Saga will work on integrating sensor systems on field robots and to test these in the field.
Our key person contributing in DigiFoods will be CCO Ellen Altenborg, CTO Lars Grimstad and CEO Pål Johan From.

OptoPrecision GmbH 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 OptoPrecison 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 build in 2021 and will be tested together with coworkers from the NMBU and UUlm team in March 2022. 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. He is the head of our analytics department.

Digital platforms, software and analytics

CAMO/AspenTech is a leader in industrial analytics and the preferred partner for industry leaders digitizing their value chain. With a world class industrial analytics platform, we help companies optimize their processes, drive better product quality and efficiency through innovative analytical solutions. Founded in 1984 by Norwegian scientists, Camo has applied analytical science to process and product quality problems for decades. 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 as part of our goal of bringing insights from science-based industrial analytics into daily operations, the food industry has been an important market for us for many years. 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 food industry. Our key personnel contributing in DigiFoods will be Geir Rune Flåten, Leslie Euceda Wood and Lars Gidskehaug. Camo was acquired by Aspen Technology, Inc. in November 2020.

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 feedback 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.

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 large scale 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 Systems AS is the world-leading provider of seafood-specific software and analytics solutions. Today, we have a Norwegian market share of 80% of the traders, 50% of processing fisheries, and 80% of food fish - 70% of all fish exports from Norway are traded through Maritech software. Currently, we are lifting our customers from on-premise solutions to our cloud platform DigitalSeafood™, while expanding globally, building our Maritech Data Platform, and developing new process support tools tailored for the seafood value chain.
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. Our key personnel contributing in DigiFoods are CEO Odd Arne Kristengård, VP Data Science Oddvar Husby, VP Technical Solutions Per Alfred Nordaune Holte and Director IoT Andre Lillebakk.

CGI was founded in 1976 and is among the largest IT and business consulting services firms in the world. Operating in hundreds of locations across the globe, CGI delivers an end-to-end portfolio of capabilities, from strategic IT and business consulting to systems integration, managed IT and business process services and intellectual property solutions. CGI contributes to the design and development of physical solutions for both the agri- and aquacultural domain in close collaboration with our customers and has a business strategy focusing on FoodTech. The focus has been on business concepts and solutions for securing sustainable food production and animal welfare, e.g. by using computer vision to capture and analyse animal behaviour. CGI is an ambitious company that wants to drive innovation through emerging technologies and new business ideas. Through the DigiFoods partnership we intend to engage in both physical product design and prototyping, as well as IT/software solutions enabling us to put research into action through new innovations.

Intelecy is a no-code AI platform for the process and manufacturing industry. The only AI software designed for the industry knowledge worker, engineers and operator to create sophisticated AI algorithms on their own. Food processing is an extremely complex and challenging industry to monitor and measure production quality due to the inherently high biological variation in raw materials. Raw materials are usually examined via lab samples to provide answers about content and quality which is a time-consuming process where results are only available several hours after production. In the DigiFoods project, the engineers used Intelecy to analyze this data and provide predictions that make it possible to adjust the process so that quality and efficiency are maintained regardless of the variation in the raw material. For Intelecy, DigiFoods is a place to learn and share knowledge with a larger community and be able to test how well machine learning algorithms will perform against more traditional approaches. Our key personnel contributing in DigiFoods will be COO Espen Davidsen and CEO Bertil Helseth.

Article

MarqMetrix – The RAMAN experts

by Wenche Aale Hægermark

DigiFoods' scientists use Raman spectroscopy to measure fatty acid and protein composition. MarqMetrix develops and supplies process Raman systems that are used for DigiFoods current Raman applications and will be used for new applications developed in the future.

MarqMetrix Founder and CEO, Brian Marquardt PhD, says "The goal for our DigiFoods participation is to develop systems that make it easier for food companies to map and control the quality of the food components, and hence be able to differentiate from their competitors".

Brian leads his Seattle based team with over 20 years of experience in the Raman industry and a Ph.D. in analytical chemistry. The application of optical analysis to determine chemical composition, quality assurance and process control has been Brian's technical and career focus.

Long-term cooperation

The majority of MarqMetrix Raman systems find their way to companies in the pharmaceutical, biopharmaceutical and oil and gas industries. Though, the food industry remains a target market for Raman hardware.

Raman spectroscopy has been used in food science laboratories to solve small, specific problems for a long time. However, recent technological developments have created new, broadened opportunities to utilize Raman spectroscopy for inline measurements in the food industry.

Photo/cc: Michael Curtis / MarqMetrix Inc.

Brian Marquardt Ph.D., MarqMetrix CEO, demonstrating the use of the All-in-One process Raman system to measure a wine sample.

Immersion Raman analysis of a wine sample using the TouchRaman® BallProbe®.

"In DigiFoods (...) we get an opportunity to work with experts in the food industry. It is nice to work with people who know which challenges that need to be solved"

Brian Marquardt and DigiFoods leader, Jens Petter Wold first met 20 years ago. They quickly developed a mutual interest for rapid measurement systems, leading to continuous cooperation and collaboration. This ongoing collaboration included Jens Petter working with Brian for a year at the Center for Process Analysis and Control (CPAC) at the University of Washington, while Brian spent several months working at Nofima in Norway.

Brian remarks, "During the years we have collaborated, the number of application possibilities and synergies have grown. For example, we can now perform Raman measurements that scan larger volumes of the food products directly and inline for improved accuracy and quality assurance".

These larger volume optics are already in use at DigiFoods, with even more sophisticated probes currently in development. Scientists at Nofima are currently developing applications to measure both fatty acid composition in salmon and protein composition in rest raw materials from poultry.

Combining people with needs, to people with solutions

Brian explains, "One great advantage with DigiFoods is the breadth of the people participating. This center of research-based innovation connects people that all will benefit from the collaboration. We get an opportunity to work with experts in the food industry. It is nice to work with people who know which challenges that need to be solved".

DigiFoods partners believes the key to innovational success involves close collaboration between:

1. Experts from the food industry, with a clear view of what they need to make their products better
2. Technology partners who are able to deliver solutions
3. Scientists who build prototype sensors and make calibrations based on data processing and the raw material knowledge

Making Raman more accessible

Raman spectroscopy offers the possibility to make fast, stable, non-destructive measurements of a product's chemistry, without removing that product from the production line. Detailed information like this serves several purposes. Food companies can use it to control the quality in different parts of the value chain, allowing them to differentiate their products from competitors. Furthermore, consumers benefit from reliable and accurate information about the products they purchase.

An important goal for MarqMetrix is to develop self-optimizing Raman systems for use in the food industry. Brian believes this is necessary if the food industry should take the next step into Industry 4.0.

He says, "We are working with techniques that should be easy to use even for non-experts. The industry must be able to use the systems purposely, without depending on scientists with years of experience. Otherwise, just a few big companies will be able to take advantages of the technology, and I would like everyone to have this opportunity."

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 2021 we focussed on the development of online applications using hyperspectral imaging, FTIR, Raman and IR, with involvement from technology providers such as Maritech, NEO, MarqMetrix, Prediktor, and nanoplus.

The main challenges in 2021 was again related to Covid-19 as it hindered site visits and effective work in the lab, where researchers could work together interactively, discussing ideas and ways forward while working on their set-ups or experiments. However, we made the best of the situation and managed to make good progress on our prototypes and the testing of these prototypes.

Another activity in Pillar 1 is the exploration of new opportunities. In 2021, this included activities such as workshops, proof-of-concepts, and conference attendance.

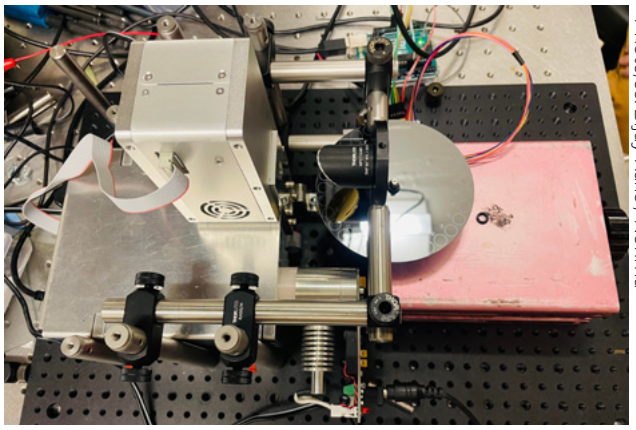
Pillar 1 is led by Marion O'Farrell at SINTEF Digital. Key end-user industrial partners in this Pillar include Lerøy Aurora, Lerøy Norway Seafoods, Lerøy Havfisk, Nortura, Norilia, Biomega and TINE.

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 contents, but also protein qualities, like for instance protein structure, peptide size distributions, 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 aspect of this research project is to develop a portable FTIR system for dry-film measurements that can be brought close to industrial process lines, enabling industrially relevant measurements. This will be a technological solution currently not commercially available. In 2021, SINTEF in collaboration with the PhD student, Bijay Kafle, have worked on developing this instrumentation, making an optical design for the first version of such an FTIR system. At the end of 2021, the optical design was finished, and the remaining work is to finish the software for running the instrument, and not least finishing and sealing the instrument. The instrument is expected to be ready for testing spring 2022. The performance of the instrument will first be evaluated at Nofima, and then in industrial environments.

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



Photo/cc: Bijay Kafle / Nofima

Optical setup of the FTIR prototype being built at SINTEF.

