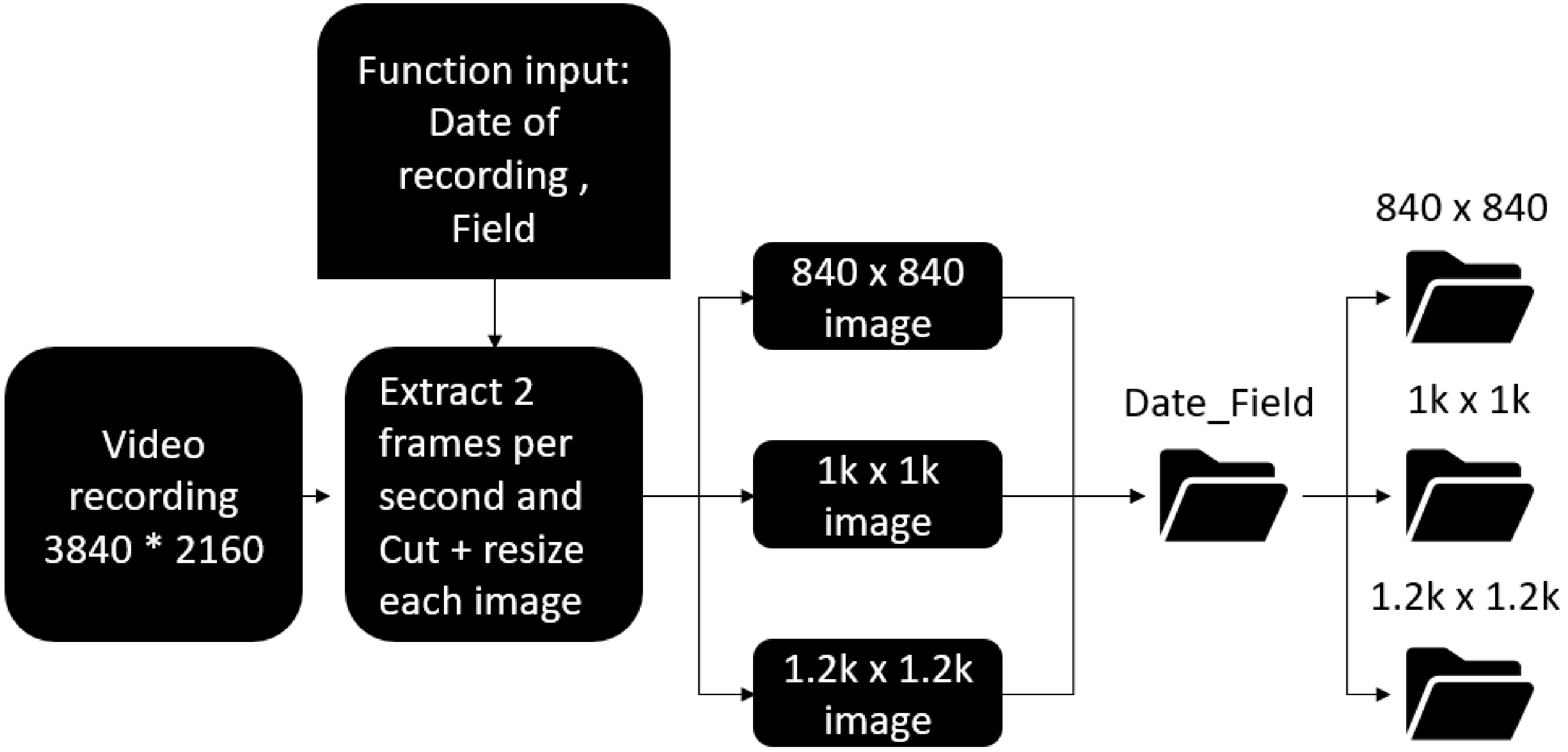
Field trial

- Goal of testing:
  - Autonomously navigate one row
  - Record videos on the go pro
  - Categories and sort videos
  - Divide into Different resolution
  - Use Yolov5 image detection
  - Apply counting algorithm



Results

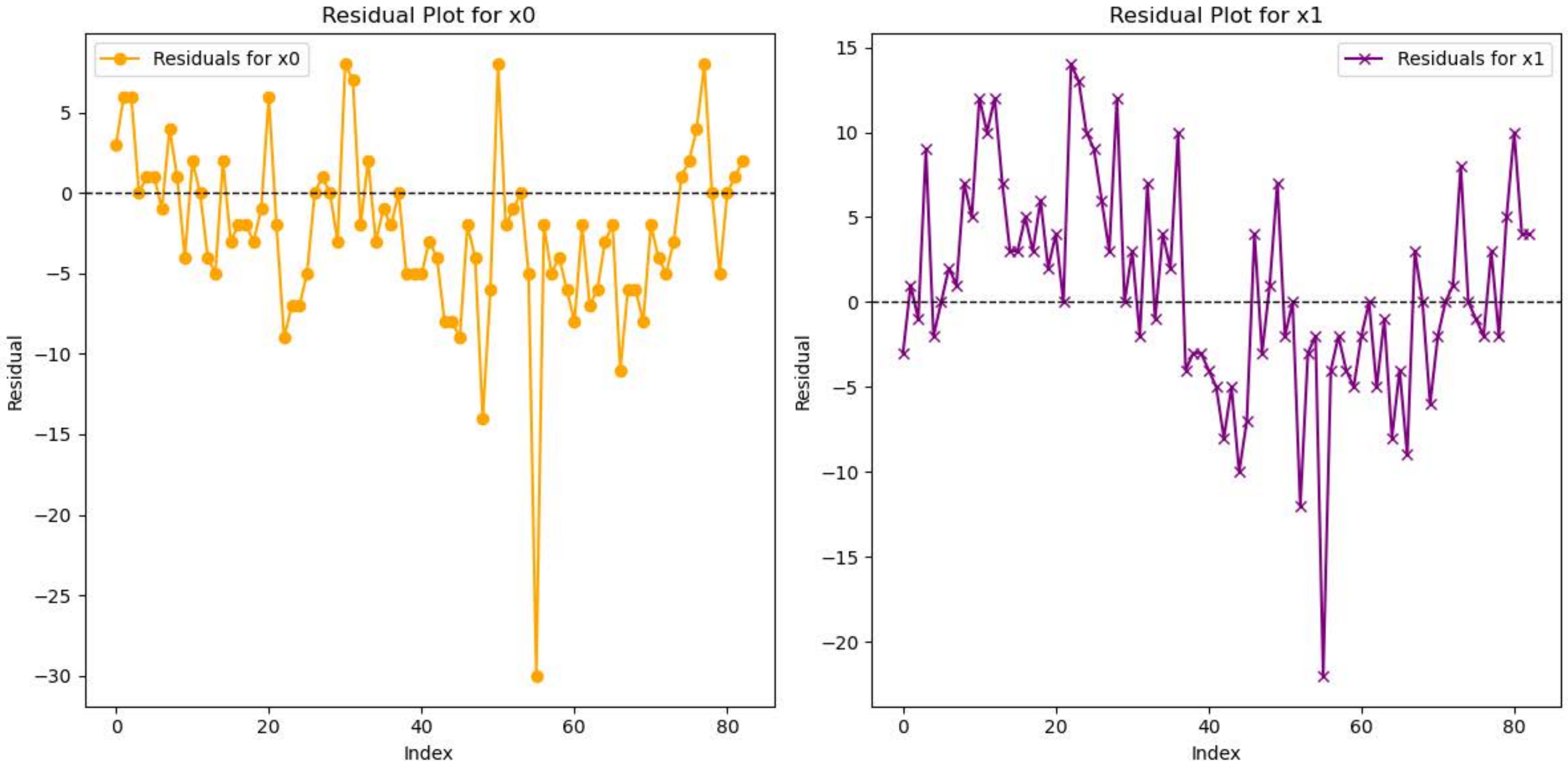
Results
Navigation

On the test dataset

Mean Absolute Percentage Error (MAPE) of

3.29% for X_0 and

4.04% for X_1



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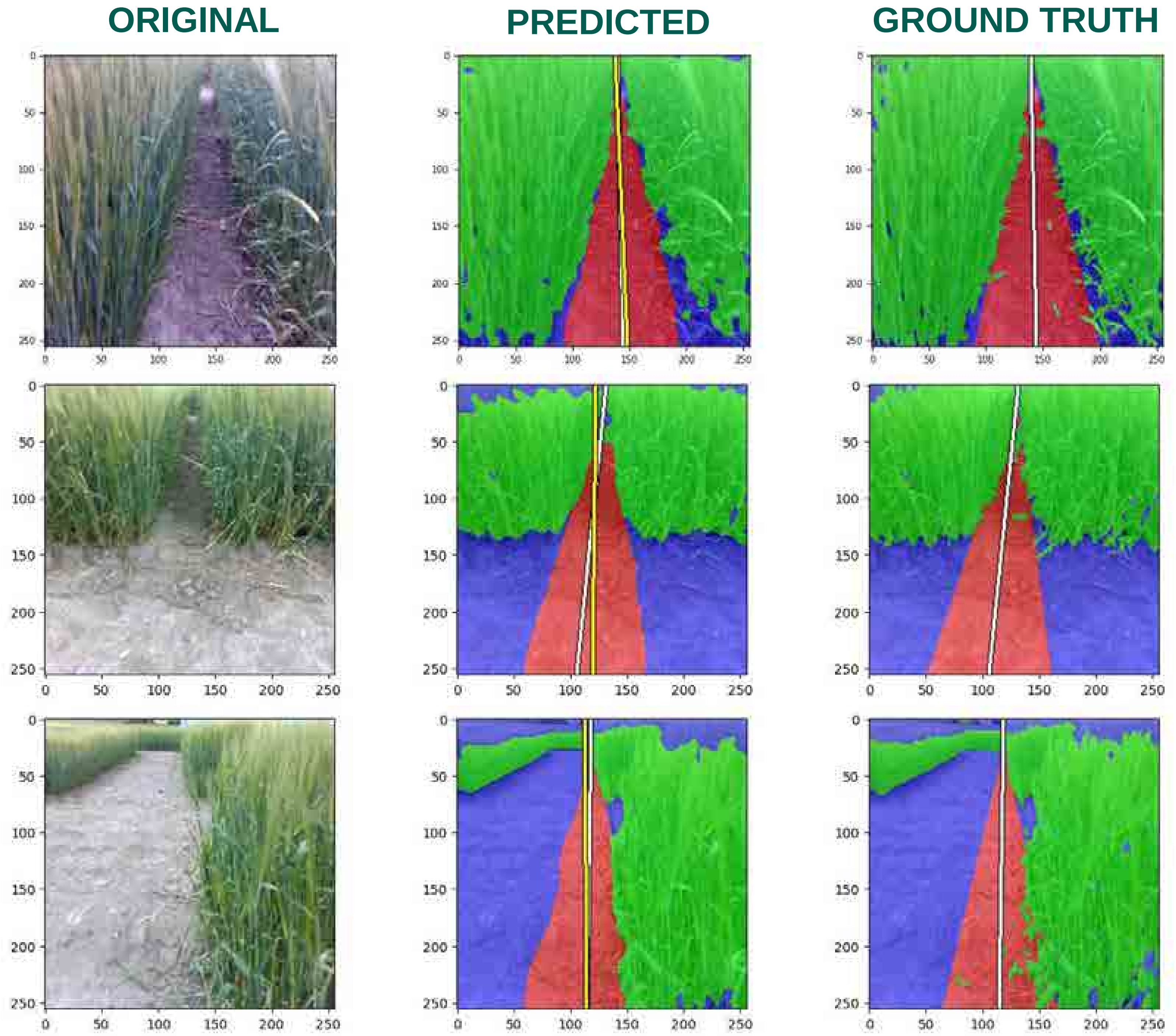


