Agricultural Robotics

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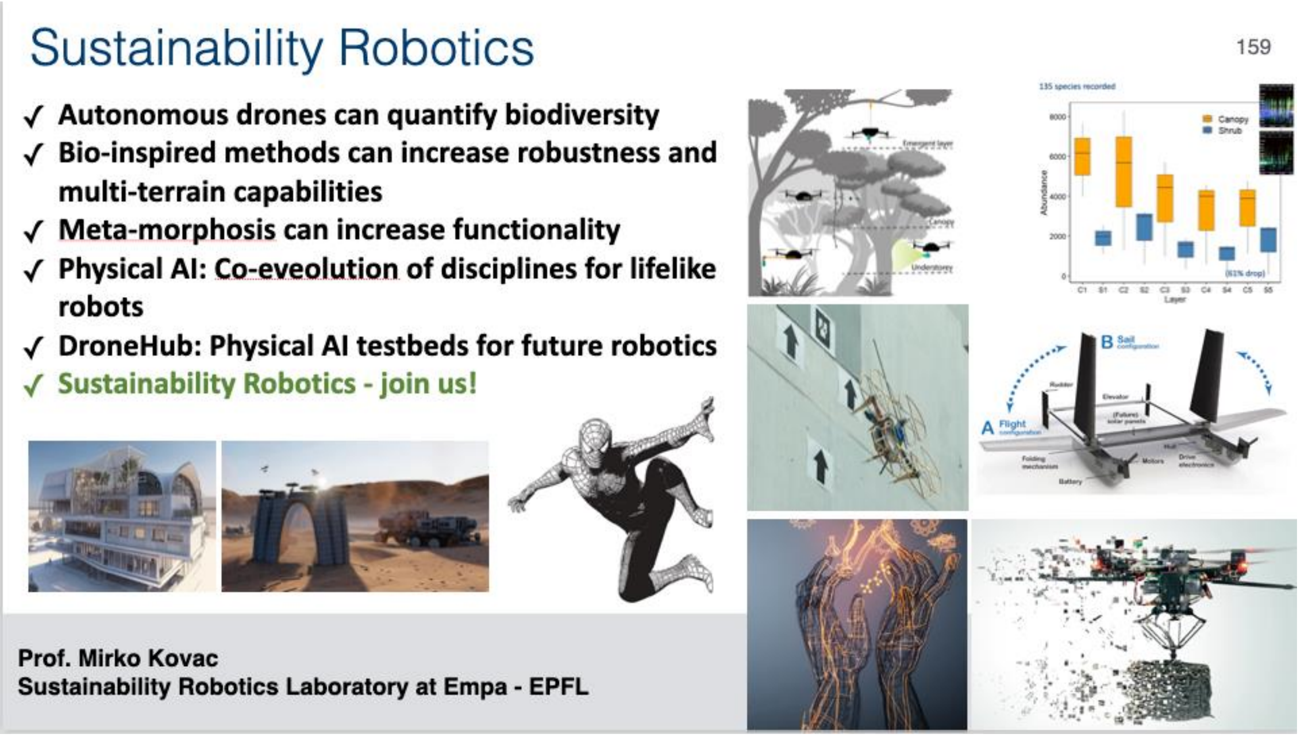
	Lecture Content	Bonus Content
1	Introduction to Sustainability Robotics	Intro to project development, hypothesis, project pitch (part 1)
	Element 1: EARTH	
2	Agriculture robotics overview (part 1)	Intro to project development, hypothesis, project pitch (part 2)
3	Agriculture robotics overview (part 2)	Guest lecture EcoRobotix
4	Autonomy for agricultural robotics	Guest presentation from Patrick Meier on the innovation pipeline
5	Multi-spectral sensing and data analysis	Tutorial to image processing
	Element 2: AIR	
6	Drone sizing fundamentals	Lecture on sustainable business and economic growth
7	Drone Aerodynamics	Guest lecture from Pix4D
8	Biodegradable drones	Personal tutorial and TA hour
9	Drones for infrastructure monitoring and repair with perching drones	Personal tutorial and TA hour
	Element 3: WATER	
10	Underwater robotics	Training on video editing
11	Aquatic systems innovation (aerial aquatic and soft underwater)	Training on data presentation
	Element 4: FIRE	
12	Search and rescue robotics	Guest lecture from FireDrone
13	Guest lecture and drop in	Guest lecture from Inverto.earth
	Element 5	
14	Final Presentations and Examination	

Recap from last week



0 Sustainability Robotics

The process of proposal development

Develop project idea → **Identify expertise** → **Build consortium** → **Define Work packages** → **Write proposal** ↔ **Draft visuals** → **Edit proposal** → **Proposal risks/plan** → **Finalise proposal** → **Submit proposal**