Photo/cc: Bijay Kafle / Nofima

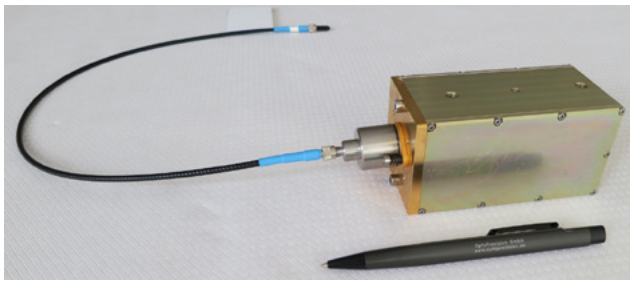
Manual sampling of protein hydrolysate at the Biomega factory.

Application development is the other important aspect of the project, and in 2021, two different applications have been in focus: protein hydrolysates and milk. We have previously shown that FTIR can be used to predict the average protein sizes of protein hydrolysates produced in the laboratory. In 2021, a range of protein hydrolysates have been sampled from industry processes, both poultry hydrolysates and salmon hydrolysates. All samples have been subjected to chemical and spectroscopic analysis in Nofima, and we have shown for the first time the applicability of FTIR to predict average molecular weights of industrial protein hydrolysates. We have also worked on the optical sampling by comparing liquid analysis of the protein hydrolysates using Attenuated Total Reflection (ATR) – FTIR and dry-film FTIR. These results show that for salmon hydrolysates, results are similar when comparing ATR and dry-film analysis. For poultry hydrolysates, on the other hand, dry-film analysis works significantly better.

This could be related to the increased complexity of protein composition in poultry hydrolysates compared to salmon hydrolysates. In addition, ATR will also be more sensitive to fluctuations in protein concentrations. Currently, a manuscript is being written based on these results. The next step in the project will be the evaluation of the prototype FTIR system for measurements of protein hydrolysates and milk.

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

“In 2021, OptoPrecision GmbH started to build a universal infrared measuring device for DigiFoods”



Photo/cc: Markus Nägele / OptoPrecision

Laser head with a MIR laser (quantum-cascade laser from nanoplus GmbH) and fiber coupling.

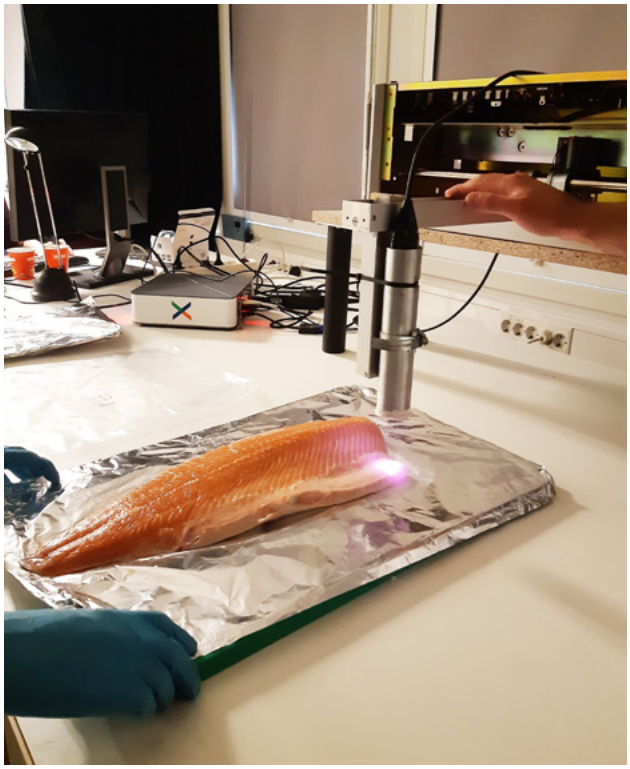
Handheld and portable IR

In this project, new infrared solutions for quality measurements of foods will be provided. In 2021, OptoPrecision GmbH started to build a universal infrared measuring device for DigiFoods. A sample can be successively illuminated with up to 7 lasers provided by nanoplus with wavelengths in the range of 3 µm to 12 µm and the backscatter or transmission can be measured with a correspondingly sensitive MCT detector.

The method provides spectral data similar to an FTIR instrument, with the higher photon density of the lasers providing faster measurements and data with higher signal-to-noise ratio. Only the seven spectral measurement positions have to be selected to fit the application, since no broadband spectrum can be measured. These measurements are made in the millisecond range, so that a fast sample analysis is possible. The basic instrument is currently being set up. All components, especially the electronic circuits and the software of the device were developed inhouse during a previous project and are now being adapted specifically for DigiFoods. The first test measurements are planned for March 2022 at the University of Ulm, a partner within DigiFoods. The devices will be made available to the DigiFoods partners for testing on food matrices such as salmon, milk and other applications. To illustrate the hardware components a laser head containing all electronics is shown in the picture to the attached picture. The final laboratory device with the integrated lasers, the detection unit and the fiber-optic coupling to the measuring unit is currently under construction.

In parallel, NMBU, nanoplus and University of Ulm have worked on designing a handheld device based on a LED infrared light source. Nanoplus has provided two LED light sources, one around 3 µm (lipid region) and a second around 6 µm (protein region), which are currently adapted to an evaluation board using a linear variable filter for infrared spectroscopy. We expect the device to be ready for testing with food matrices within 2022.

NMBU has in addition started to adapt data analysis approaches for pre-processing and calibration to the new devices and light sources. When using seven separate laser wavelengths or infrared LEDs covering only parts of the infrared region of the electromagnetic spectrum, new approaches for pre-processing and variable selection are needed. The best pre-processing for data sets with seven wavelengths was achieved when a laser at 1800 cm-1 was used for baseline correction and another laser at 880 cm-1 for normalization. For some data sets, the multiplicative signal correction (MSC) method was also a good method for pre-processing sparse laser data.



Photo/cc: Antonio Candea Leite / NMBU

Scanning of salmon fillet by Raman spectroscopy.

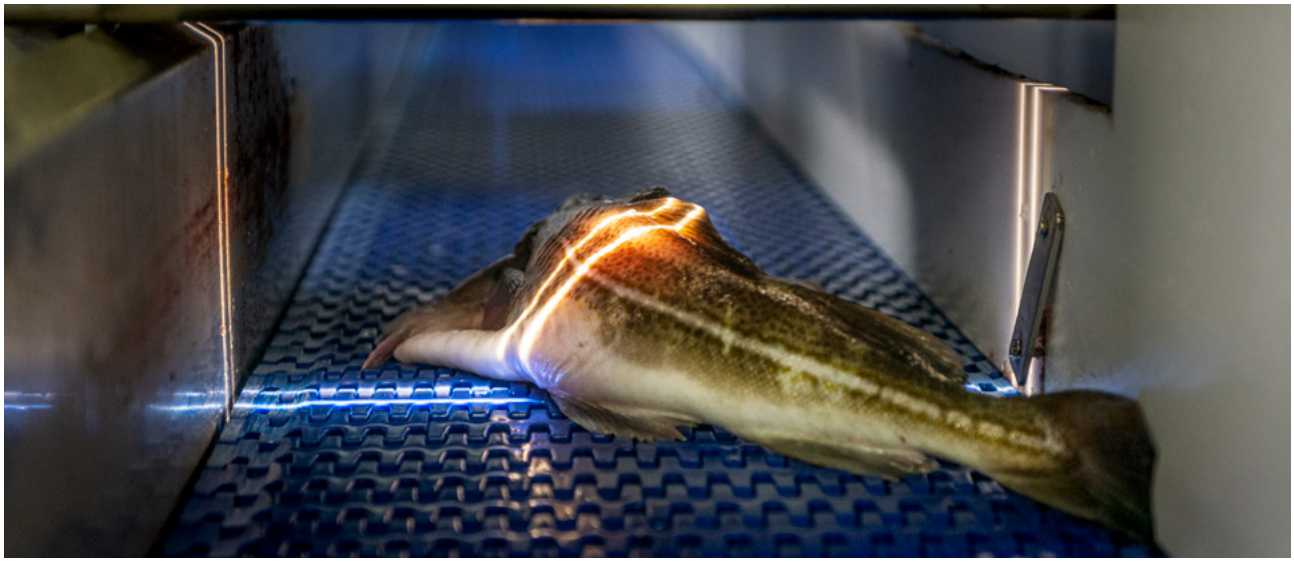
"In 2021 we evaluated Raman for rapid and non-destructive measurement of fatty acid features (EPA+DHA)"

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 2021 we evaluated Raman for rapid and non-destructive measurement of fatty acid features (EPA+DHA) in ground salmon and residual bone fractions in mechanically recovered poultry meat. The samples were measured with a MarqMetrix Raman system with a stand-off probe while moving on a conveyor belt. We got very promising results and showed that it is possible to obtain Raman spectra of sufficient quality within 2-10 seconds of exposure. This work is published. We continued by developing the application of in-line determination of EPA+DHA in intact salmon fillets. This is of interest in the salmon industry for quality differentiation, efficient evaluation of feeding regimes, as well as for studies within breeding and genetics. Rapid quantification of fatty acids is a target also in other food industries. By using a set of 51 fillets for calibration and 20 independent fillets for testing we have shown that it is possible to determine EPA+DHA with an excellent accuracy (R2=0.96). Such accuracy is obtained based on Raman scans of only two seconds, indicating that in-line use is feasible. It is important to do the Raman measurements along the belly where the fat contributes to strong Raman signals. This experiment was coordinated with HYPERSPEC where the same samples were measured with high-speed hyperspectral NIR imaging. PhD student Tiril Aurora Lintvedt will publish a very interesting article, where these two methods are compared in terms of accuracy and practical use. The work has been a collaboration between MarqMetrix, AspenTech, Norilia, Lerøy Aurora and Nofima.