Results

Detection

- 6 images from different plots
- 2 165 Spikes
- Accuracy was modified
- Notable variations in performance
- Larger resolution = Better results

	840x840	1000x1000	1200x1200
Recall	87.1%	89.8%	91.1%
Precision	98.3%	98.7%	98.5%
Accuracy*	85.8%	88.7%	89.9%
F1 Score	92.4%	94.0%	94.7%

Results

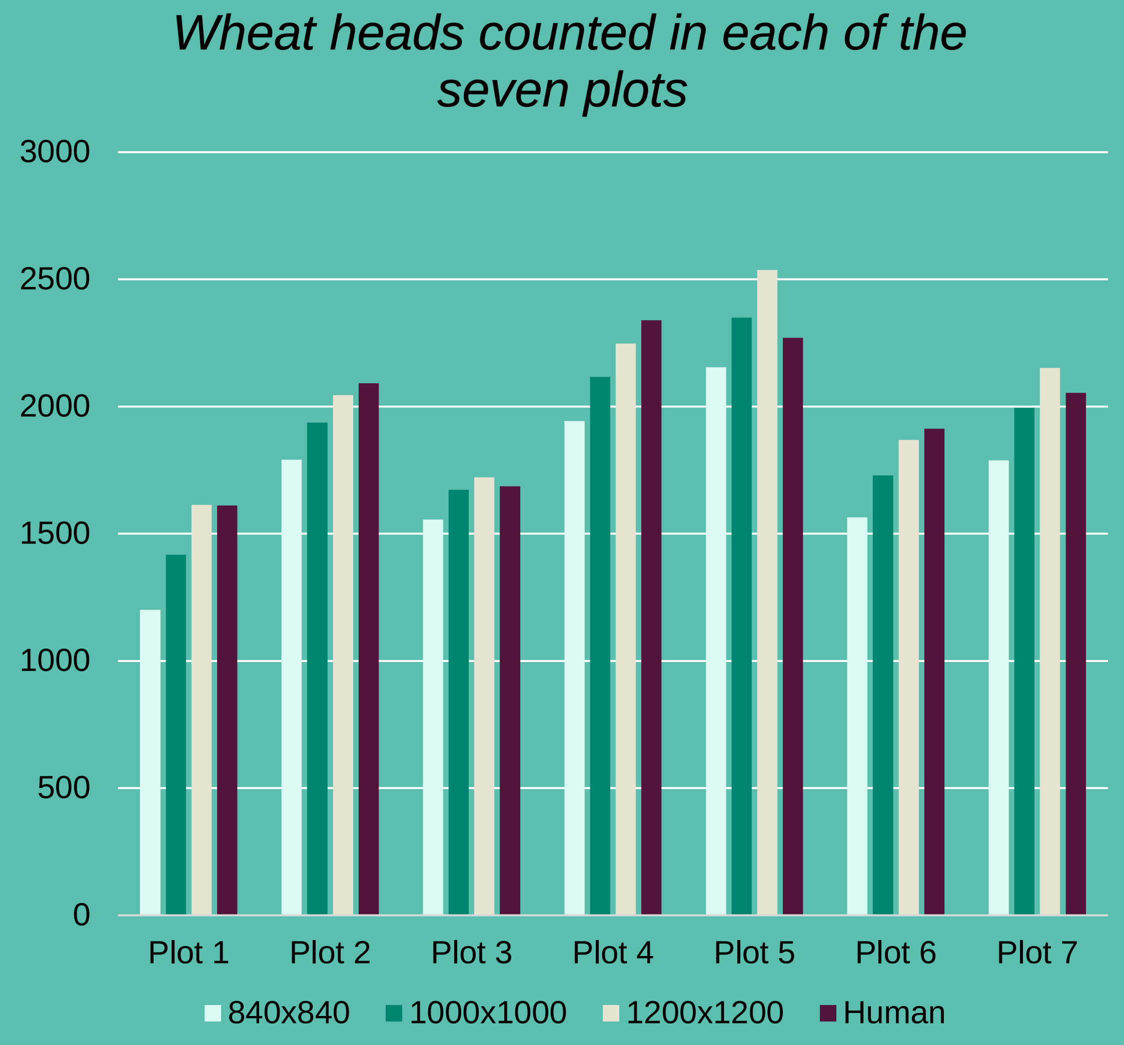
Counting

- 7 plots
- Benchmarking by average of 2 humans
- Almost 28 000 spikes counted by hand

$$\sum_{i=1}^{7} \sum_{f=1}^{nframes} |Human - robot|$$

Mean absolute count difference Resolutions vs Humans

840 x 840	1000 x 1000	1200 x 1200	Human difference
281	129	84	94
14.07%	6.48%	4.19%	4.75%



Results

Counting

- Significantly faster than humans
- Favoring smaller resolution

	840x840	1000x1000	1200x1200	Human
Total time	21 min 54 s	29 min 54 s	40 min 23 s	161 min
Per plot	3 min 8 s	4 min 16 s	5 min 46 s	23 min

Future improvements

- LiDAR
- 100% autonomous – Navigation & Counting
- Use RNN and/or CNN to calculate image difference
- Running more test and higher confidence results








Mathias Johan Dyrén, Håkon Bråten, Muhammad Fahad Ijaz, Igor Ferreira da Costa,

Ingunn Burud, Morten Lillemo, Antonio Candea Leite and Sahameh Shafiee

NLR

Graminor

NMBU Norges miljø- og biovitenskapelige universitet

NMBU

Norwegian University
of Life Sciences

Adaptive Sensing in Agri-Food

Weria Khaksar (NMBU)

November 26th, 2024

AGROMEK Seminar 2024, Herning, Denmark

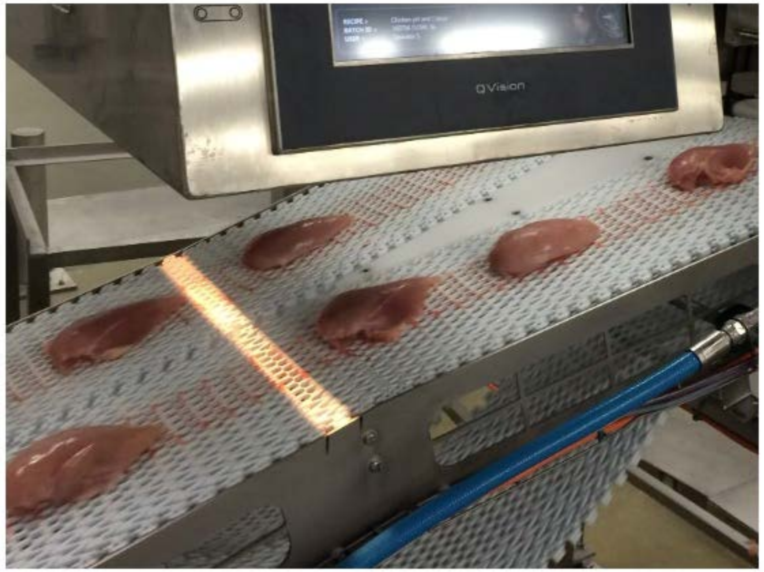
Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

DigiFoods aim at developing smart sensor solutions for food quality assessment directly in the processing lines, throughout the food value chains.

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality



Integrated in-line sensing solutions

Adaptive Sensing in Agi-Food

DigiFoods

NMBU

DigiFoods SFI: Digital Food Quality

Integrated in-line sensing solutions

Novel sensor systems and application development

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

Integrated in-line sensing solutions

Novel sensor systems and appli

Robot and sensor integration

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Integrated in-line sensing solutions