Develop project idea
- ✓ Novel, creative
- ✓ Impactful
- ✓ Needed

Identify expertise
- ✓ Skill fit
- ✓ Culture fit
- ✓ Track record

Build consortium
- ✓ Clear tasks
- ✓ Resource split
- ✓ Trust

Define Work packages
- ✓ Clear
- ✓ Complete
- ✓ Needed

Write proposal

Draft visuals
- ✓ Visionary
- ✓ Pilot results
- ✓ Professional

Edit proposal
- ✓ Narrative/logic
- ✓ Clear scope
- ✓ Clear focus

Proposal risks/plan
- ✓ Impact levels
- ✓ Honest
- ✓ Accountable

Finalise proposal
- ✓ 100% correct
- ✓ Word count
- ✓ Formatting

Submit proposal
- ✓ On time
- ✓ Complete
- ✓ Approved

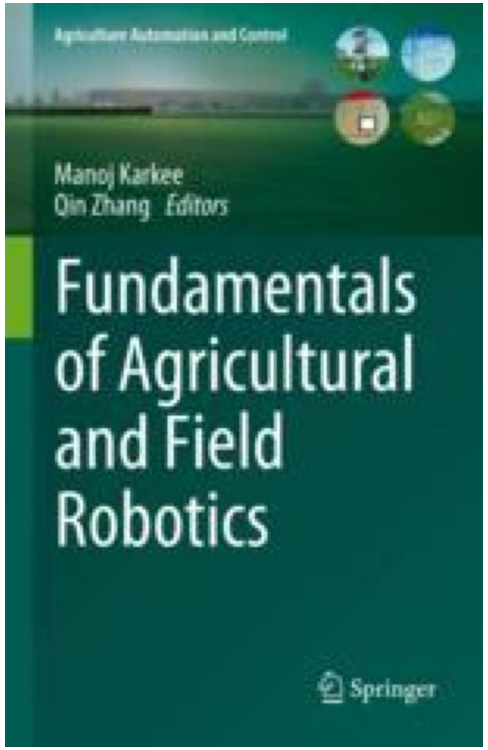
Learning goals

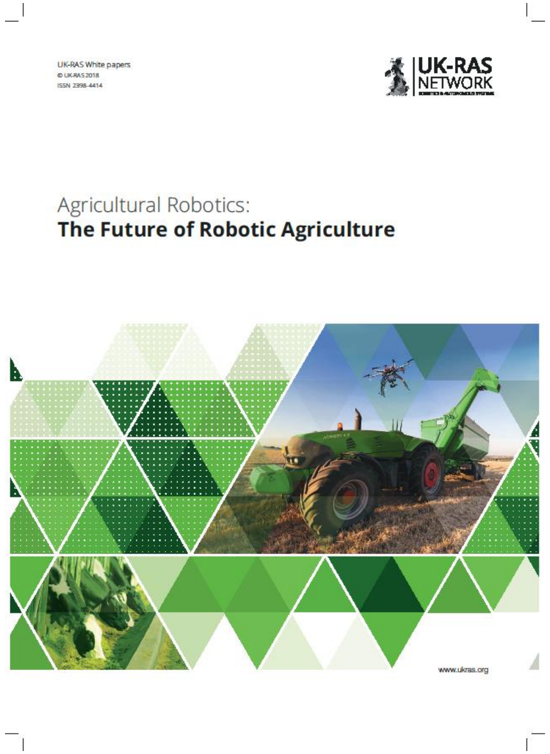
- Explore critical challenges in agriculture that robotics can address
- Learn what ways a robot can harvest plants
- Understand how robotics can improve livestock management
- Identify what is automated farming and what it entails
- Understand what is precision agriculture
- Be able to discuss ethical considerations from robotics in agriculture

Reference material

- **Fundamentals of agricultural and field robotics.**
  - https://link.springer.com/book/10.1007/978-3-030-70400-1
  - Chapters 2, 3
  - Access through EPFL bibliography
  - Karkee M, Zhang Q, editors. Fundamentals of agricultural and field robotics. USA: Springer; 2021 Jul 27.

- **Agricultural robotics: the future of robotic agriculture.**
  - https://arxiv.org/pdf/1806.06762
  - Duckett T, Pearson S, Blackmore S, Grieve B, Chen WH, Cielniak G, Cleaversmith J, Dai J, Davis S, Fox C, From P. Agricultural robotics: the future of robotic agriculture. arXiv preprint arXiv:1806.06762. 2018 Jun 18.



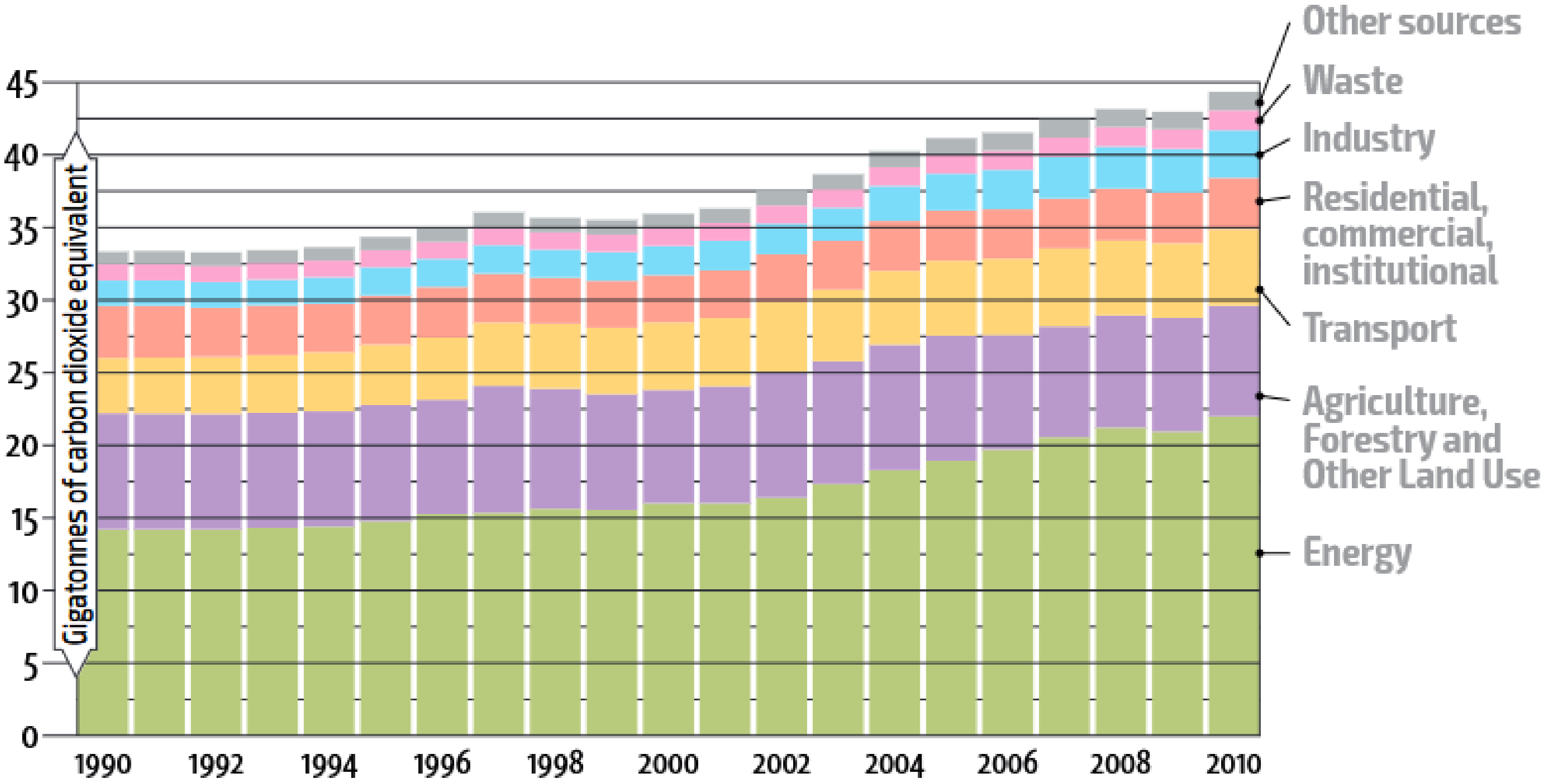


1) Slide specific sources / image sources / extra reading

Motivation

- Greenhouse gas reduction
- Labour shortage
- Food scarcity
- Farmer and worker safety
- Biodiversity

Global greenhouse gasses



1) Food and Agricultural Organisation. https://openknowledge.fao.org/server/api/core/bitstreams/8a7dd930-961f-4855-9952-74a7c221af7b/content