This application of Raman and fatty acids in salmon fillets will be adopted by the project ROBOSENSE where we in 2022 will study how high-speed scanning and robotic control of the Raman probe can enable quality monitoring of samples such as fish fillets and meat.



Photo/cc: ySpex/Norsk Elektro Optikk

Commercial solution (Maritech Eye) based on hyperspectral imaging for quality assessment of whitefish before processing the fish into products. Solutions are also developed for redfish fillets and within the DigiFoods project the potential for including new quality attributes to the solution is investigated.

HYPERSPEC

As Maritech and NEO are active partners in DigiFoods most activities are focused on developing and testing solutions based on the Maritech Eye and the hyperspectral cameras from NEO. Three specific applications have been addressed in 2021, “Fatty acid composition in salmon fillets”, “Identification of Mushy halibut syndrome in blue halibut” and “Estimation of cod shelf life”.

Complementary to Raman, a hyperspectral imaging setup was tested to determine EPA+DHA. The fillets were imaged on a conveyer belt running at 40 cm/s with diffuse illumination using the HySpex SWIR-384 camera. As mentioned in the RAMAN part Phd student Tiril Lintvedt will publish an article comparing Raman and hyperspectral imaging for estimating EPA+DHA in 2022.

In recent years, increasing number of cases with “mushy halibut syndrome” (MHS) in halibut has been reported. As there exists no technology for early screening for MHS the applicability of hyperspectral imaging has been studied in two experiments, one based on fresh and the other based on frozen/thawed samples. The results are promising for sorting whole halibut based on MHS, especially measuring on the blind side of the fish. One article has been submitted and a short communication is to be submitted. From the frozen thawed experiment samples has been prepared and shipped to Nofima at Ås as frozen samples. The plan is to measure those samples with another NIR interactance system and compare the performance with hyperspectral images taken using the Maritech Eye.

Quality assessment of fish and fish products involves several quality attributes of high importance. Several of those are related to blood quantification and are already implemented in the Maritech Eye instrumentation. Another important attribute is related to proper chilling of the round fish and products. As of today the whole fish temperature at landing is used as a quality attribute, but scientific results shows that factors as how fast the temperature was lowered and time between catch and delivery are important.
In collaboration with a RCN project, EthiCatch, we have studied how different storage conditions, before landing, impact the shelf life of cod. Based on whole fish measurements by the Maritech Eye the shelf-life of cod can be estimated with a certainty of one and a half day.

Due to corona challenges last year activities on improving the modelling of interactance between light and sample tissue have been postponed till 2022. The activities on soft tissue on halibut will be followed up in an innovation project proposal. Soft tissue in cod will be addressed together with Lerøy Norway Seafoods. Activities on combining Magnetic Resonance Imaging and hyperspectral imaging for improved analysis has been initiated and will continue in 2022.

"This project centres on finding new opportunities and managing new ideas"

OPPORTUNITIES

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

In 2022, we conducted several workshops

- In collaboration with CPACT, the Centre for Process Analytics and Control Technology, we held their first ever food related workshop, called Process Analysis and Control in Food Manufacturing. It was held on 26th of October, with approximately 90 delegates from industry and academia. The webinar comprised invited talks and a discussion panel. In 2022 we hope to hold a follow-on workshop based on the theme "Developing and maintaining robust models for process analysis and control in food manufacturing"

- On the 29th of November, we held a workshop in collaboration with MiNaLab, where SINTEF has its micro and nano research and production facilities. The theme of the workshop included potential technology for microfluidics in dairy and hydrolysis applications, substrate design for Surface Enhanced Raman Spectroscopy and MEMS technology for miniaturised spectroscopic instrumentation, in particular Fabry Perot filters. The SERS work is early-stage research, but SINTEF continues to explore possibilities for this technology in 2022 in an internally funded project, where this can be further discussed with DigiFoods when they have more results. SINTEF is also continuing their work in Fabry Perot filters in a project funded by the European Space Agency. Although not directly applied to the food industry, this work can have direct benefits for other applications, including food and agriculture.

- On the 15th of September 2021, Nofima held a workshop called Sharing data in the value chain, why and how, with 116 participants. The themes discussed at this workshop included how data sharing can lead to more satisfied customers, the vision and system behind IBM's Food Trust and Seafood Trust, and how Maritech plans to use data analysis to change the seafood industry. This was followed by a fruitful discussion where the industry shared their own experiences with data sharing.

- On the 15th of October 2021, NMBU held a workshop called Lipid Spectroscopy, where challenges in fat analysis, previous projects in lipid research and several potential technologies were presented. Examples were presented from several industries and processes, and the advantages and disadvantages of several measurement techniques were discussed.

In addition to the workshops, SINTEF started a proof-of-concept which explored cutting strawberry stems using lasers instead of mechanical shears, as this would require fewer moving parts and less maintenance in agricultural robots for picking fruits. This work was with Saga Robotics and will continue in 2022.

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.

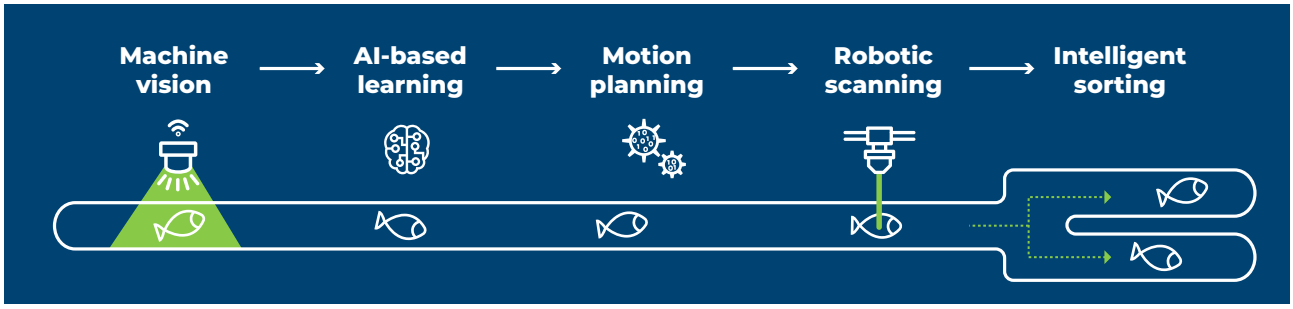
In this pillar, we are looking at how robots can be used to enhance the performance of sensors by accurate positioning of sensors for optimal sample taking and measurements. We are also looking at how sensors can be used to increase the performance of robots and improve decision making and overall performance.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

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

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

ROBOSENSE

In ROBOSENSE we have started to design a robotic system that can control a Raman probe to measure EPA+DHA in salmon fillets on the line. The application is chosen as a good demo case since the Raman probe needs to be optimally placed and moved relative to the fillets for the system to obtain spectra of high quality. This work is done in close collaboration with the project RAMAN. A minimum viable product (MVP) has been designed, including a camera, machine vision, a robotic arm and a Raman system that can be triggered by the robotic system. The aim for 2022 is to build and program this MVP so that it can be demonstrated and be the main case of one of more scientific papers. A major challenge for such a system is to handle the high speed that is required on a commercial production line. The movement path of the probe has to be calculated very quickly based on inputs from the machine vision. The learning from this project will be of generic value and can be transferred to other similar cases with different probes and different food products. NMBU is managing the project and is collaborating closely with Nofima. RobotNorge contributes with valuable hardware and knowledge, MarqMetrix with a specially designed Raman instrument, and Lerøy Aurora with fish and process knowledge.



Main steps in robotically controlled in-line sensing of foods.

"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"

Photo/cc: Jon Are Berg Jacobsen / Nofima

Researcher Anders Hansen, measuring strawberries in the field using a spectrometer.

MOBILESENSE

The purpose of this work is to develop fully autonomous robots for the automatic collection of large-scale quality data in agricultural areas. We will integrate a suite of sensors on the Saga Robotic'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.

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

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, both for the instruments that are already used commercially, but not least 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. Put 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 actually provide the user with reliable quantitative outputs. This was the core research initiated in ROBUST for 2021, but since Covid-19 very effectively hindered site visits and industrial research, the work has been slightly delayed.

In DigiFoods, implemented sensors will also be used to explore and map variation in food processes over time. Many of the sensors proposed in DigiFoods will provide previously unavailable information from food processes. In 2021 we therefore also initiated the project EXPLORE, where we will document and map quality variations along processes and over time with in-line sensors, evaluating the potential for process improvements, real-time process control and product differentiation. This work will start at full pace in 2022.

Pillar 3 is led by Dr. Nils Kristian Afseth at Nofima. For 2021, key partners in this Pillar have included all food partners, NEO, AspenTech, Prediktor, MarqMetrix, Idletechs, SINTEF and NMBU.

ROBUST

A major bottleneck for industrial sensor implementation is to get from the measured signal to reliable estimates of food quality attributes. A robust calibration model needs to handle chemical and physical sample variations as well as harsh and changing surroundings. Spectroscopic sensor technology has many application areas in in-line food quality analysis.