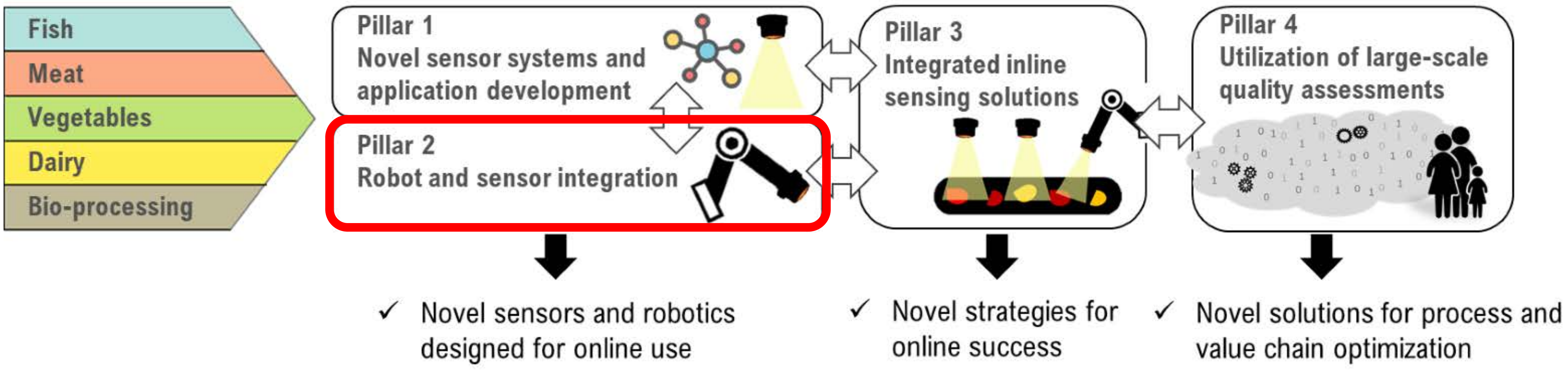
Novel sensor systems and appli

Robot and sensor integration

Utilization of large-scale quality assessments

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality



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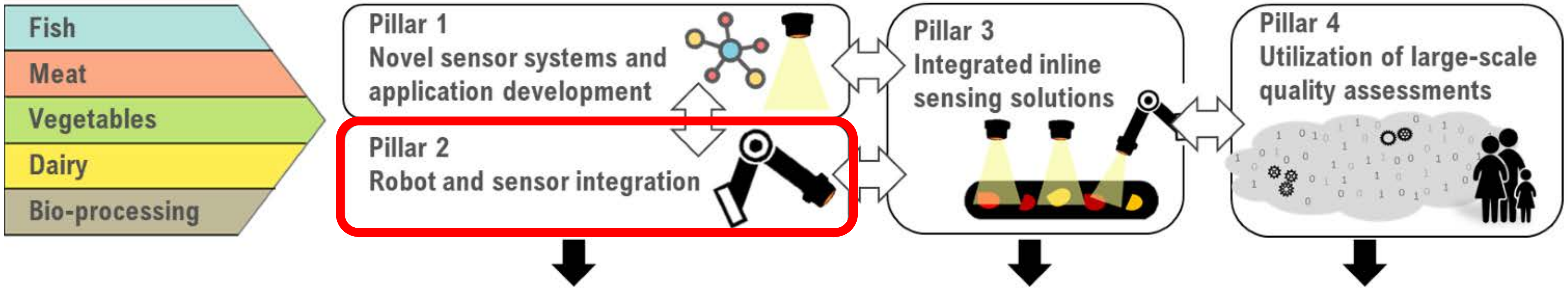
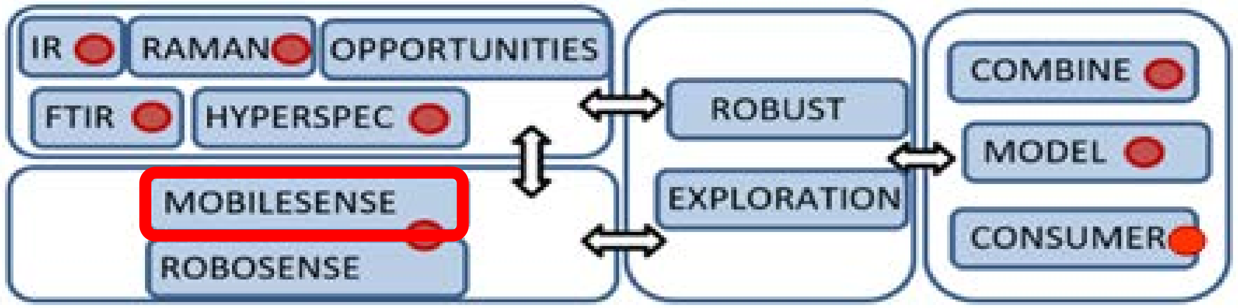
DigiFoods SFI: Digital Food Quality



- ✓ Novel sensors and robotics designed for online use
- ✓ Novel strategies for online success
- ✓ Novel solutions for process and value chain optimization



Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project

Assurance of Overall Fruit Quality:

- Inspecting conditions such as ripening, nutrient absorption, and diseases

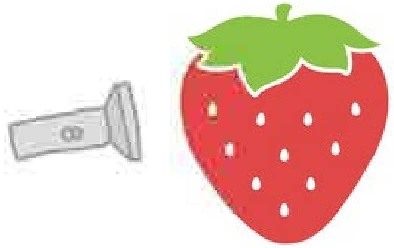
Autonomous inspection systems:

- Deliver continuous valuable agricultural information to farmers
- Minimize manual effort in fruit quality control

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

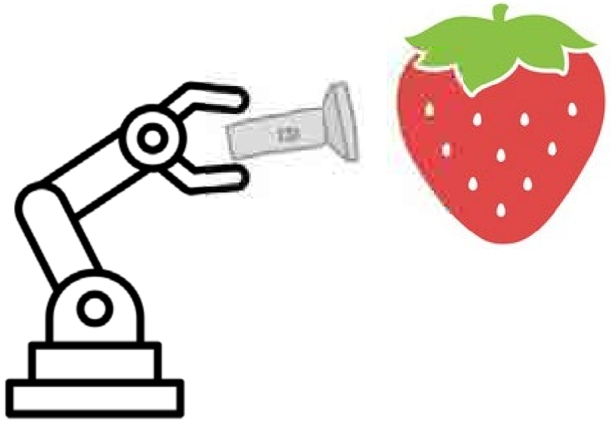
MobileSense Project



Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project



Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

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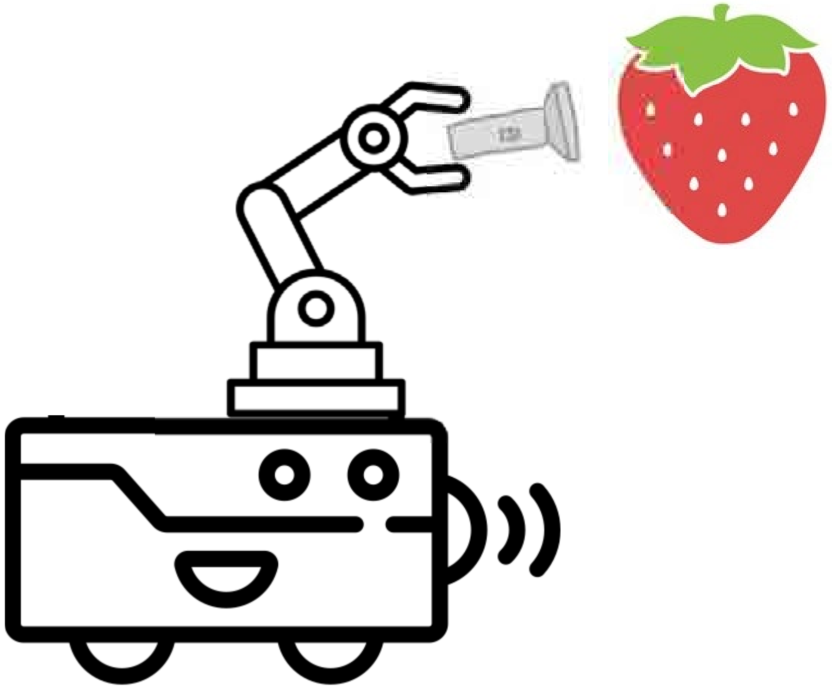

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

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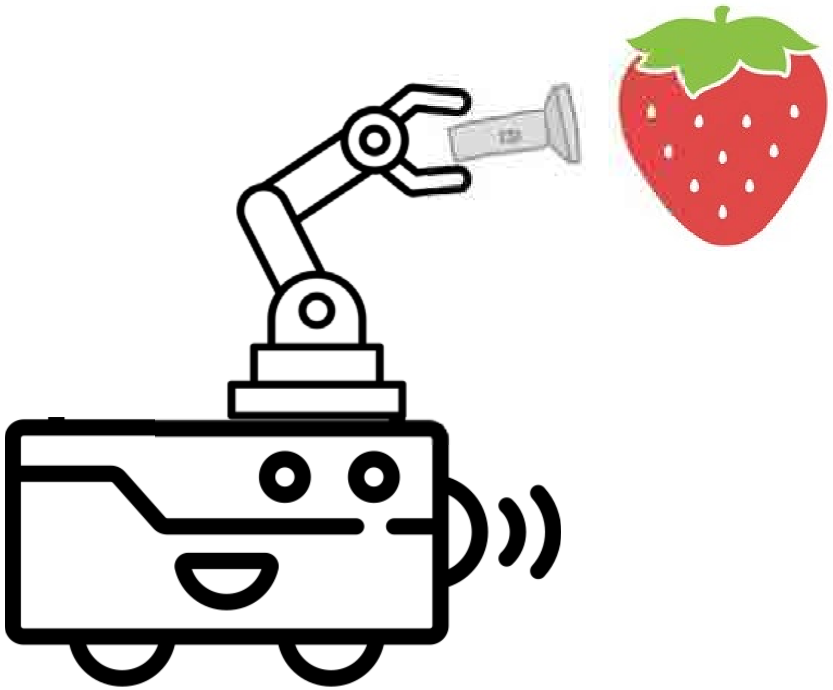


Advantages:

- Increased efficiency
- Precision and accuracy
- Continuous operation
- Reduced labor costs
- Improved data collection and analysis
- Enhanced crop monitoring
- Minimized environmental impact
- Optimized resource usage
- Ability to cover large agricultural areas

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project

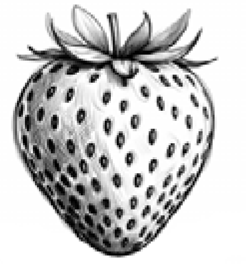
Conventional methods:

- Requires samples from the strawberries, which destroys the fruit.
- Requires contact with the strawberries, which could spread diseases and even damage the strawberries.
- Needs multi-angle measurements for accurate averaging.
- Both sensors need human operation due to measurement complexity.

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project



Spectroscopic sensor:

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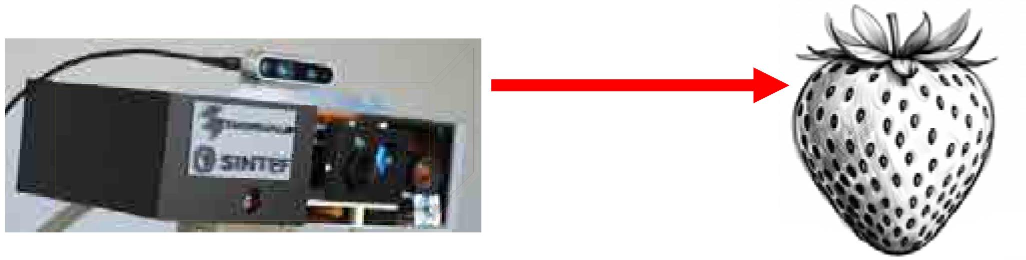
MobileSense Project



Spectroscopic sensor:

- Projects a strip of light that penetrates the fruit

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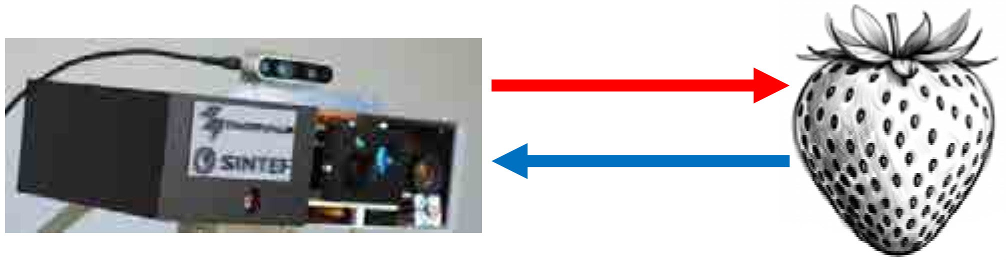

Spectroscopic sensor:

- Projects a strip of light that penetrates the fruit
- Reads the strawberry's spectroscopy data

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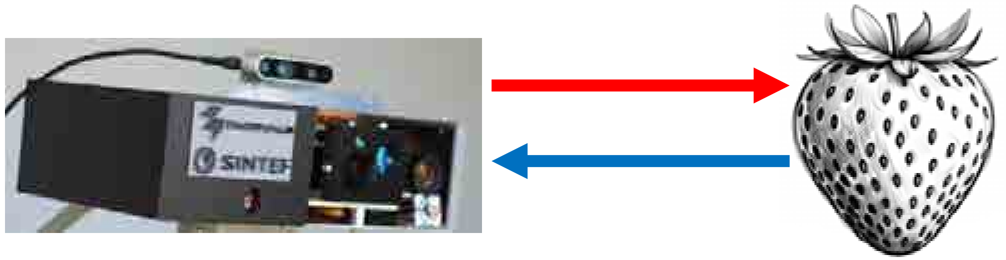
MobileSense Project



Spectroscopic sensor:

- Projects a strip of light that penetrates the fruit
- Reads the strawberry's spectroscopy data
- Non-contact, non-destructive, integrates with robots for automated data collection.