Labour shortage

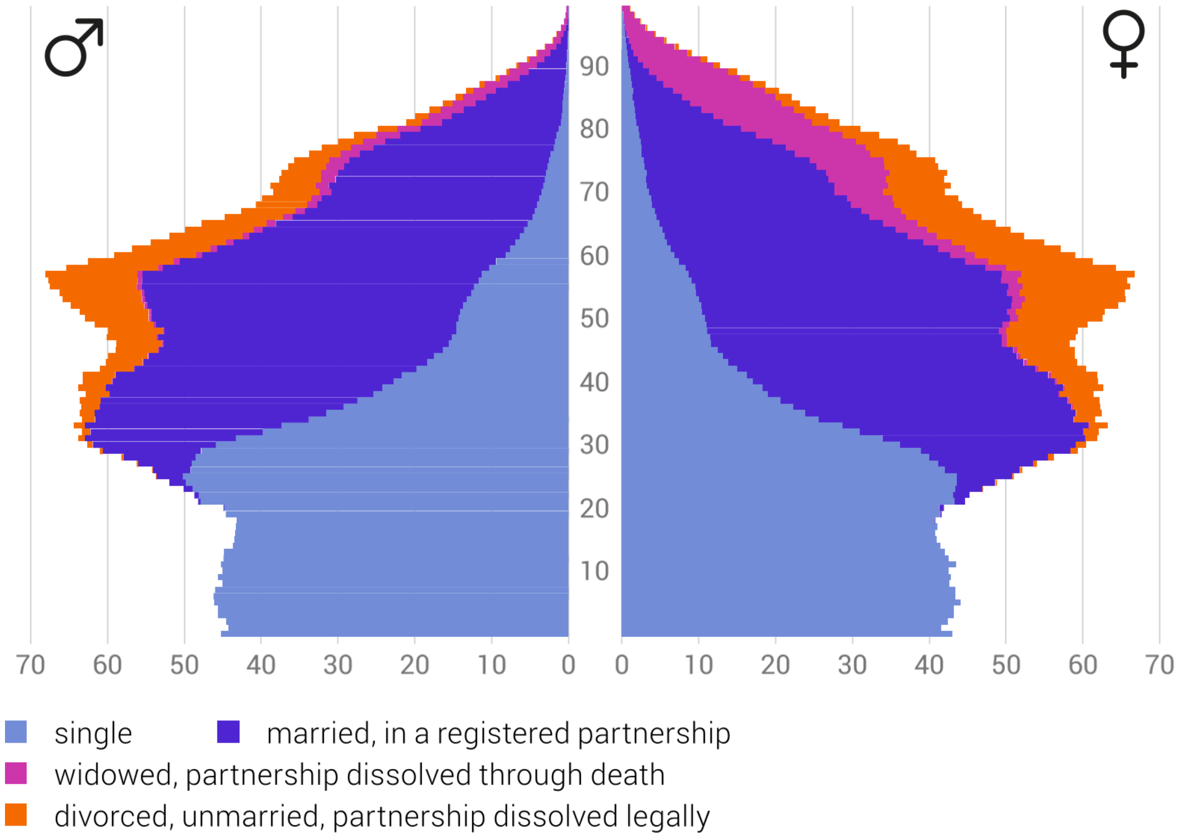
- Population change
  - Aging population, plummeting fertility rates
  - Trend in movement from rural to urban areas (next slide)

- Farming requires large amounts of labour
  - Rise in university educated and highly trained labour