Some applications are well established, and robust calibration models can be purchased from instrument vendors. New or less standardised applications require development of new calibration models, which can be a time consuming and expensive task. Also, it is frequently necessary to maintain models over time for both instrumental, environmental and process reasons.

In 2021, a study of calibration transfer techniques was initiated and will be pursued in 2022. There are many existing approaches, but little documentation on whether and when methods may work better than the alternatives. The focus here has hence been on addressing the circumstances under which methods may be expected to work. The ideas behind our approach were presented at the 17th Scandinavian Symposium on Chemometrics at Aalborg in Denmark, 2021.

"...we are developing and validating efficient solutions and strategies for successful sensor implementation in food production"

Photos/cc: Jens Petter Wold / Nofima

In-line determination of dry matter in potatoes before frying by NIR spectroscopy.

In ROBUST the main aim is to define strategies and methods for efficient and robust calibration and maintenance of in-line spectroscopic instruments.

This will be based on collecting relevant calibration and process data from in-/on-line processes at selected industry partners. Due to Covid-19 restrictions, some of this work has been delayed, but it is well under way at HOFF where two NIR instruments have been mounted on the production line and where the data has provided HOFF with valuable insight already. These data sets will provide valuable test benches for evaluating robustness of model building and maintenance, as well as for input to other projects within DigiFoods such as MODEL and EXPLORE.

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 investigate how the growing focus on food waste may impact food choice with respect to product quality.

In addition to the projects COMBINE and MODEL, Pillar 4 arranged an open webinar on data sharing in 2021, with presentations from IBM, Maritech, Nortura, TINE and Nofima. A new project, CONSUMER, is planned for 2022.

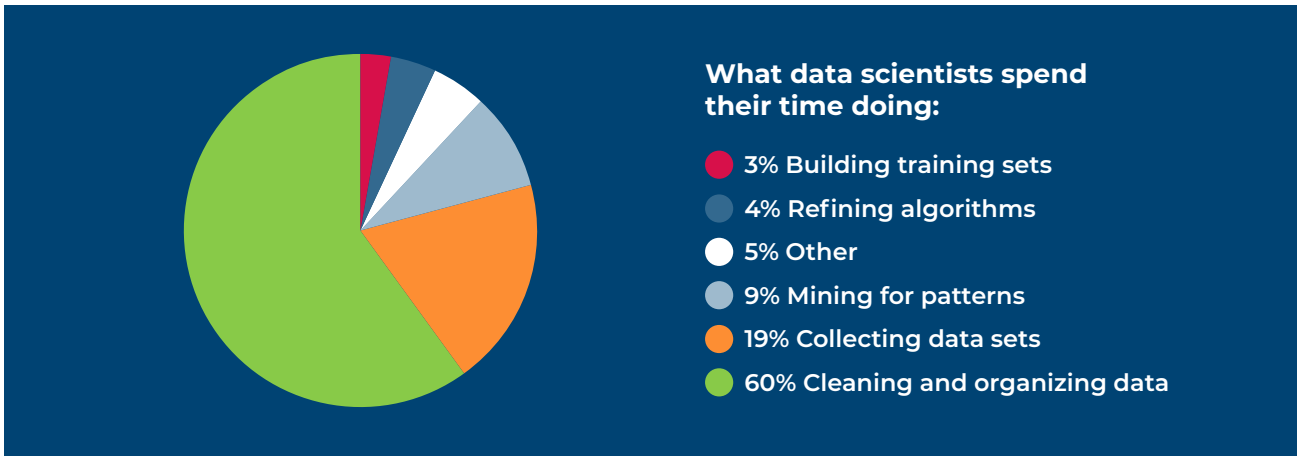
Pillar 4 is led by Ingrid Måge at Nofima. Key partners in 2021 were TINE, Nortura, Bioco, Intelecy, AspenTech, Ideltechs, Maritech, IBM, NMBU and UPV.

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, the objective of COMBINE was to identify the main challenges for combining data in the food industry, review existing tools and solutions, and point out directions for further research and development.

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



What data scientists spend their time doing.

Five challenges were identified based on experiences from the DigiFoods partners:

1. Joining data that is scattered on different platforms
2. Cleaning inline process measurements, including outlier removal and selection of relevant variables and measurement periods
3. Handling multi-granularity, i.e. data sampled at very different resolutions in time
4. Identifying correct time-lag between measurement points
5. Combining data of different types, such as single- and multi-channel sensor data, images, curves or trajectories and categorical variables

Two topics 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. These data sources are of different types and resolution, and are needed to investigate potential causes for variation in cheese quality. The second topic is comparison of statistical/computational methods to identify lags between process measurements. The comparisons are performed by PhD student Marco Cattaldo and will mainly be based on data from the Bioco process. The results are expected to be relevant for several future DigiFoods case studies. Other topics may be addressed later, depending on needs and resources.

MODEL

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

Path models are intended to model causal relationships between sets of factors. In collaboration with Nortura, PhD student Christian Thorjussen has defined a case study on understanding causes for health parameters in broiler chicken, based on data collected from farmers and the slaughterhouse. He is currently reviewing different modelling strategies, particularly methods for representing growth curves and exploiting multilevel data in Structural Equations modelling (SEM). This work will continue in 2022.

The second type of model is intended for real-time monitoring, control, or decision support. In collaboration with Bioco, we have explored variation ranges and correlations between inline NIR and other process variables and identified potential cases for process monitoring and control. These initial results lay the foundation for a new round of data collection in 2022, with the aim of utilizing inline NIR measurements to optimise enzyme dosage and obtain early warning of clogging. PhD student Marco Cattaldo is responsible for these modelling tasks.

• Photo/cc: Kristoffer Skarsgård / Saga Robotics

Thorvald, an autonomous robotic platform in a strawberry field in California. The robot controls powdery mildew through UV-C treatment and is a tool carrier for other applications. Thorvald is designed, developed and operated by Saga Robotics.

5. International collaboration

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

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 in DigiFoods 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.

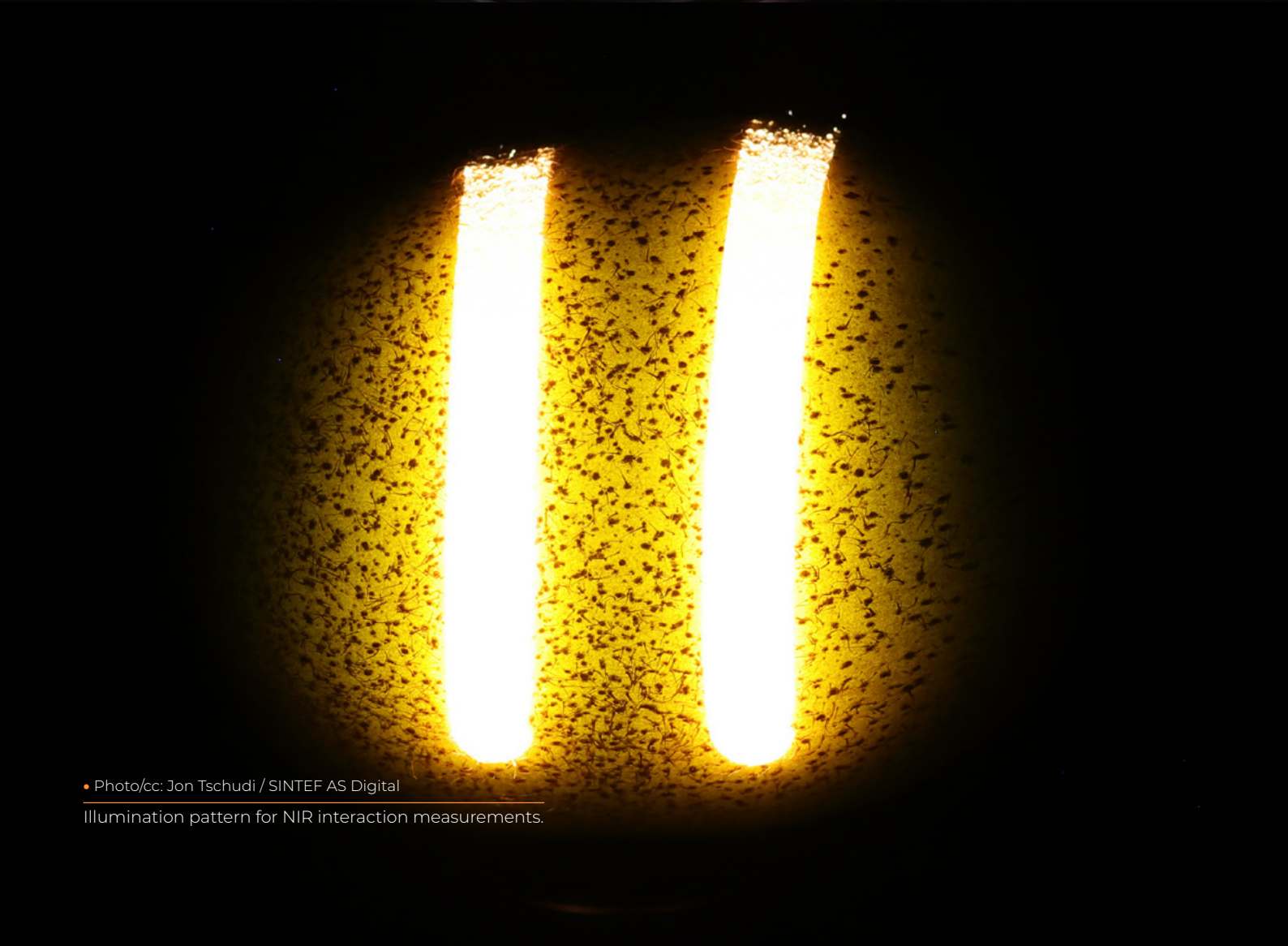
3. **The Polytechnic University of Valencia (UPV),** (Spain), is represented by Professor Alberto Ferrer, group leader of the Multivariate Statistical Engineering Group. The group is devoted to research, development and innovation activities in the area of multivariate statistical techniques for quality 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 in DigiFoods, 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 based on Raman. He will contribute with knowledge and instrumentation in the project RAMAN.