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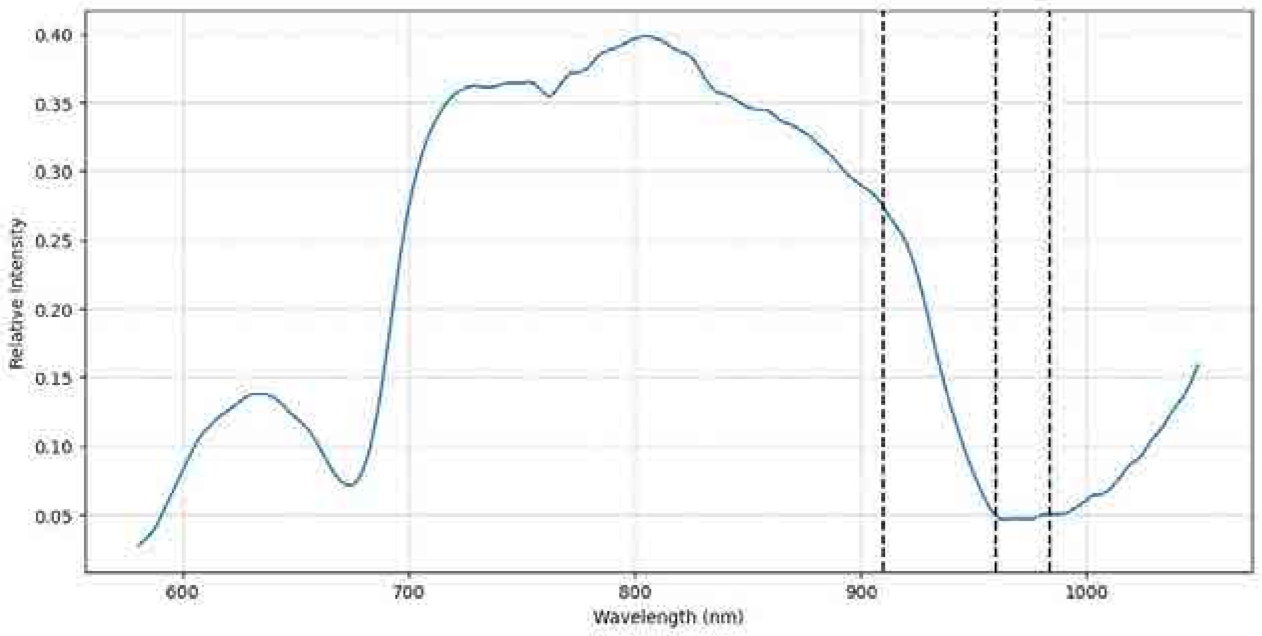
MobileSense Project

Determination of Sugar Content Using Spectroscopy:

- Wavelengths of interest for sugar content: 910nm, 960nm and 984nm
- Sensor accuracy can also be derived from the curve



Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project

- **Mobile Robot:**
  Thorvald Slim
- **Manipulator:**
  Mitsubishi RV-2AJ
- **Spectrometer System:**
  FragoPro
- **3D Camera:**
  RealSense D435
- **3D Lidar:**
  Ouster OS1-128

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

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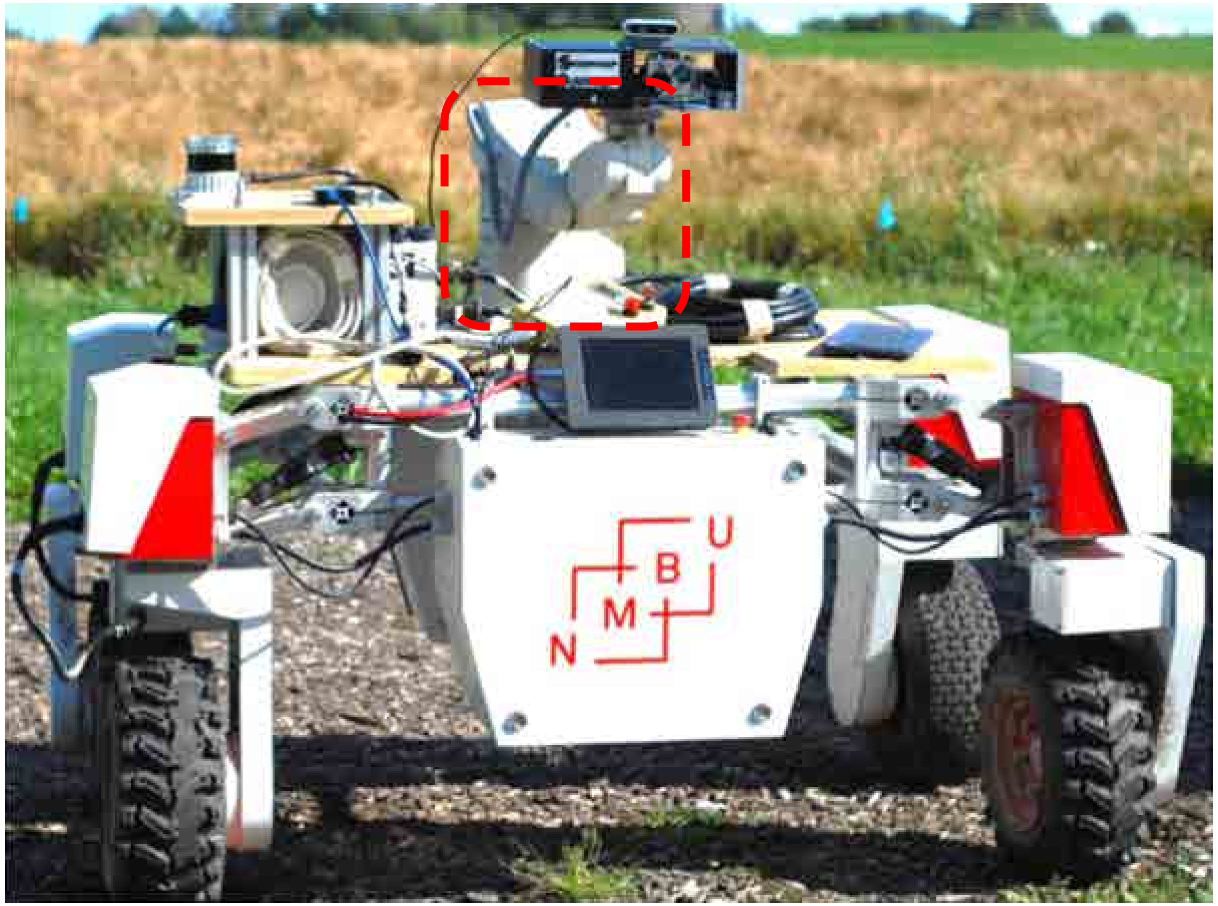
Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project



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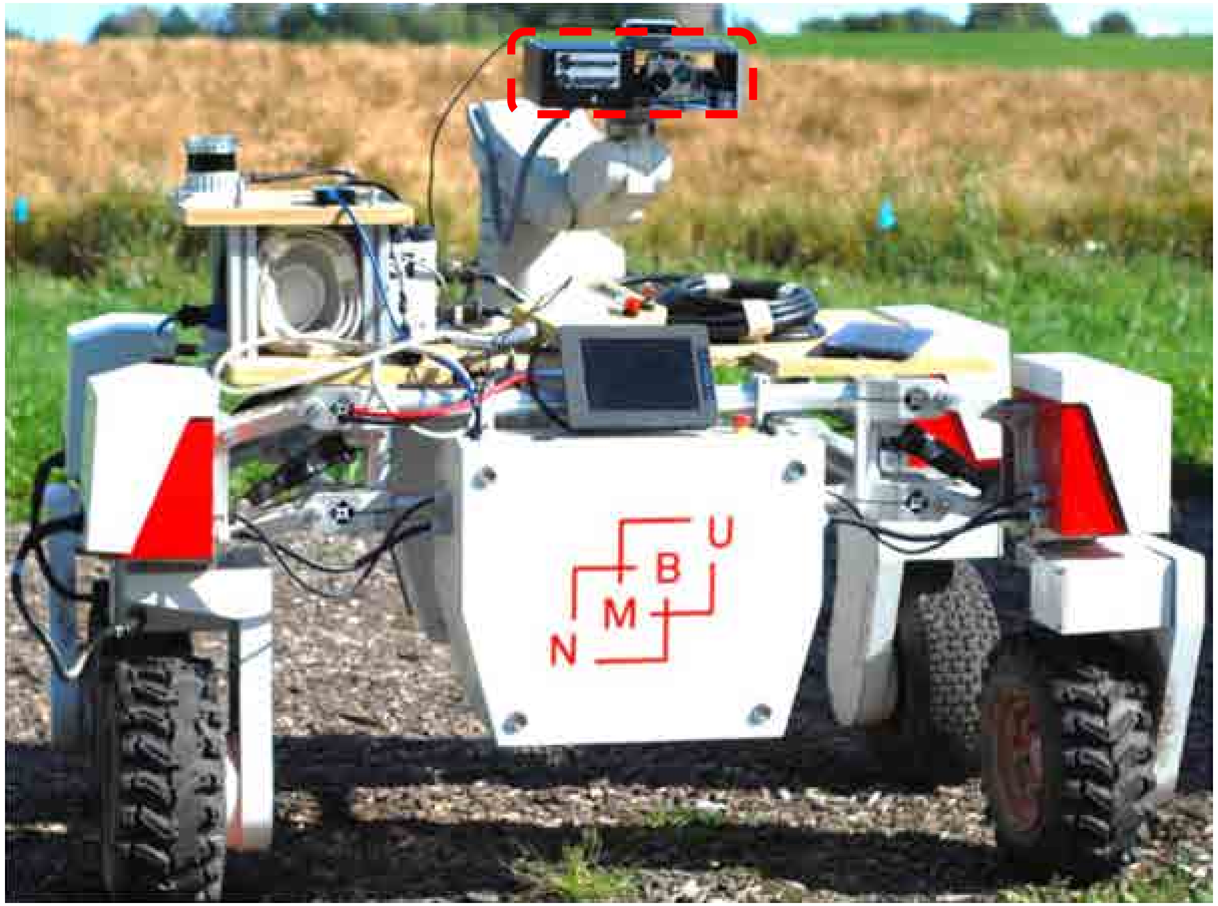

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Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