- *Not enough labourers to effectively run farms*

Population pyramid by age, sex and marital status, on 31.12.2021

Number of people in 1000



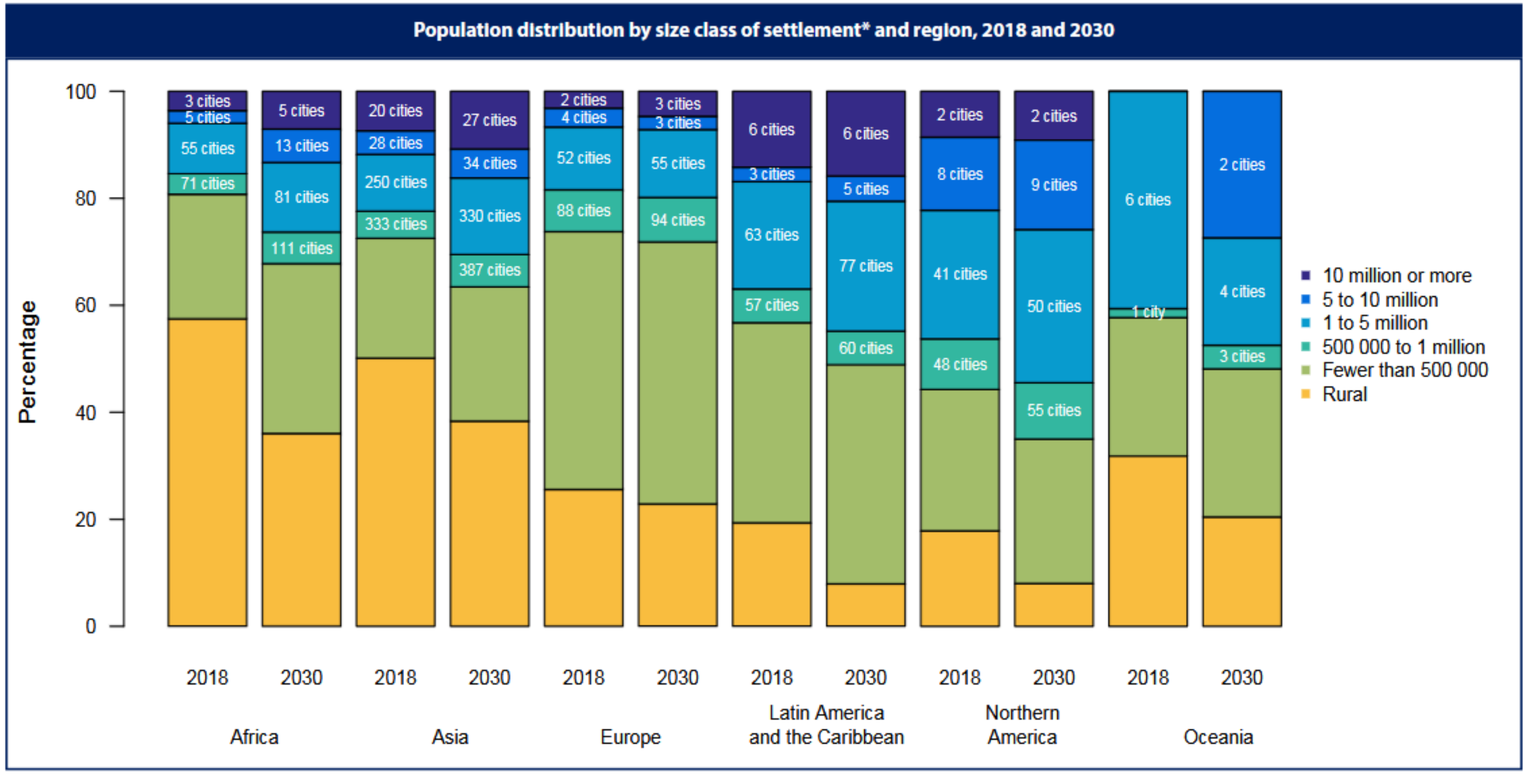
Source: FSO – STATPOP

Swiss population pyramid, 2021

1) https://www.bfs.admin.ch/asset/en/23104092

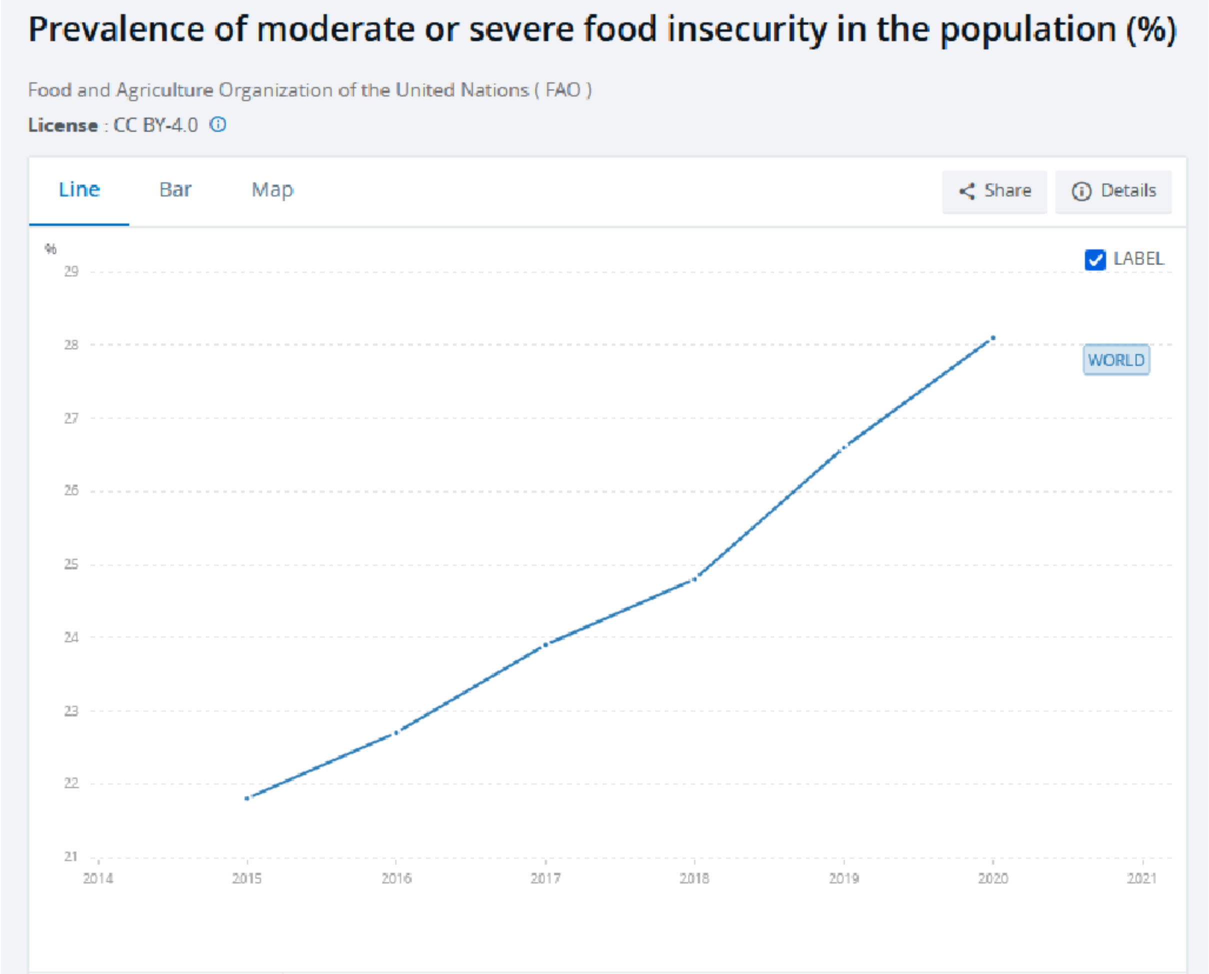
Urbanisation

- Populations moving from rural to urban areas
  - Movement away from agriculture



1) https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Jan/un_2018_worldcities_databooklet.pdf

Food insecurity increasing

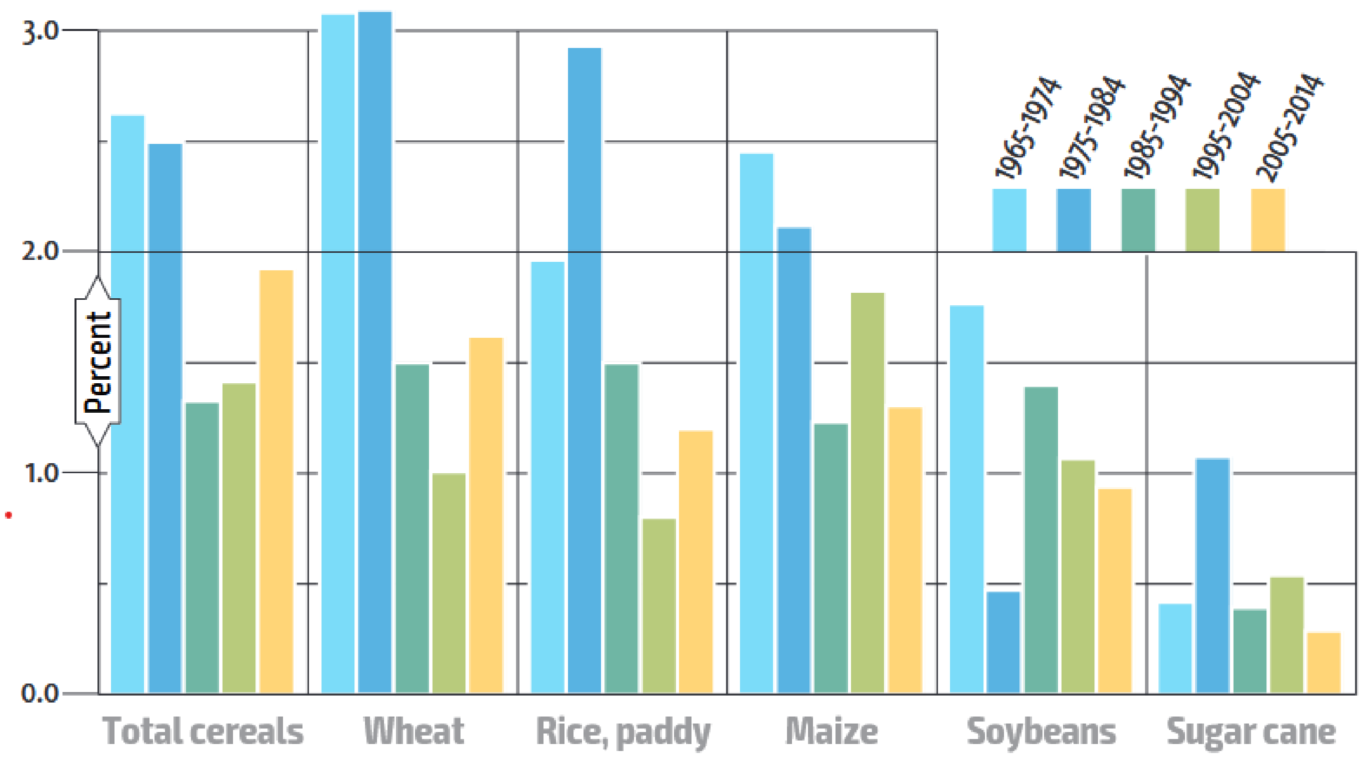


1) https://data.worldbank.org/indicator/SN.ITK.MSFI.ZS?end=2021&start=2014&view=chart