5. **nanoplus Gmbh,** (Germany), is represented by Dr. Johannes Koeth. They will 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 will be 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 the project IR.



• Photo/cc: Jon Tschudi / SINTEF AS Digital

Illumination pattern for NIR interaction measurements.

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. Most of the candidates have been employed and have started to work on their projects. These candidates cover a large range of applications and instrumentations in the food industry. Their projects cover key areas from methodological and instrumental developments, optimal deployment and usage of sensors and analysis and understanding of sensor data.

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

At Nofima in Tromsø post doctor Samuel Ortega Sarmiento is working 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 Andreas U. N. Persch is developing a prototype hand-held IR instrument for food quality applications. Antonio Candea Leite was employed as a post doctor to work on robot–sensor integration on autonomous mobile agricultural robots to gather data on yield estimates, diseases, ripeness, etc. and develop algorithms for robotic arm controlled near-infrared sensors in food production lines. He was later offered a permanent position at NMBU, so a replacement is being sought with the aim of hiring within the first quarter of 2022.

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. The available projects include machine learning and calibration transfer for hyperspectral data and analysis of production data from food industry and aqua-culture. When the projects of DigiFoods have all started, potential for further relevant master thesis topics, for students finishing in 2024 and beyond, is high.

	Location	Candidate	Funding	Project	2020	2021	2022	2023	2024
PhD-students	Nofima	Tiril Aurora Lintvedt	Nofima	RAMAN					
	Nofima	Christian Thorjussen	Nofima	MODEL					
	Nofima/UPV	Marco Cattaldo	RCN	MODEL					
	Nofima/SINTEF	Bijay Kafle	RCN	FTIR					
	NMBU	Andreas U.N. Persch	RCN	IR					
Post-docs	Nofima	Samuel Ortega Sarmiento	Nofima	HYPERSPEC					
	NMBU	Replacement for A.C. Leite*	RCN	MOBILESENSE					

* In September 2021 Antonio Candea Leite got a permanent position at NMBU as assistant professor. He will continue to work on ROBOSENSE and an aim is to have a Post-doc in replacement for him within first quarter of 2022.

Article

Thorvald saves strawberries – next: Wine and Friday Taco

by Georg Mathisen

Thorvald UV-treated ten acres of strawberries last year – this year he'll treat four times that amount. Now the agricultural robot is on its way to being able to pick out the best berries, completely without biting into them.

The clone army of reality doesn't conduct war between the stars – it strolls around in the strawberry field. 40 Thorvalds do a job for a better environment and better strawberries.

"We have probably produced about 80 robots in total. Some are retired, but now there are about 40 who are out doing a job on the fields", says NMBU professor Pål Johan From.

UV against disease

Thorvald is the agricultural robot who learns how to keep the strawberry plants healthy and pick the best berries. NMBU collaborates with SINTEF and Nofima on the strawberry nurse of the future.

"Most robots go and treat the strawberry plants against mildew. Last year we treated about ten acres with ultraviolet light, but this year we are increasing that to 40. We are also setting up a couple of robots on vineyards in California. Vines can get the same fungal disease as strawberries: mildew", says From.

In the DigiFoods centre, robots and sensors are going into fields to make food better. Thorvald is an important fellow player. Many robots out in fields provide the opportunity to collect the data that the project needs. But then the sensors must be improved, and they must know what to measure.

Boosts value

"If we ensure that all berries are picked at the right time and that sick and damaged berries are removed quickly, then we increase the value on the crops", explains SINTEF researcher Anders Hansen. He works with the sensors that will be mounted on Thorvald.

"The strawberry market is growing rapidly worldwide. But short maturation windows, weather dependence and vulnerability to disease and pests can all reduce the value of the crops", he says.

"Robot pickers are a new technology that makes it possible to harvest with a greater degree of precision. But today's robots lack well-developed sensors to assess the quality of each individual berry", according to Hansen.

Untouched by robot hands

He develops new sensors that measure the degree of ripeness and the health of the strawberries and monitor the crop throughout the growing season. The sensors must be small enough for Thorvald to be able to take them with him, and all measurements must be made without the robot touching the berries. If he does, there is a risk of them being infected with disease from other berries.

"Today, the robot does not have the senses that a human picker has. When the robot is not as fast as humans, it means that it has to compete in other areas. So we want it to be able to assess the quality of each individual strawberry better than a human being can", he says.

Thorvald has good taste

Senior researcher Jens Petter Wold and his colleagues at Nofima are well on their way to ensuring this."We have checked that such a sensor can measure the same as a sensory panel, i.e. Thorvald can taste the same as you and I would taste when we take a strawberry from a basket", he says.

He has a sense of taste for the sensors with what the sensory panel of Nofima experiences. The professional food tasters, in other words. The sensors can determine if the berries are sweet or sour.

Now the job is to make the sensors small enough so that they actually fit on Thorvald so he can take them out into the field.

Photos/cc: Håkon Sparre/ NMBU

Thorvald is the agricultural robot who learns how to keep the strawberry plants healthy and pick the best berries.

Rescuing the Friday taco

"The sensor should measure a little way into the berries, also for other types of fruit and other types of berries", says Wold. He cites avocados and mangos as examples. How many people have not had their Friday taco ruined because it is not possible to see on the outside if the avocado is good?

"The key for Digifoods is sensors that allow us to measure things without cutting them up", according to Jens Petter Wold. Scientists do this with invisible light, namely radiation in the range called "near infrared". When you send the radiation through the berries, different chemicals will block different wavelengths. Sugar absorbs certain wavelengths, so it is possible to see what radiation is passing through and use this information to determine how sweet the berries are.

"In addition, we need a set of cameras that can see the berry in 360 degrees to see whether it is ripe in both the front and back and to judge the size, shape and colour", says Anders Hansen at SINTEF.

Sustainability

He emphasises that it is a huge benefit for both the environment and the economy if Thorvald can detect the onset of diseases early, before the disease can spread to other berries. In other countries, the appearance of the berries is also much more important than in Norway:

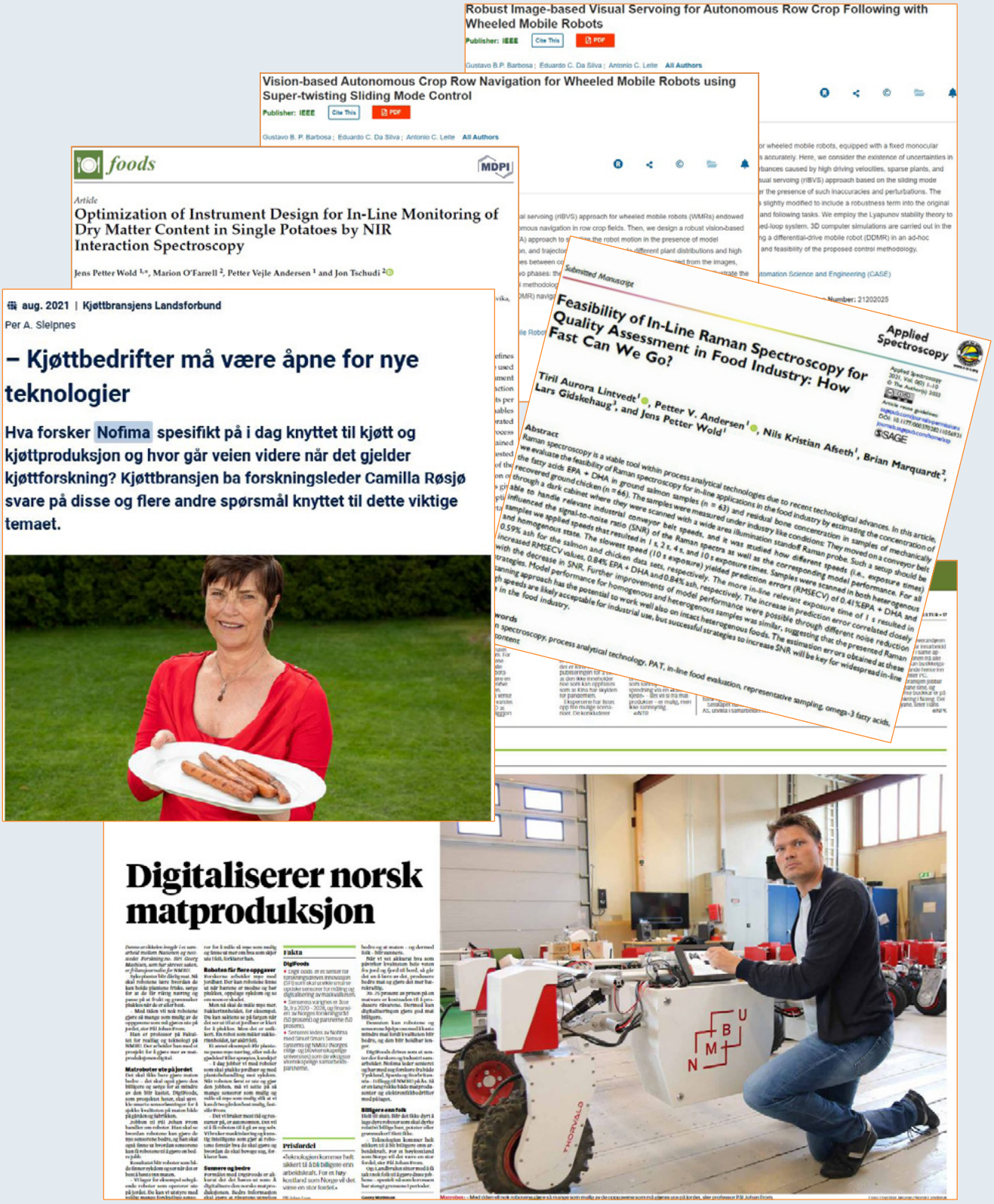
"In Norway, we buy strawberries on a ferry quay and eat them there. In other countries, strawberries are a premium product where the prettiest are used as decorations on layer cakes. This means that the robot has to possess a certain aesthetic sense", he says.