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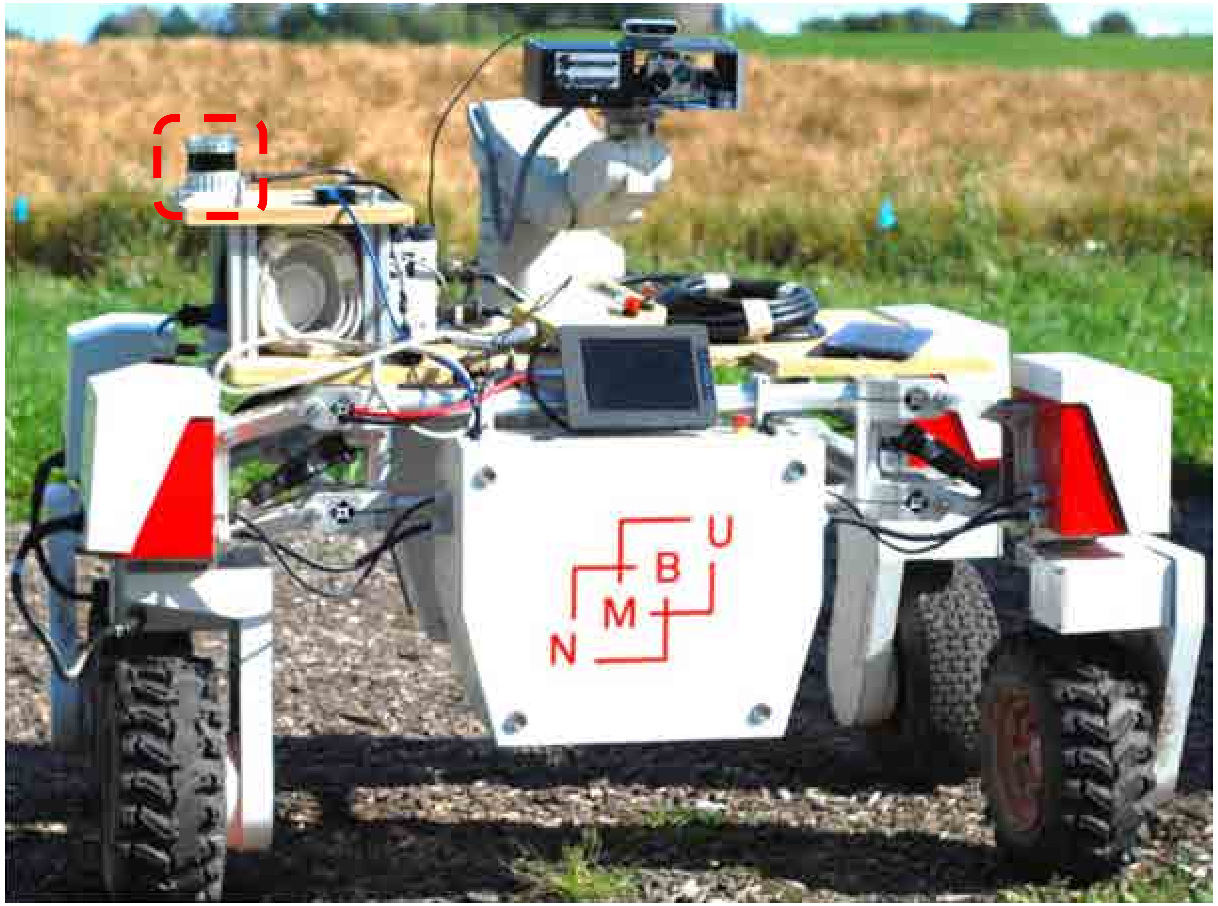
MobileSense Project



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Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project:

- **Complete simulation model**
- **Autonomous performance**
- **Sensor placement optimization**
- **Adaptive sensing**

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project:

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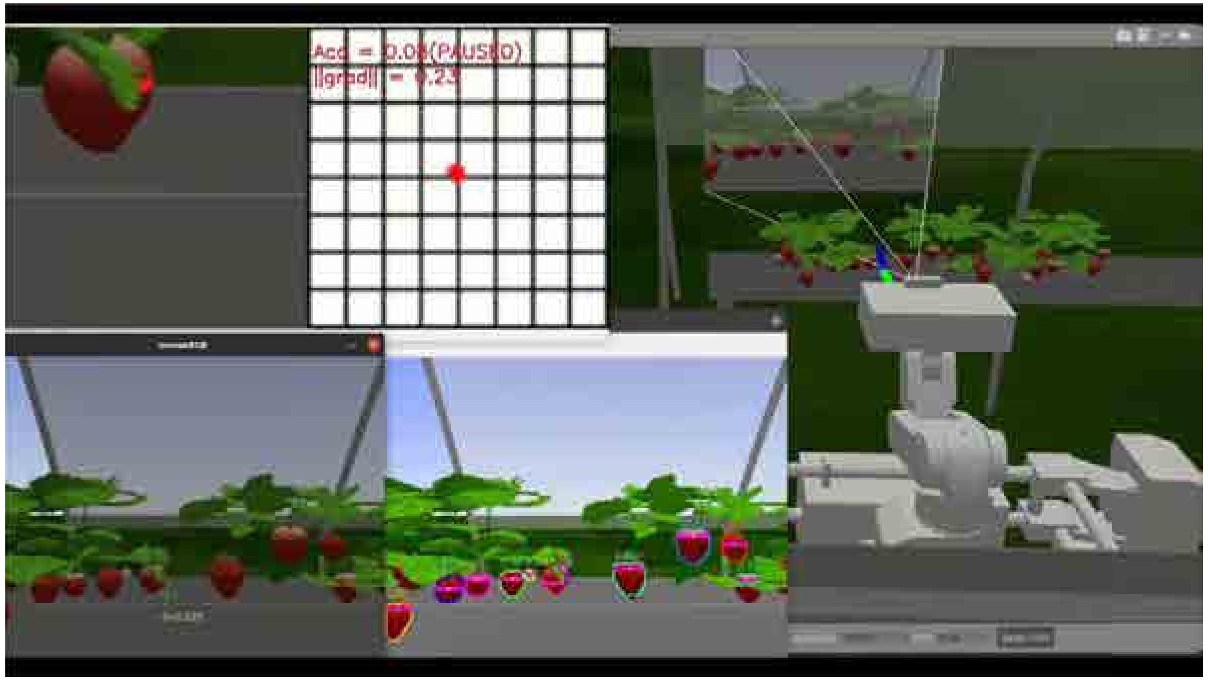

Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project:

- Complete simulation model
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Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

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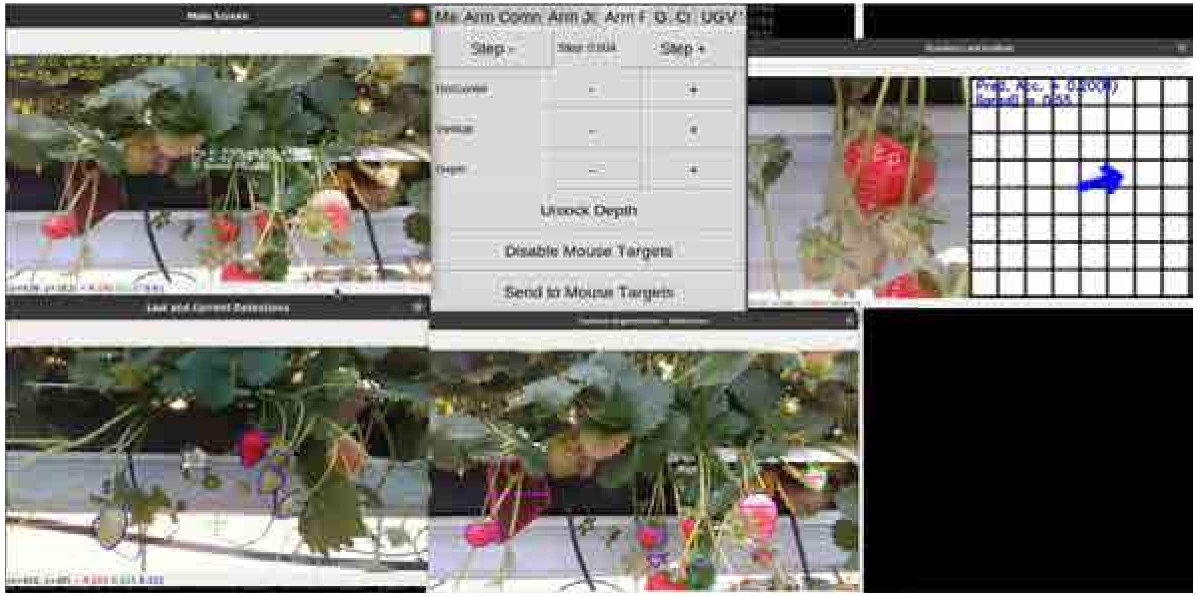
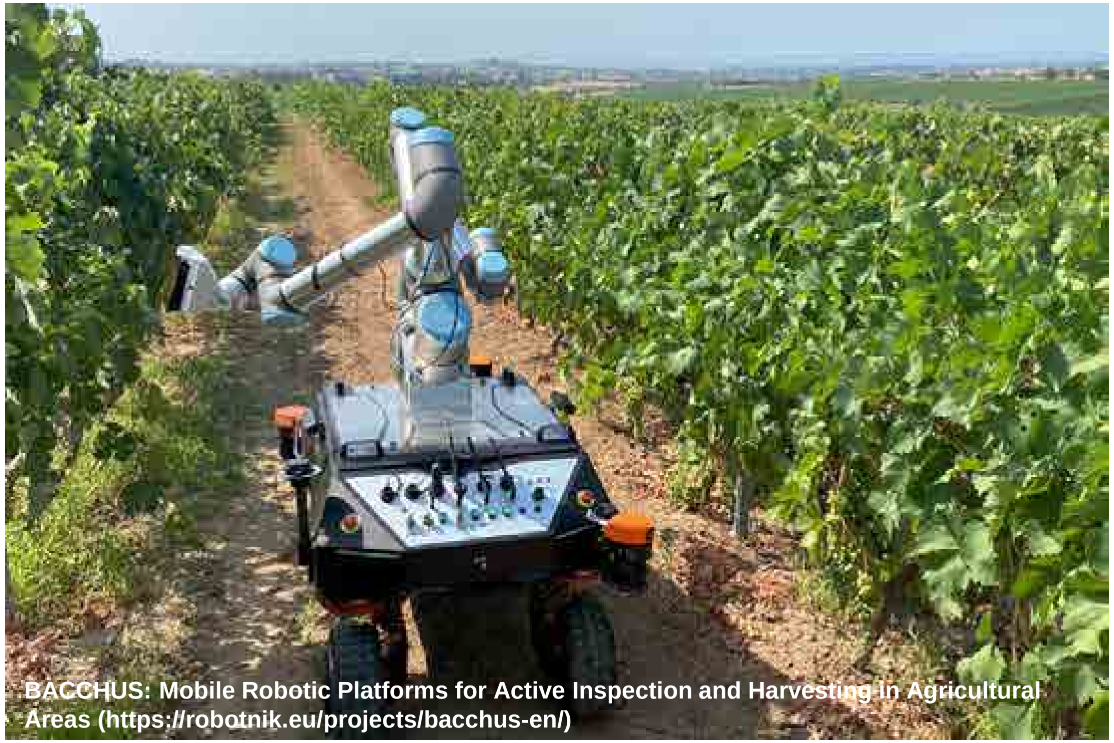


Adaptive Sensing in Agi-Food

DigiFoods SFI: Digital Food Quality

MobileSense Project:


BACCHUS: Mobile Robotic Platforms for Active Inspection and Harvesting in Agricultural Areas (https://robotnik.eu/projects/bacchus-en/)

- Complete simulation model
- Autonomous performance
- Sensor placement optimization
- **Adaptive sensing:**
  - ❑To manipulate the environment for better sensing.
  - ❑There will be an additional manipulator on the robot.