Food and Agricultural Organisation

- Growing population – increase of crop yield decreasing

Figure 1 Average annual rate of increase in crop yields



1) https://openknowledge.fao.org/server/api/core/bitstreams/8a7dd930-961f-4855-9952-74a7c221af7b/content

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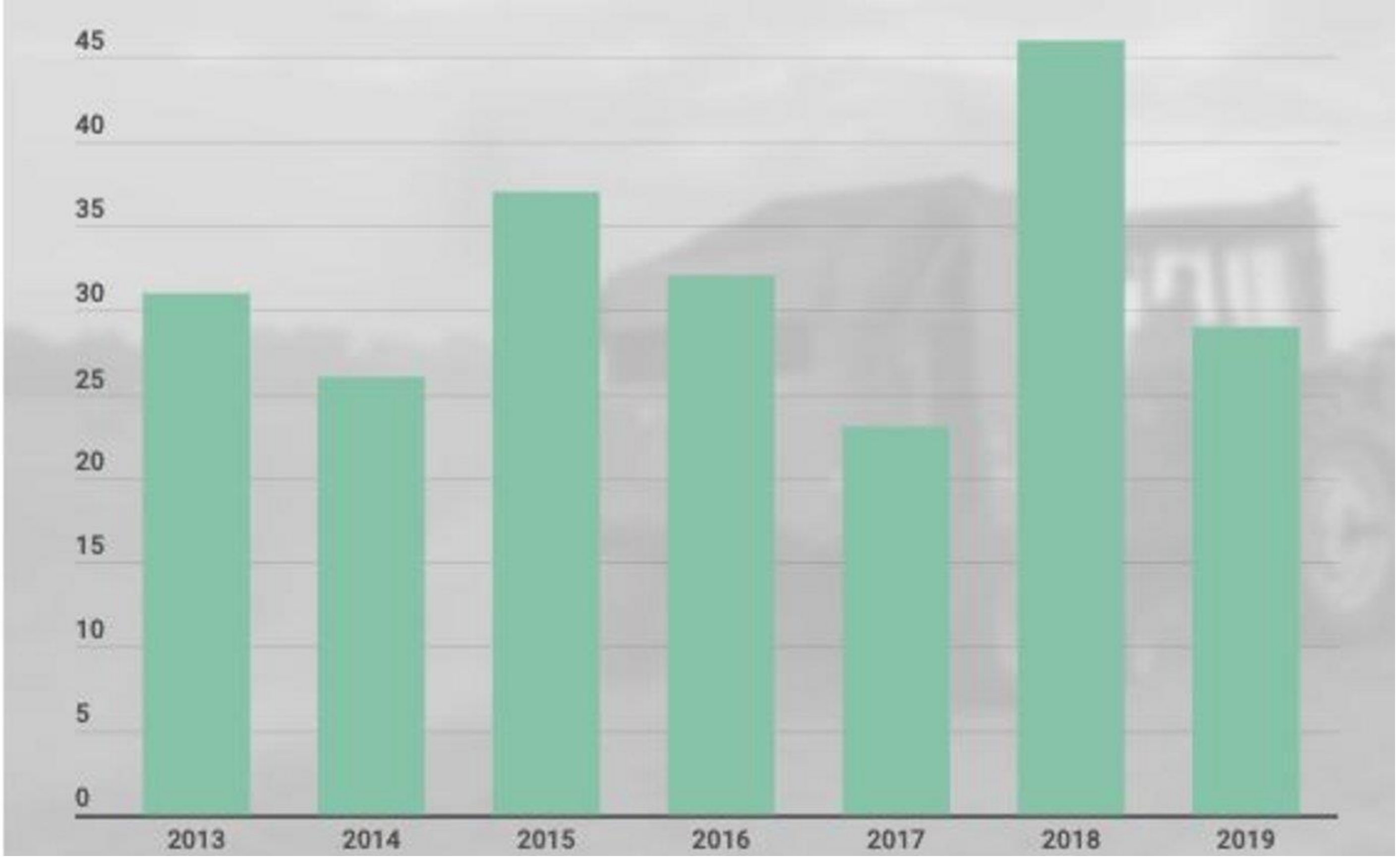
Agricultural safety

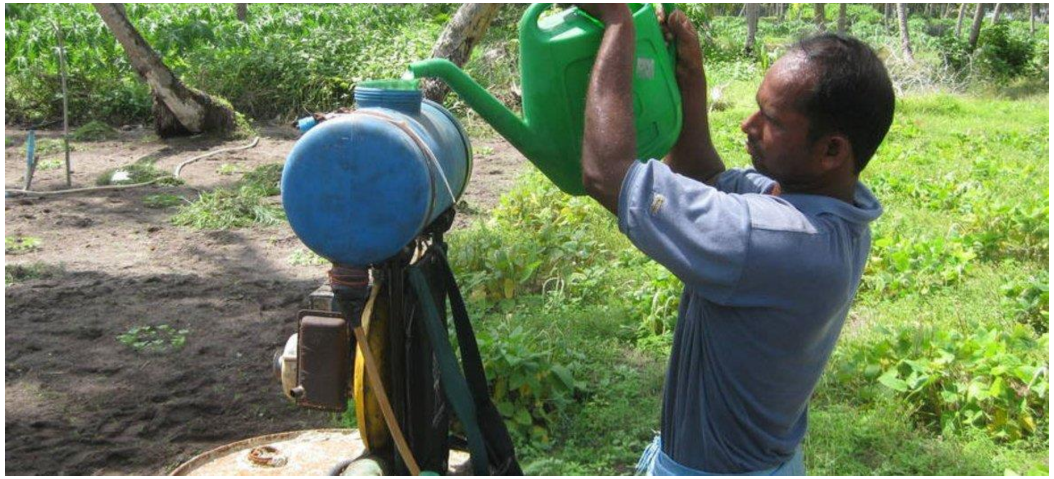
- Fatal accidents in Swiss agriculture



1) https://www.bauernzeitung.ch/artikel/landwirtschaft/infografik-toedliche-unfaelle-in-der-landwirtschaft-359768

Pesticide handling

- 200,000 annual deaths associated with pesticide poisoning
  - 99% in developing nations
- Long exposure to pesticides can cause:
  - Alterations to nervous system, muscle damage, cancer, Alzheimer's, Parkinson's, hormone disruption, developmental disorders and sterility
- Effects to liver and kidneys observed with just 3 days exposure!
- Problem is also awareness
  - Not all farmers informed of all pesticide risk
    - E.g., contamination through skin contact
- Organic farming can reduce exposure to farmers