Before Thorvald starts picking the berries when they are sweetest and most attractive, he will make sure that the strawberry production is more sustainable.

"When we reduce the use of pesticides, we are able to produce strawberries in a more sustainable way that provides healthier plants and healthier food for the consumer", says Pål Johan From at NMBU.

"Thorvald is the agricultural robot who learns how to keep the strawberry plants healthy and pick the best berries"

7. Communication and dissemination



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

Our primary target groups are:

- Food and bioindustry, technology companies
- Scientist and students
- The Public, including funding bodies and policymakers.

During 2021 there were 18 news articles in the press about DigiFoods. The SFI was presented in both trade magazines, like Kjøttbransjen, and more public medias like E24.no and Forskning.no.

We have arranged two public digital seminars with around 100 participants from the industry, RTD sector and public officials:

- *"Sharing of data in the value chain: why and how?"*
- *Process Analysis and Control in Food Manufacturing Event*

In November we had our first physical annual meeting, where results were disseminated, and the needs in the food industry and challenges for technology partners were discussed.

In addition, we had two presentations of DigiFoods at Arendalsuka 2021:

Fra forskning til forretningsmuligheter:

- *Om SFI DigiFoods og hvordan deres innovasjons modell bidrar til at forskningsresultater omdannes til samfunnsnyttige løsninger,* Jens Petter Wold, Seniorforsker, Nofima
- *Grønn digital transformasjon mot 2030,* Alexandra Bech Gjørv, Konsernsjef, SINTEF

In 2021, DigiFoods had four Peer-reviewed publications accepted and all are now published.

Article

Molecular weight is a key to control quality

by Wenche Aale Hægermark

Consistent quality is the key to good products. By estimating the molecular weight and hence the size of the proteins, Nofima scientists can characterize and control the protein quality.

Quality control is an essential part of all types of production – and a field that really interests Bijay Kafle in Nofima. Now he is looking into quality of milk and by-products made from residual raw materials from poultry and fish.

He started studying quality control of pharmaceuticals and clinical pharmacy in his home country Nepal, then shifted to traditional medicine. Now, as a Ph.D. student in DigiFoods, he works with food and residual raw materials from the food industry.

A future in spectroscopic techniques

With a focus on FTIR spectroscopy, he has started to develop applications using a robust, cost-effective, and simple FTIR (Fourier Transform Infrared) instrument. The plan is to take FTIR spectroscopy closer to in-line by testing at process lines in the food industry.

"Previously, I have used different spectroscopy techniques and other technical instruments. My aim for the future is to work more on quality control of different foods and medicines using different spectroscopic techniques".

From pet food to human food

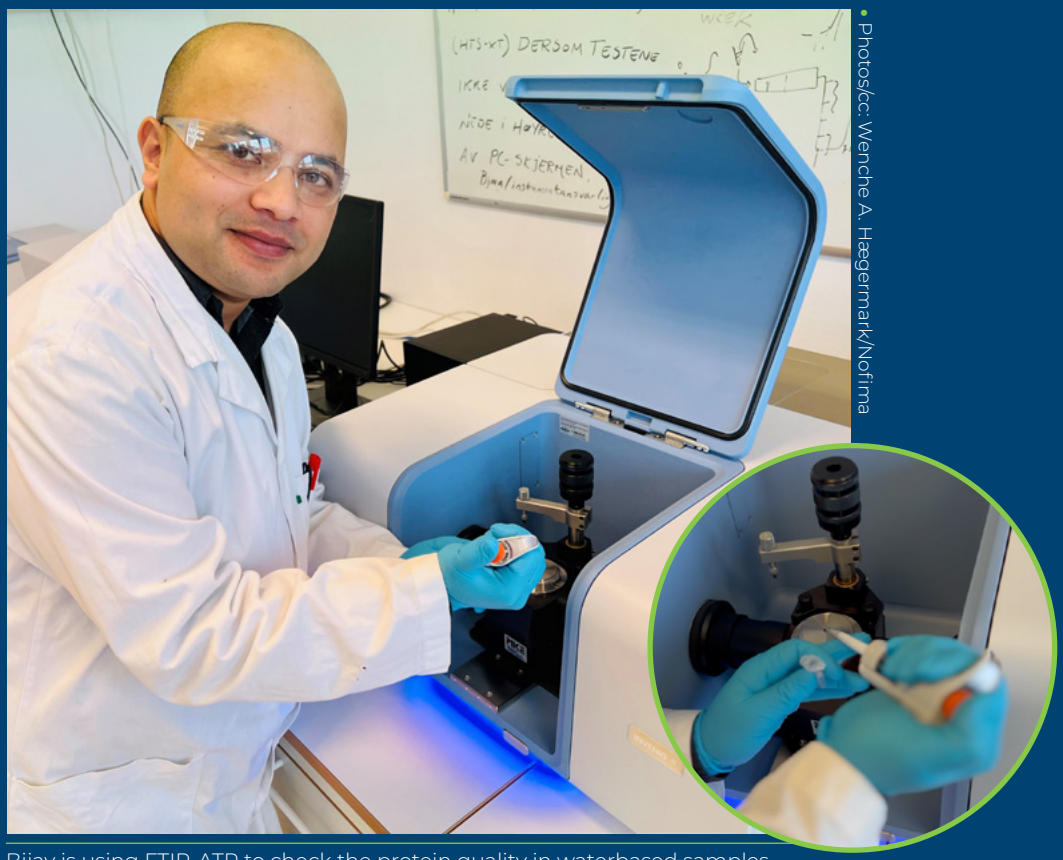
Norilia and Biomega, who are industrial partners in Digifoods, process residual raw materials from fish and poultry, respectively. They both produce value-added protein hydrolysates. Currently, the main market for these products are animal feed and pet food.

However, a long-term goal is to increase the percentage of protein hydrolysates found in food and food supplements. Several of these food products are already currently being launched, but such a change also requires more consistent quality. However, the industry does not characterize the protein hydrolysates, making it difficult to guarantee the quality of the protein hydrolysates.

Nofima researchers have found that average molecular weight is one of the parameters to monitor the enzymatic hydrolysis process and protein quality. Generally, the molecular weight can serve as a protein quality indicator, related to for instance taste, functional properties and composition.

"We are in the process of developing different applications related to prediction of molecular weights of protein hydrolysates using FTIR spectroscopy. Our aim is that an industrial FTIR approach both can be used to monitor the hydrolysis process and at the same time document product quality", says Nils Kristian Afseth, senior scientist at Nofima. He is also one of Bijays supervisors.

"My aim for the future is to work more on quality control of different foods and medicines using different spectroscopic techniques, says Bijay"



Photos/cc: Wenche A. Hægermark/Nofima

Bijay is using FTIR-ATR to check the protein quality in waterbased samples.

The steps of an industrial prototype

Bijay started his work by checking the quality of lab-based protein hydrolysates compared to hydrolysate samples obtained from food processing industries. Different sampling techniques, FTIR-ATR (attenuated total reflectance) with water background subtraction and FTIR dry films approach were applied.

The reason for choosing these methods was to reduce the effect of water interference on protein spectra. Different pre-processing techniques have been applied and the FTIR spectra of protein hydrolysates are used to develop the prediction models for average molecular weight using multivariate regression analysis.

"It is necessary to adapt measurement methods and instruments to the condition of the sample. For example, water can interfere in FTIR spectra, and since protein hydrolysates contain water, it is more demanding to examine and control the quality of protein hydrolysates. Therefore, we have to adapt the FTIR approach so that it can be done in dried samples", Bijay explains.

In this process, the researchers mapped the protein quality based on the average molecular weight, against measured FTIR dry film spectra, allowing them to predict the protein quality. The dry film approach has potential for future use at-line in industrial settings.

Together with researchers from SINTEF Digital, Bijay is in the process of developing a dry film FTIR prototype which will be compared with the established lab instruments, calibrated, and taken to industrial environments for industrial sample analysis.

"The prototype we are developing must be reasonable sized and robust enough when compared to the lab FTIR so that we can bring it to industrial process lines. We must also make it as simple as possible to make and present the dry films to the instrument so that Bijay can gather enough good data during his industrial trials", explains Marion O'Farrell, senior scientist at SINTEF, and Bijays other supervisor.