Adaptive Sensing in Agi-Food

DigiFoods NMBU

DigiFoods SFI: Digital Food Quality

MobileSense Project:

Adaptive sensing: <u>Challenges</u>

- **Coordination and Synchronization:** Managing two arms simultaneously for different tasks can be complex.
- **Sensor Integration:** Ensuring accurate data collection while the robot manipulates the environment.
- **Mobility and Navigation:** Navigating uneven terrain while performing tasks.
- **Energy Consumption:** Balancing power usage between sensing and manipulation tasks.

Adaptive Sensing in Agi-Food

DigiFoods

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MobileSense Project:

Adaptive sensing: Solutions

- **Advanced Control Systems:** Implementing sophisticated algorithms for arm coordination.
- **Robust Sensor Fusion:** Integrating multiple sensors for reliable data collection.
- **Autonomous Navigation Systems:** Using GPS and mapping technologies for efficient movement.
- **Efficient Energy Management:** Optimizing power distribution among robotic components.

Thanks for your time …

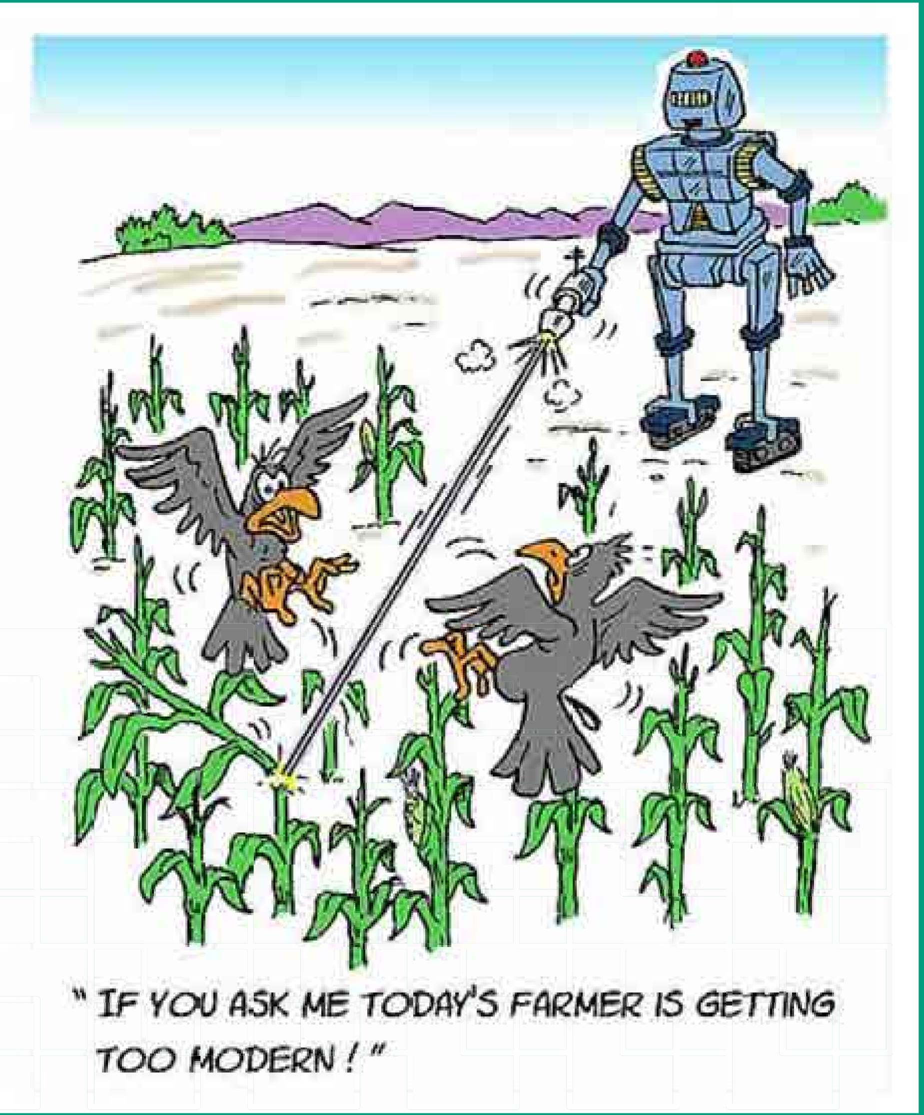


Image processing in fruit and berries

Siv Fagertun Remberg[1] & Ingunn Burud[2]

Norwegian University of Life Sciences (NMBU)

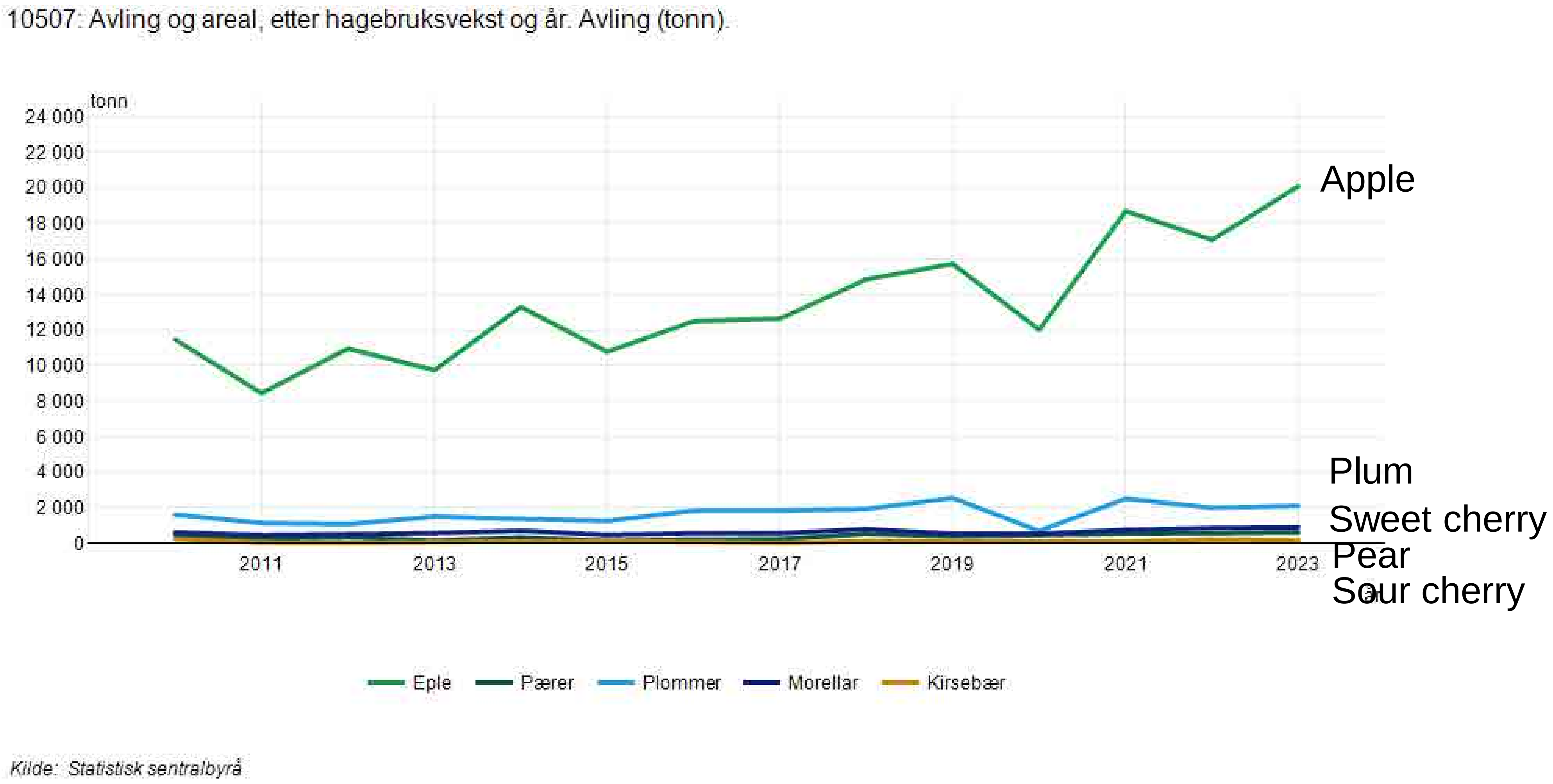
[1]Faculty of Biosciences

[2]Faculty of Science and Technology

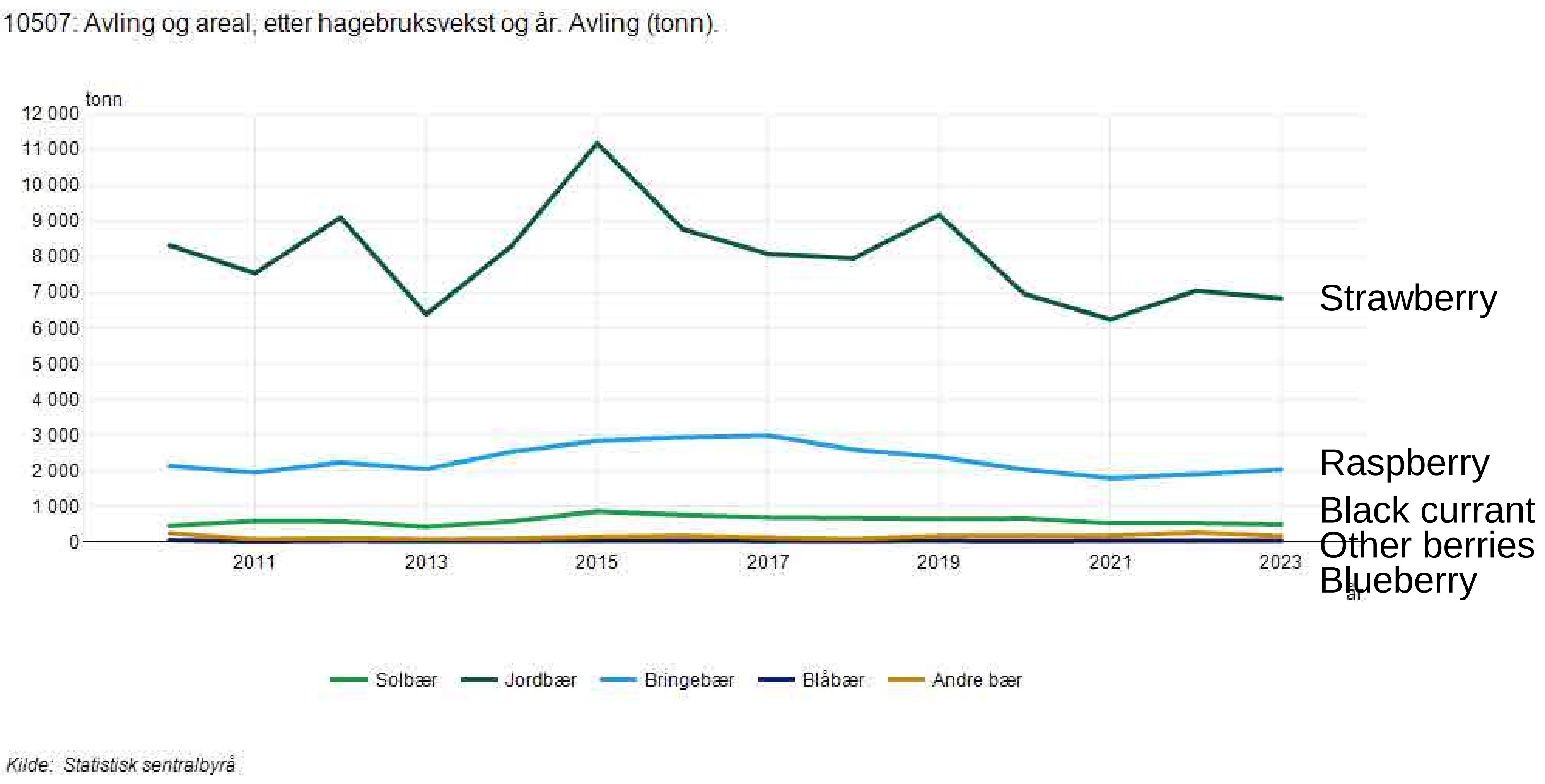
Advances and Innovations in Agricultural Engineering