1) https://pmc.ncbi.nlm.nih.gov/articles/PMC7879472/
2) https://news.un.org/en/story/2017/03/552872
3) https://www.organic-center.org/sites/default/files/project/2018/09/Reducing-Occupational-Pesticide-Exposure.pdf ; https://pmc.ncbi.nlm.nih.gov/articles/PMC4532340/

Monoculture farming

- One crop per field
  - Easier to handle
  - Same planning, maintenance, and harvesting for all

- Downsides:
  - Reduced biodiversity
  - Higher use of pesticides
  - Higher soil degradation
  - Higher water use
  - Reduced pollinator nutrient diversity

1) https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/rise-and-fall-monoculture-farming https://eos.com/blog/monoculture-farming/

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Challenges in agriculture (summary)

- Food and Agricultural Organisation
  - Climate Change
  - Resource Scarcity
  - Labour Shortages
  - Pests and Diseases
  - Growing Population

- World Bank
  - Environmental Sustainability
  - Market and Economic Pressures
  - Technological Integration and Education

Food and Agriculture Organization of the United Nations

WORLD BANK GROUP

All of these challenges lead to opportunities in robotics

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How do you think robots can be used in agriculture?

1 Go to wooclap.com

2 Enter the event code in the top banner

Event code
YYNHBJ

Agricultural robot - definition

*An agricultural robot as defined by is a **reprogrammable mechatronic device** that performs **different farming tasks**, often interacting with the biological and physical environments **without direct human intervention** and it adapts to its environment through data collection and analysis.*

1) Attard G. Robots in Livestock Management. InEncyclopedia of Smart Agriculture Technologies 2023 Apr 25 (pp. 1-12). Cham: Springer International Publishing.

Labour – Dull, difficult, and dirty

- Farming is tedious and labour intensive
  - Harvesting often not mentally engaging

- Farming is dangerous
  - Severe accidents every year

- *Goal is not to replace farmers, but to replace the* ***difficult*** *and* ***unsafe*** *parts with robotics*

1) https://www.dreamstime.com/farm-workers-loading-boxes-close-view-group-picking-vegetable-crops-near-chilliwack-bc-canada-september-image126486176

Robotics benefits towards Agriculture

- Labour Efficiency
  - Labour shortages
  - Repetitive / labour-intensive tasks
- Precision Farming
  - Optimizing input use
    - Water, pesticides, fertilizers
  - Boost yields
- Monitoring and Data Collection
  - Real-time measurements
- Health and Safety

1) https://www.parvalux.com/how-robots-are-used-in-agriculture/
2) Agroscope, Dr. Louis Sutter

Agricultural safety by robotics (1)

- Reduction of Physical Strain
  - Repetitive and labour-intensive tasks
    - Lifting heavy loads
    - Bending for extended periods during harvests.
- Minimizing exposure to hazards
  - Automated pesticide and herbicide spraying
  - Operators kept away from direct exposure to harmful chemicals

1) https://www.swisswine.ch/en/news/grape-harvest-in-switzerland
2) Agroscope, Dr. Louis Sutter

Agricultural safety by robotics (2)

- Safe Operation in Extreme Environments
  - Steep slopes
  - High-temperature conditions
- Reduction of accidents with heavy machinery
- Biosecurity and hygiene
  - Diseases and contamination

1) https://www.antoniocarraro.it/en/catalogue/ttr-ergit-100
2) Agroscope, Dr. Louis Sutter

Example: Robot mowing

Probotics

Scythe

1) https://www.youtube.com/watch?v=QM5uRdX4UAY https://www.youtube.com/watch?v=qrS_TfJfXKA

Section: Automated Farming

Automated farming

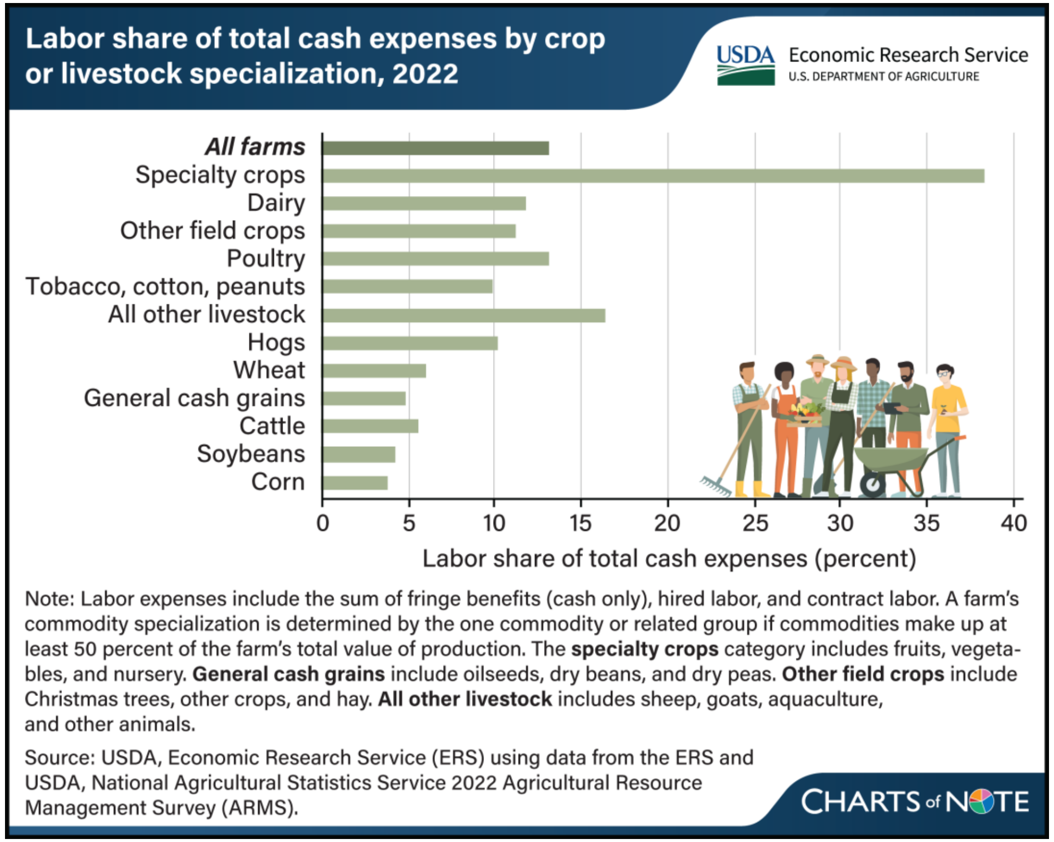
- Robots which interact the physical farm

- Applications
  - Harvest / plant maintenance
  - Livestock
  - Aquaculture
  - Vertical farming