Facts about FTIR spectroscopy

FTIR (Fourier Transform Infrared) is a spectroscopy technique that uses infrared light to initiate molecular vibrations in a sample. In just a matter of seconds, information can be gathered about the molecules that are present in the sample. The technique is frequently used in industrial laboratories for food analysis.

Publication and dissemination

Peer-reviewed publications

Barbosa, G. B. P., Da Silva, E. C., and Leite, A. C. (2021). Vision-based Autonomous Crop Row Navigation for Wheeled Mobile Robots using Super-twisting Sliding Mode Control. 2021 European Conference on Mobile Robots (ECMR), Bonn, Germany. ISBN:978-1-6654-1213-1. 2021, pp. 1-6. DOI: 10.1109/ECMR50962.2021.9568819.

Barbosa, G. B. P., Da Silva, E. C., and Leite, A. C. (2021). Robust Image-based Visual Servoing for Autonomous Row Crop Following with Wheeled Mobile Robots. 2021 IEEE 17th International Conference on Automation Science and Engineering (CASE), Lyon, France. ISBN:978-1-6654-1873-7. 2021, pp. 1047-1053. DOI: 10.1109/CASE49439.2021.9551667.

Lindtvedt, T.A., Andersen, P.V., Afseth, N.K., Marquardt, B., Gidskehaug, L., Wold, J.P. (2021). Feasibility of In-Line Raman Spectroscopy for Quality Assessment in Food Industry: How Fast Can We Go? Appl Spectroscopy. DOI: 10.1177/00037028211056931.

Wold, J.P., O'Farrell, M., Andersen, P. V. and Tschudi, J. (2021). Optimization of Instrument Design for In-Line Monitoring of Dry Matter Content in Single Potatoes by NIR Interaction Spectroscopy. Foods. 10(4), 828. DOI: 10.3390/foods10040828.

Presentations (oral or poster)

Afseth, N.K. (2021). Paving the way for Raman spectroscopic analysis of heterogeneous foods. SciX 2021, Digital, USA, 26.09 – 01.10.2021.

Afseth, N.K. (2021). Towards in-process and on-farm applications of dry-film FTIR spectroscopy. 1st Sensorfint international workshop, Porto, Portugal, 30.09.-01.10.2021.

Afseth, N.K. (2021). Spectroscopy vs. reference: what can we expect? Lipid spectroscopy workshop, Ås, 15.10.2021.

Berg, P. (2021). Hvordan kan digitalisering, data og prognoser endre råvarestyring og spekepølseproduksjon. Deling av data i verdikjeden: Hvorfor og hvordan, Webinar, 15.09.2021.

Berg, P. (2021). Challenges in fat analysis. Lipid spectroscopy workshop, Ås, 15.10.2021.

Bråthe, E. (2021). Verdien av datadeling for norsk mat - Økt kvalitet, omdømme og omsetning. Deling av data i verdikjeden: Hvorfor og hvordan, Webinar, 15.09.2021.

Heia, K. (2021). Revolusjonerende kvalitetsverktøy for fiskeindustrien. Torskefiskkonferansen 2021, Tromsø, 21.10.2021.

Husby, O. (2021). Hvordan algoritmer vil endre sjømathandelen. Deling av data i verdikjeden: Hvorfor og hvordan, Webinar, 15.09.2021.

Kirkhus, T. (2021). MeatCrafter: Automatic classification of lamb carcasses. Lipid spectroscopy workshop, Ås, 15.10.2021.

Kohler, A. (2021). Infrared handhold and portable spectrometers for lipid measurements in foods and feeds. Lipid spectroscopy workshop, Ås, 15.10.2021.

Lindtvedt, T.A., Andersen, P.V., Afseth, N.K., Marquardt, B., Gidskehaug, L., Wold, J.P. (2021). Feasibility of in-line Raman spectroscopy for quality assessment in the food industry. European Biosensor Symposium, Digital, 21.09.2021.

Lindtvedt, T.A., Andersen, P.V., Afseth, N.K., Marquardt, B., Gidskehaug, L., Wold, J.P. (2021). Raman spectroscopy for in-line food quality sensing on a conveyor belt. SciX 2021, Digital, USA, 26.09 – 01.10.2021.

Ma, K. (2021). Rapid Infrared analysis for Marine Oil – Instrument selection and assessment of method performance. Lipid spectroscopy workshop, Ås, 15.10.2021.

Marquardt, B. (2021). Applications of process Raman spectroscopy: from food to fuel. IFPAC 2021, Process Raman Session, Digital, 01.03.2021.

Marquardt, B. (2021). Innovations in Raman spectroscopy for process analysis in food. Process Analysis and Control in Food Manufacturing, Webinar, 26.10.2021.

Måge, I. (2021). Design of Experiments – the ultimate Chemometrick. Scandinavian Symposium on Chemometrics (SSC17), Ålborg, 06.09.2021.

Måge, I. (2021). Intro til DigiFoods. Deling av data i verdikjeden: Hvorfor og hvordan, Webinar, 15.09.2021.

Måge, I., Böcker, U., Wubshet, S. G., Afseth, N.K. (2021). FTIR fingerprinting for quality assessment of protein hydrolysates. Food Analytics Conference 2021, Copenhagen, 17.11.2021.

Måge, I., Solberg, L.E., Dankel, Katinka, Wold, J.P. (2021). Inline NIR reveals unknown process dynamics and give more precise estimates of batch quality. Process Analysis and Control in Food Manufacturing, Webinar, 26.10.2021.

O'Farrel, M. (2021). Optimalisering av instrument design for NIR målinger av heterogene og komplekse matvarer i prosesslinjen. Automatsering i Næringsmiddelindustrien 2021, Oslo, 19.-20.10.2021.

O'Farrel, M. (2021). Grønn digital transformasjon mot 2030. Arendalsuka – Fra forskning til forretningsmuligheter, Arendal, 16.08.2021.

O'Farrel, M. (2021). Panel Discussion - Process Analysis and Control in Food Manufacturing. Process Analysis and Control in Food Manufacturing, CPACT, 26.10.2021.

Ottestad, S. (2021). Fat analysis by NIR/Imaging. Lipid spectroscopy workshop, Ås, 15.10.2021.

Shapavel, V., Zimmermann, B. (2021). Monitoring fat in bioprocesses (robot/process). Lipid spectroscopy workshop, Ås, 15.10.2021.

Solberg, L. E., Næs, T., Indahl, U. (2021). Comparing calibration transfer approaches. Scandinavian Symposium on Chemometrics (SSC17), Ålborg, 07.09.2021.

Thorsveen, J.A. (2021). Blockchain på gården, presentasjon av pilot-prosjekter på området. Deling av data i verdikjeden: Hvorfor og hvordan, Webinar, 15.09.2021.

Varela, P.A.T., Almli, V.L. (2021). Quality data sharing to increase consumer trust, satisfaction and reduce food waste. Deling av data i verdikjeden: Hvorfor og hvordan, Webinar, 15.09.2021.

Wold, J.P. (2021). Digital Food Quality – DigiFoods. Fagdag i LMD, Digital, 26.03.2021.

Wold, J.P. (2021). Om SFI DigiFoods og hvordan deres innovasjons-modell bidrar til at forsknings-resultater omdannes til samfunnsnyttige løsninger. Arendalsuka – Fra forskning til forretningsmuligheter, Arendal, 19.08.2021.

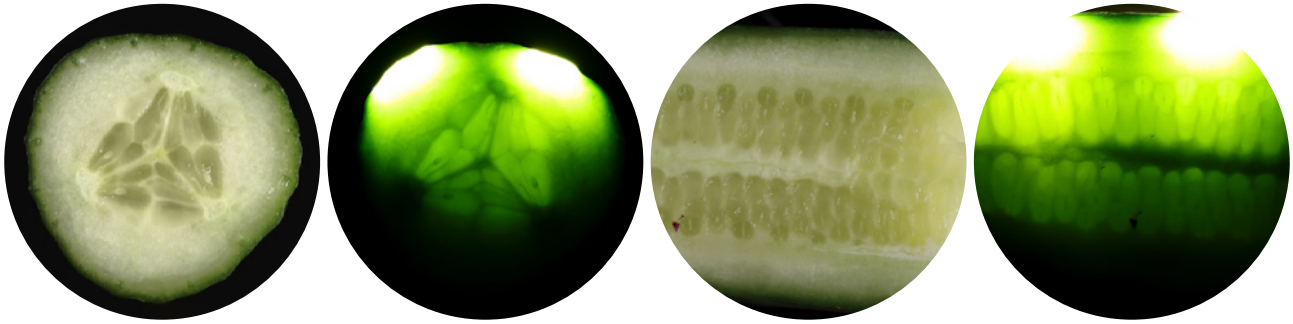
Wold, J.P. (2021). Optical Sampling Design for In-line Monitoring of Complex Foods by NIR Spectros-copy. SensorFINT2021: Smart Spectral Sensors for Agri-Food Quality and Process Control, Porto, Portugal, 30.09.-01.10.2021.

Wold, J.P. (2021). Opportunities and challenges with in-line measurements of food quality. Process Analysis and Control in Food Manufacturing, Webinar, 26.10.2021.

Wold, J.P. (2021). Måling og digitalisering av matkvalitet – en forutsetning for vellykket digitalisering av matindustrien. Automatsering i Næringsmiddel-industrien 2021, Oslo, 19.-20.10.2021.

Wold, J.P. (2021). Towards in-line Raman spectroscopy in the food industry. Food Analytics Conference 2021, Copenhagen, 17.11.2021.