The 5th NJF – EurAgEng – Agromek Joint Seminar, Herning, Denmark, 26.-27. November 2024

Fruit production in Norway 2011-2023



Berry production in Norway 2011-2023



Fruit and berry production in Norway

- Short growing season, cold climate and challenging weather conditions
- Consequence: some limits on what species and cultivars that can be grown
  - Adapted to the growing conditions in the Nordic region
  - Large variety in genetic material
- The plants must handle all seasons «stuck» in the ground (perennial crops)
  - New growing techiques in commercial production today for some berry species and cultivars
- High investment- and production costs
- Competition: import!

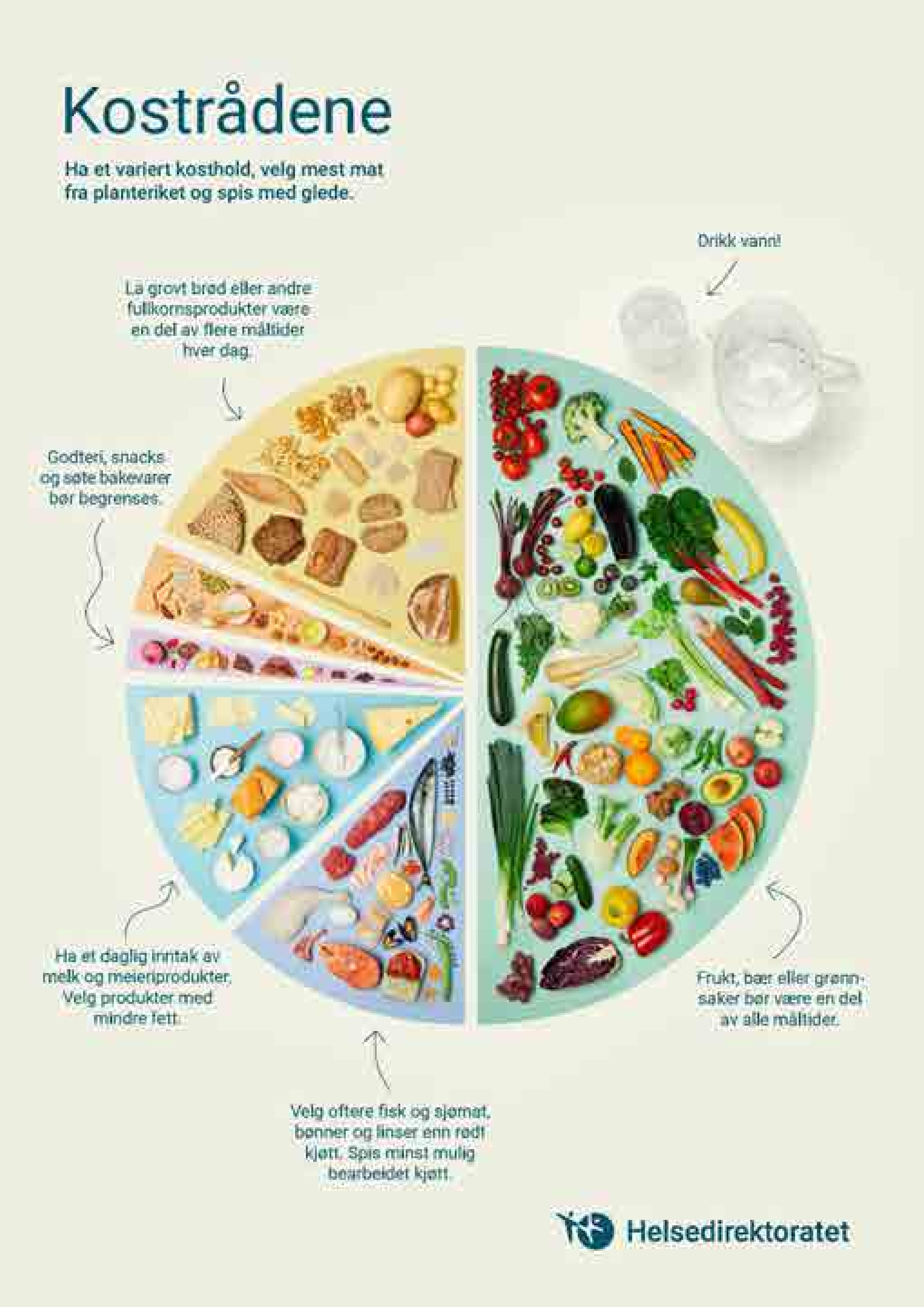
Norwegian fruit and berry production compared to import (2023)

- 33,2 % of all fruit and vegetables consumed in Norway (fresh), is produced in Norway

- Potatoes: 82,4 %
- Vegetables: 53,7 %
- Berries: 24,5 %
  - Raspberry 36%, strawberry 31%
- Fruit: 3,2 %
  - Plum 36%, Cherry 32%, Apple 17%, Pear 4%

5-8 fruit & vegetables a day!

- New/updated dietary advice in Norway 2024
- The amount of f&v pp is not acchieved. By doing so, the Norwegain fruit and vegetable production would increase its production and value
- What is important to increase the intake of f&v?
  - Price, availability, taste
- Taste!
  - Quality – but what is meant by this?

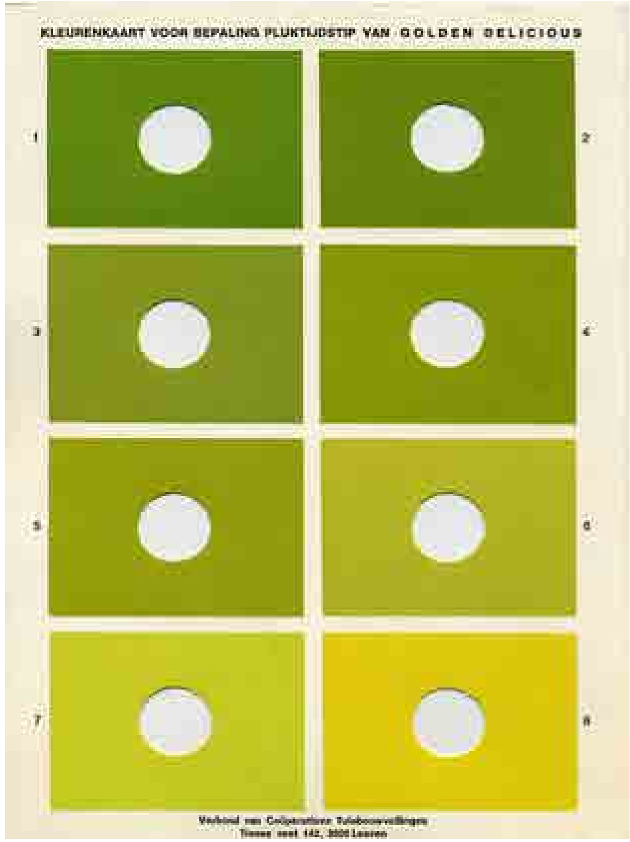


Fruit and berry quality – what does that mean?

- Depends on who you ask!
- How is quality evaluated in fruit and berries?
  - Evaluation/assessment (subjective): different characteristics
  - Measurements (objective): different characteristics– we get a number!
  - There are different standards for different quality characteristics
- Why is the focus on quality in fruit and berries so important?
  - Food loss (production->processing) and waste (at retail & consumer level)
    - must be kept as low as possible!
  - Quality at harvest and postharvest life – quality must be assessed at harvest!
- Which characteristics are important to assess, measure and monitor?

How do we evaluate or measure different quality attributes in fruit and berries with traditional methods?

Quality assessments in fruit and berries: <u>colour</u> (apple)



https://www.setop.eu/en/product/planchettes-colorimetrique-de-maturite-frui

Quality assessments in fruit and berries: colour (berries)

https://www.setop.eu/en/product/planchettes-colorimetrique-de-maturite-fruit

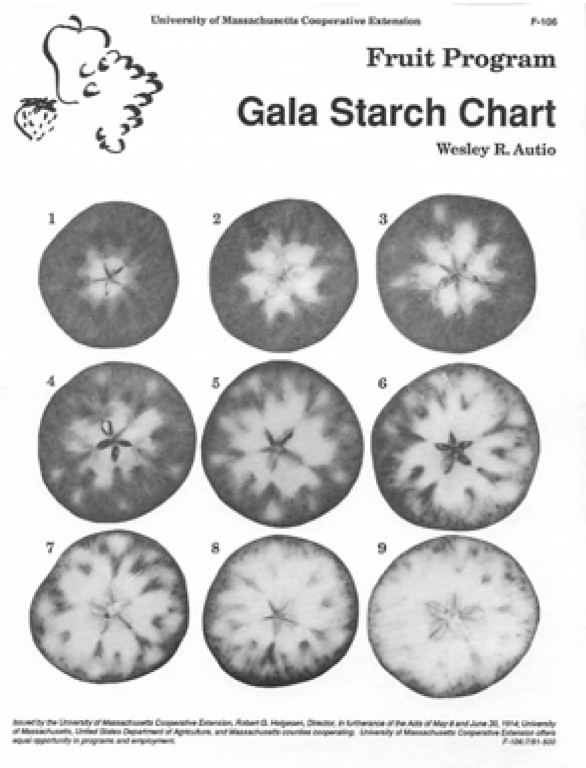
Quality assessments in fruit and berries: firmness

Quality assessments in fruit and berries: soluble solids

Quality assessments in fruit: starch

- Application of an iodine solution on cut apple surface
  - The iodine solution attaches to the starch grains on the apple
  - Scale from 1-10, where 1: max starch and 9/10: no starch left
  - The higher the index, the riper the fruit

- A good example on personal/subjective assessment!
  - Degradation pattern differ between apple cultivars
  - Assessment depends on the person evaluating the fruit




Gravenstein
6/9-18
1
Aroma
10/9-18
Nanna
3/8-18
Tohoku 2
3/9-18
1

How to go from destructive to non destructive measurements?