1) https://www.youtube.com/watch?v=gMaQq_vRaa8

Harvest

- Specialty crops have highest labour costs
- High-value crop
  - Labour cost correlated to harvesting
  - Size of crop vs amount of effort
- Berry farming very labour intensive



1) https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=110172

Harvest - Components of a robot

- Hardware (and mechatronics)
  - Manipulation / **end-effector**
  - External sensor / vision
  - Internal sensors
  - Power source

- Software (and algorithms)
  - Path planning
  - Control
  - Object handling system
  - Safeguards

(a) (b)

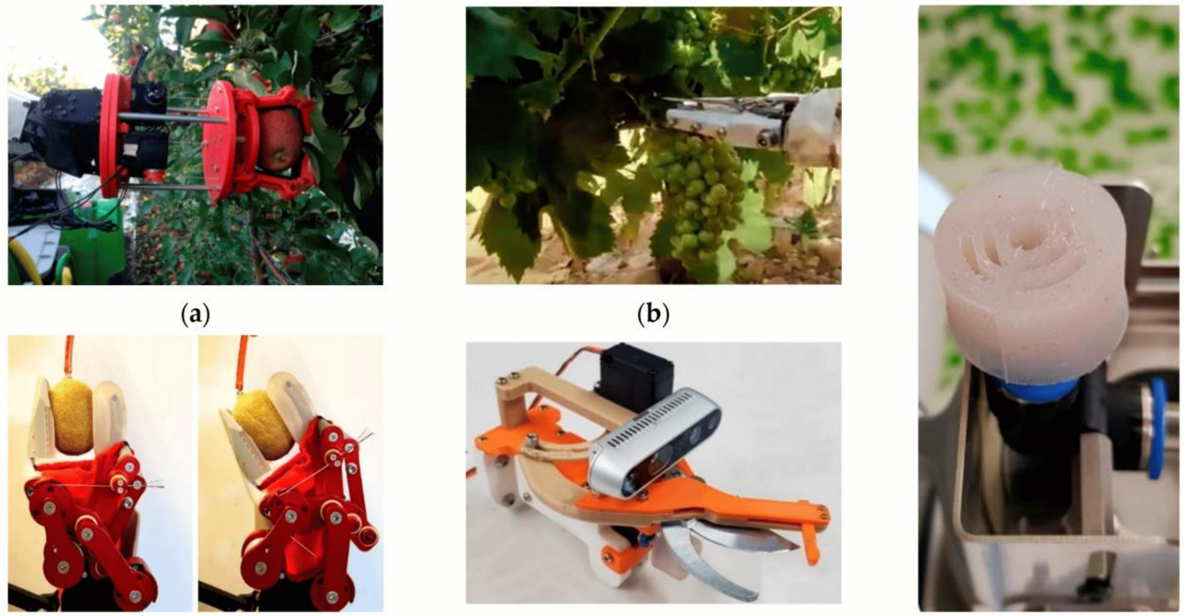
1) Vrochidou E, Tsakalidou VN, Kalathas I, Gkrimpizis T, Pachidis T, Kaburlasos VG. An overview of end effectors in agricultural robotic harvesting systems. Agriculture. 2022 Aug 17;12(8):1240.

Harvest – End effector

- End effector
  - Anything that attaches to the wrist of a robotics arm
    - Robotic “hand”

- Poor picking can damage crops
  - Different grasping for different fruits

- Types of harvesting end effector
  - Fruit-holding
  - Stem-holding
  - Direct-separating
  - New and novel (soft material)



(a) (b) (c) (d) (e)

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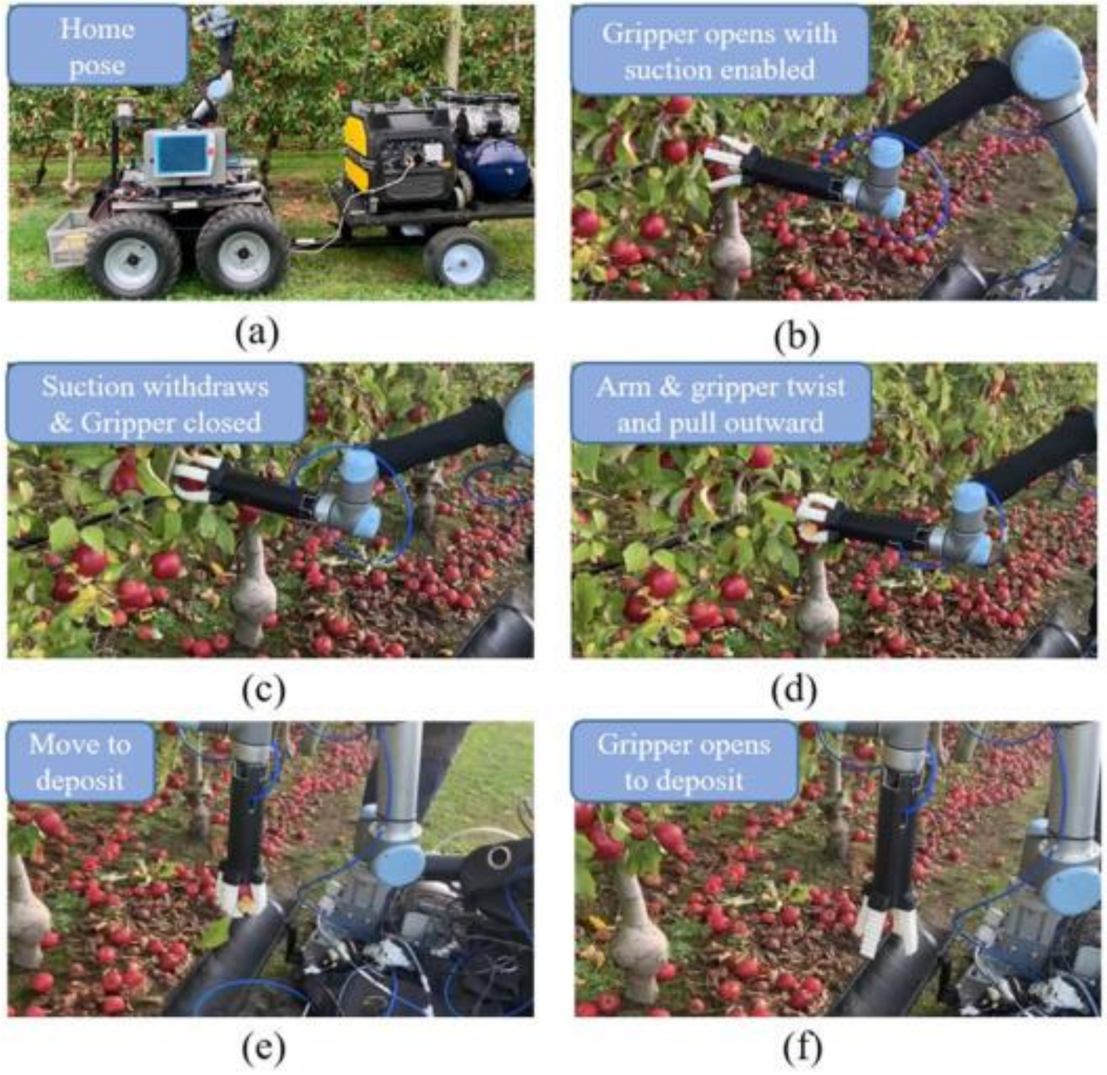
1) Vrochidou E, Tsakalidou VN, Kalathas I, Gkrimpizis T, Pachidis T, Kaburlasos VG. An overview of end effectors in agricultural robotic harvesting systems. Agriculture. 2022 Aug 17;12(8):1240.