Wold, J.P., Afseth, N.K. (2021). Raman lipid analysis of Salmon and dry film measurements by FTIR spectroscopy. Lipid spectroscopy workshop, Ås, 15.10.2021.



• Photo/cc: Jon Tschudi / SINTEF AS Digital

Illumination pattern for NIR interaction measurements.

8. Administration

Key personnel

Postdoctoral researchers with financial support from the Centre budget

Name	Period	Topic
Samuel Sarmiento Ortega	2021–2024	Hyperspectral imaging applied to food quality analysis
Antonio Candea Leite*	2021–2021	Robot and Sensor Integration

*To be replaced

PhD students with financial support from the Centre budget

Name	Period	Topic
Bijay Kafle	2021–2024	Dry-film FTIR spectroscopy for in-process food quality measurements.
Andreas Ulrich Nicolas Persch	2021–2025	Portable IR-spectroscopy for food quality measurements
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

Photo/cc: Anne-May Johansen / Nofima

Sampling with Senior researcher Karsten Heia, Post doc Samuel Ortega, Engineer Amanda Karlsen and Researcher Tatiana Ageeva.

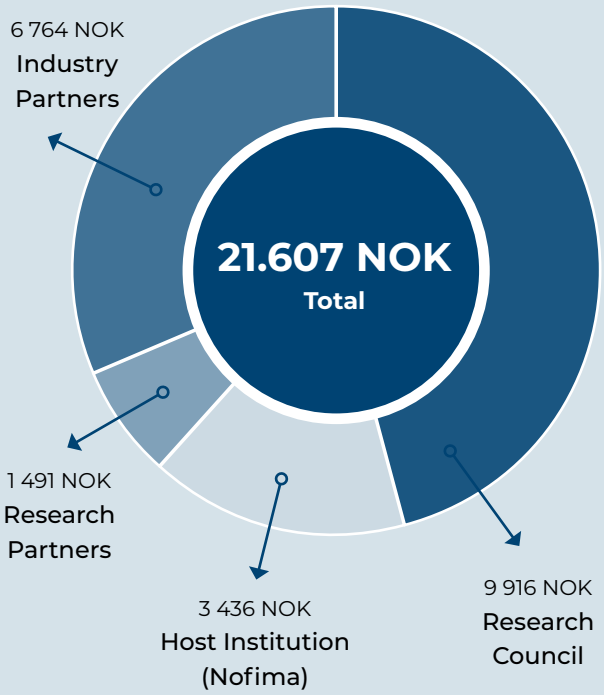
Key researchers

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
Shaheen Syed	Nofima	1	Data analysis
Sileshi Gizachew Wubshet	Nofima	1	Analytical chemistry
Stein-Kato Lindberg	Nofima	1	Applied spectroscopy
Svein Stormo	Nofima	1	Applied spectroscopy and chemistry
Nils Kristian Afseth	Nofima	1,3	Applied spectroscopy and chemistry
Erik Tengstrand	Nofima	3	Applied spectroscopy and chemometrics
Lars Erik Solberg	Nofima	3,4	Data analysis
Ingrid Måge	Nofima	4	Multivariate data analysis
Paula Varela	Nofima	4	Sensory and consumer science
Valérie Lengard Almli	Nofima	4	Sensory and consumer science
Achim Kohler	NMBU	1	Applied spectroscopy and physics
Boris Zimmermann	NMBU	1	Applied spectroscopy and chemistry
Valeria Tafntseva	NMBU	1	Spectroscopy
Volha Shapaval	NMBU	1	Spectroscopy and biotechnology
Antonio Candea Leite	NMBU	2	Robotics
Lars Grimstad	NMBU	2	Robotics
Nils Bjugstad	NMBU	2	Agricultural technology
Pål Johan From	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
Zahra Ghadyani	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
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

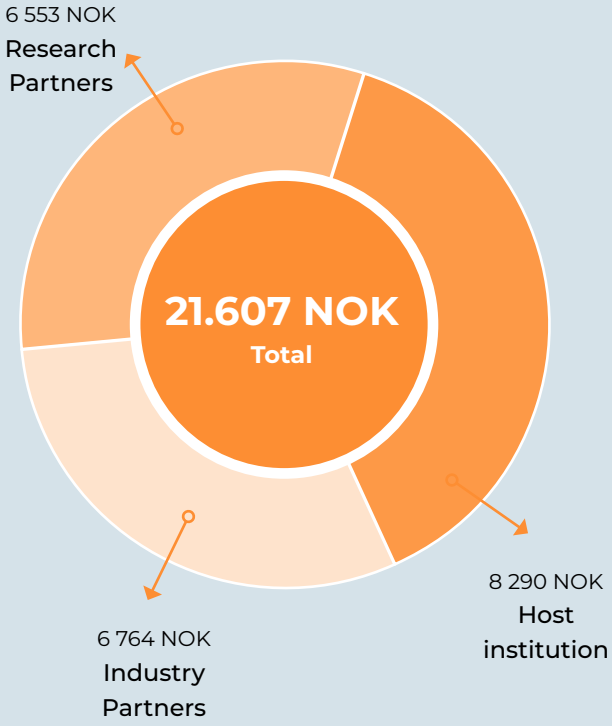
Annual accounts

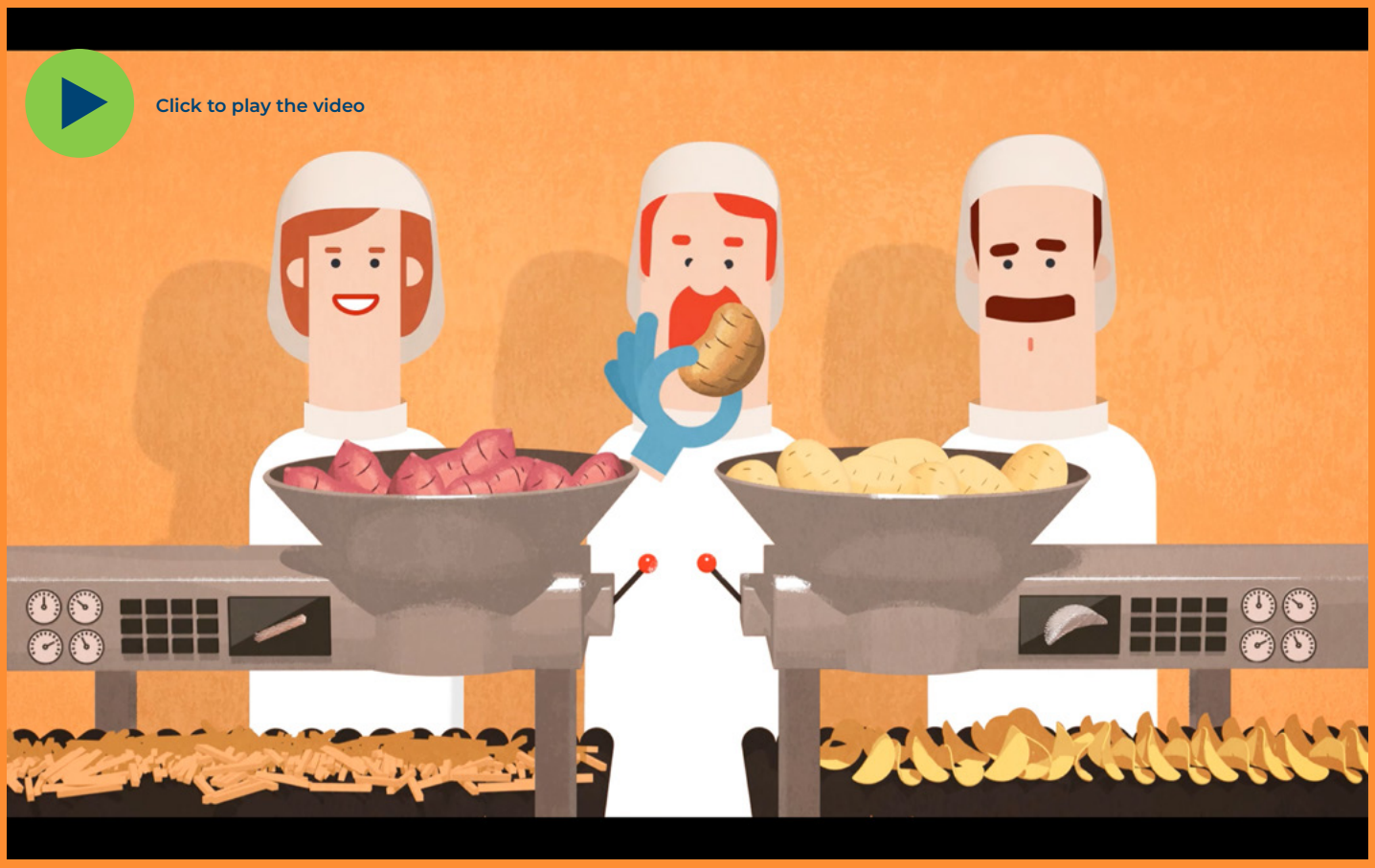
The total budget for SFI DigiFoods is 188 mill NOK over eight years. The financing of SFI DigiFoods is based on contribution from the Research Council of Norway and cash and in-kind from the Industry Partners and the Norwegian Research Partners.

Funding



Costs





Smart sensors – sustainable foods

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.

www.digifoods.no

sfi = Senter for forskningsdrevet innovasjon

Norges forskningsråd