Some examples from NMBU

Characterisation of quality parameters in apples during ripening

NMBU

- Ripening processes in apples: starch and soluble solids

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 323 (2024) 124903

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Molecular and Biomolecular Spectroscopy

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ELSEVIER

SPECTROCHIMICA ACTA

Check for updates

Raman spectroscopy as a tool for characterisation of quality parameters in Norwegian grown apples during ripening

Olga Monago-Maraña [a,b,*], Jens Petter Wold [b], Siv Fagertun Remberg [c], Karen Wahlstrøm Sanden [b], Nils Kristian Afseth [b]

[a] *Department of Analytical Sciences, Faculty of Science, Universidad Nacional de Educación a Distancia (UNED), Avda. Esparta s/n, Crta. de Las Rozas-Madrid, 28232, Las Rozas, Madrid, Spain*
[b] *Nofima AS – Norwegian Institute of Food, Fisheries and Aquaculture Research, Muninbakken 9-13, Breivika, Postboks 6122 Langnes, NO-9291 Tromsø, Norway*
[c] *Faculty of Biosciences, Department of Plant Sciences, Norwegian University of Life Sciences, PO-BOX 5003, 1432 Ås, Norway*

NMBU
Noregs miljø- og biovitskaplege universitet

Masteroppgåve 2016 60 stp.
Institutt for plantevitenskap

Ikkje-destruktive målemetodar på eple.

Ingvill Hauso
Plantevitenskap

https://doi.org/10.1016/j.saa.2024.124903

http://hdl.handle.net/11250/2398761

Characterisation of quality parameters in apples during ripening

- Hauso 2016: using different non destructive instruments comparing with destructive measurements to predict right harvesting time for Norwegian grown apples
- Q: can these tools be used to sort out apple groups

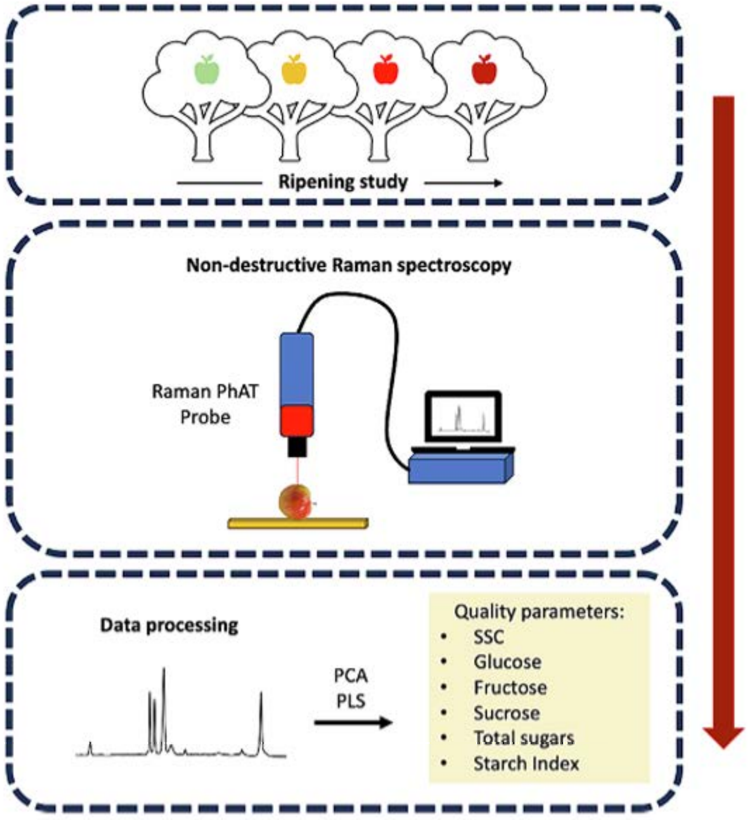
- Results harvesting time:
  - VIS/NIR spectroscopy ok model for soluble solids, but not starch
  - DA meter and Multiplex-3® (index for chlorophyll content)

- Results from sorting prior to and during storage:
  - No clear results based on starch content
  - Soluble solids related to pathological and physiological damage in apples

http://hdl.handle.net/11250/2398761

Characterisation of quality parameters in apples during ripening

- Monago-Maraña et al. 2024: using Raman spectroscopy to characterise quality parameters in two Norwegian grown apple cvs. 'Elstar' and 'Aroma'
- Could this be a tool to follow ripening processes in apple fruits for more accurate harvesting time and more uniform quality?



- Results:
  - Higher starch content in 'Elstar' than 'Aroma'
  - Starch degradation could be detected in the Raman spectra

«The results suggest that Raman spectroscopy in the future could be used to determine the optimal time of harvesting and to sort apples into different degrees of ripeness»

https://doi.org/10.1016/j.saa.2024.124903

Characterisation of quality parameters in strawberry during ripening

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 309 (2024) 123853

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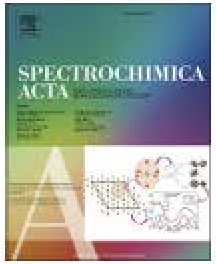
journal homepage: www.journals.elsevier.com/spectrochimica-acta-part-a-molecular-and-biomolecular-spectroscopy



Inter seasonal validation of non-contact NIR spectroscopy for measurement of total soluble solids in high tunnel strawberries

Jens Petter Wold [a,*], Petter Vejle Andersen [a], Kjersti Aaby [a], Siv Fagertun Remberg [b], Anders Hansen [c], Marion O'Farrell [c], Jon Tschudi [c]

[a] Nofima AS - Norwegian Institute of Food, Fisheries and Aquaculture Research, PB 210 NO-1431, Aas, Norway
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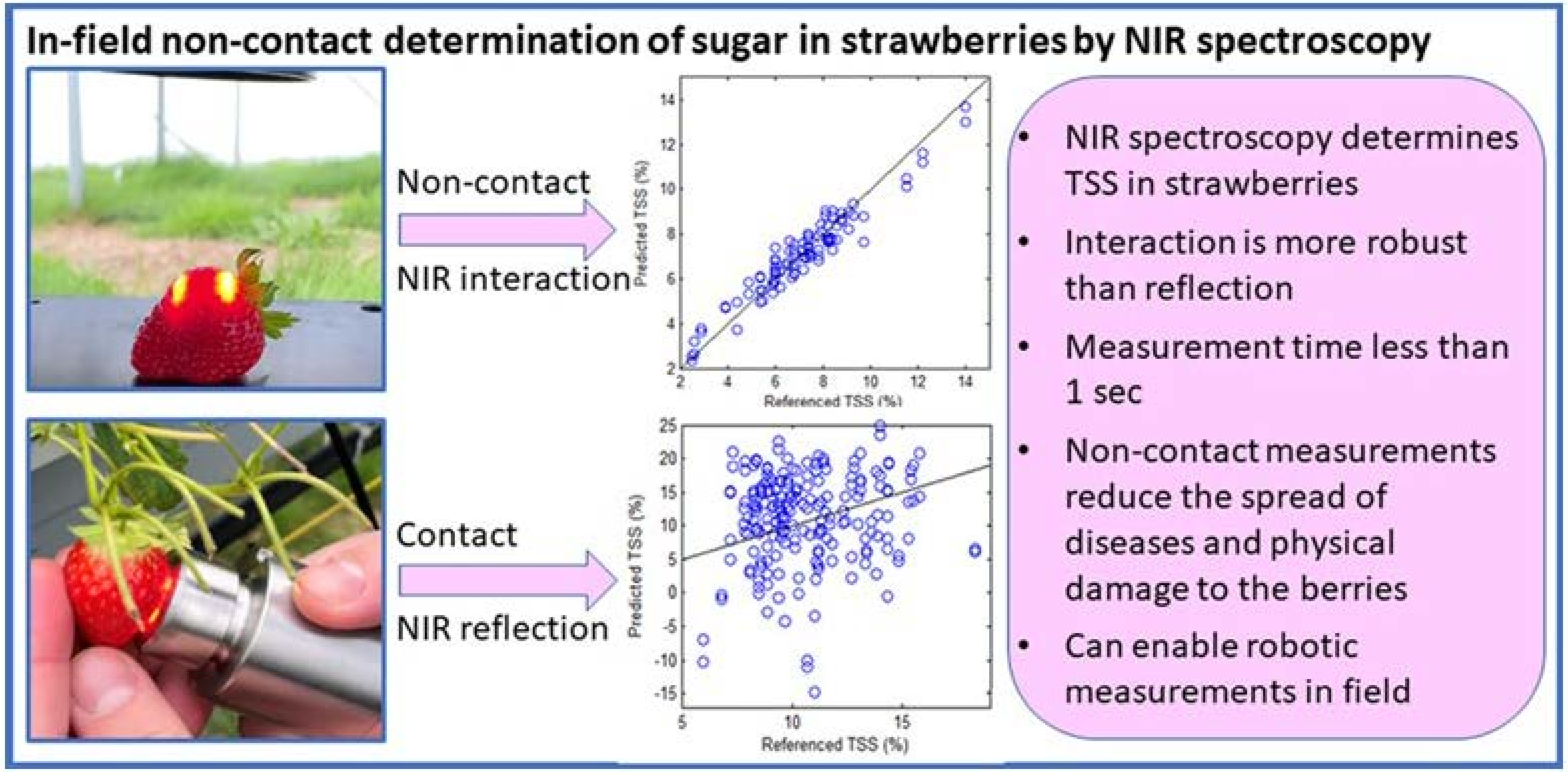
Characterisation of quality parameters in strawberry during ripening

- Wold et al. 2024: using NIR spectroscopy to measure soluble solids in strawberry
- Could this tool be used to predict the content of soluble solids in single berries?
- Comparison of a commercial handheld NIR reflection instrument and a special designed prototype system

- Interaction NIR spectroscopy is well suited for non-contact determination of total soluble solids in strawberries.
- NIR interaction measurements are less affected by irrelevant fruit surface properties than reflection.
- The method works well outside in the field with ambient daylight.
- Measurement time is less than 1 sec.
- Measurements in the 760 – 1080 nm region has a probing depth of about 6–7 mm into the strawberries.



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Examples on non-destructive quality measurements in f&b

- Using hyperspectral imaging for measuring quality components in strawberry and apple
  - Hyperspectral imaging – similar to NIR spectroscopy but with a full spectrum in each pixel
  - Cooperation with Realtek and Biovit (NMBU) + University of Foggia, Italy
  - Could be used to estimate soluble solids (sugar content)?
  - Other components?
  - What is possible?
  - What are the limitations?
  - What is possible in the future?

Where do we go from here?

- Still common to use destructive quality measurements in fruits and berries
- In the future, we have to start implementing non destructive measurements:
  - Big opportunities in different productions!
    - Field, tunnel, greenhouses, plant factories and in laboratories
  - Costs & investments..
  - Need and possibilities for rapid, non-contactable instruments used during planning, production, sorting and packing, storage and distribution
  - Results: less food loss and waste, and thus a more sustainable food production