Harvest – Fruit holding end effector

- Fruit holding
  - End effector makes direct contact with fruit

- End effectors technologies
  - Elastic buffering material
  - Under-actuated fingers
  - Flexible driving medium
    - Soft robotics
  - Clamping force feedback control
  - Air suction



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2) Wang X, Kang H, Zhou H, Au W, Wang MY, Chen C. Development and evaluation of a robust soft robotic gripper for apple harvesting. Computers and Electronics in Agriculture. 2023 Jan 1;204:107552.

Harvest – Stem-holding end effector

- Stem-Holding
  - End effector grasps the stem
  - Separate blade cuts the stem

- Target example fruits - long stems
  - Cucumbers (a)
  - Tomatoes (b)
  - Strawberries
  - Grapes

a) b)

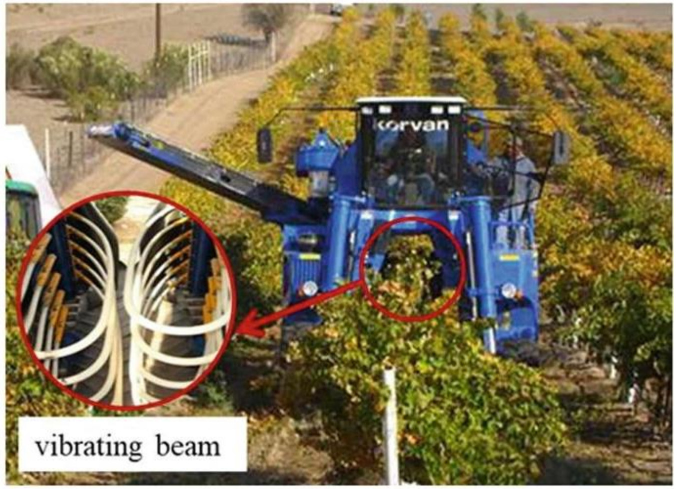
1) Feng, Qingchun. "End-Effector Technologies." *Fundamentals of Agricultural and Field Robotics* (2021): 191-212.

Harvest – Direct separation

- End-Effectors for direct separation
  - Separate the fruit from the plant without clamping it
  - E.g., clamp stem and vibrate

- Examples
  - Wolfberry harvesting (a)
  - Wine grape harvesting (b)

a)



b)

1) Feng, Qingchun. "End-Effector Technologies." *Fundamentals of Agricultural and Field Robotics* (2021,

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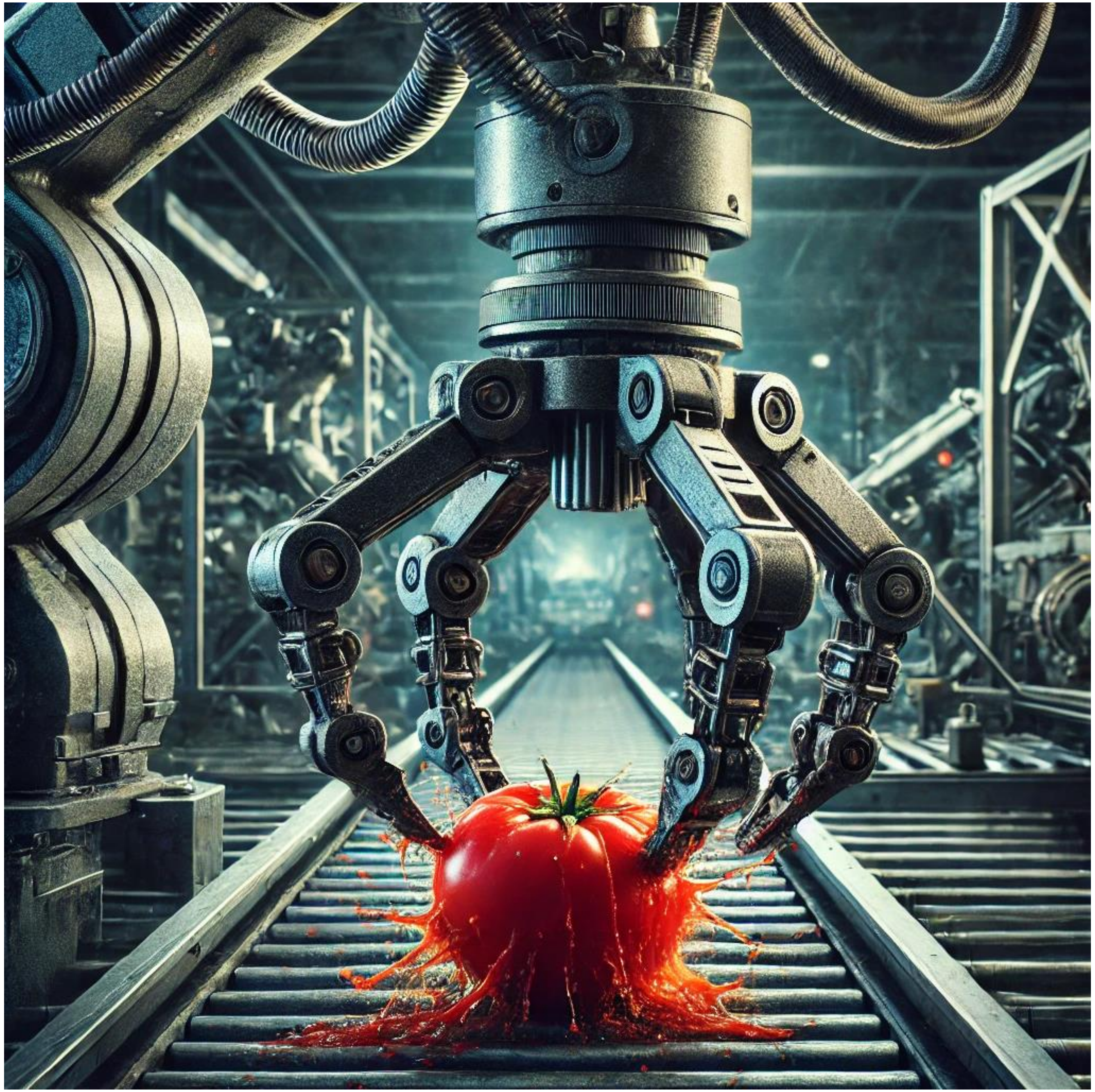
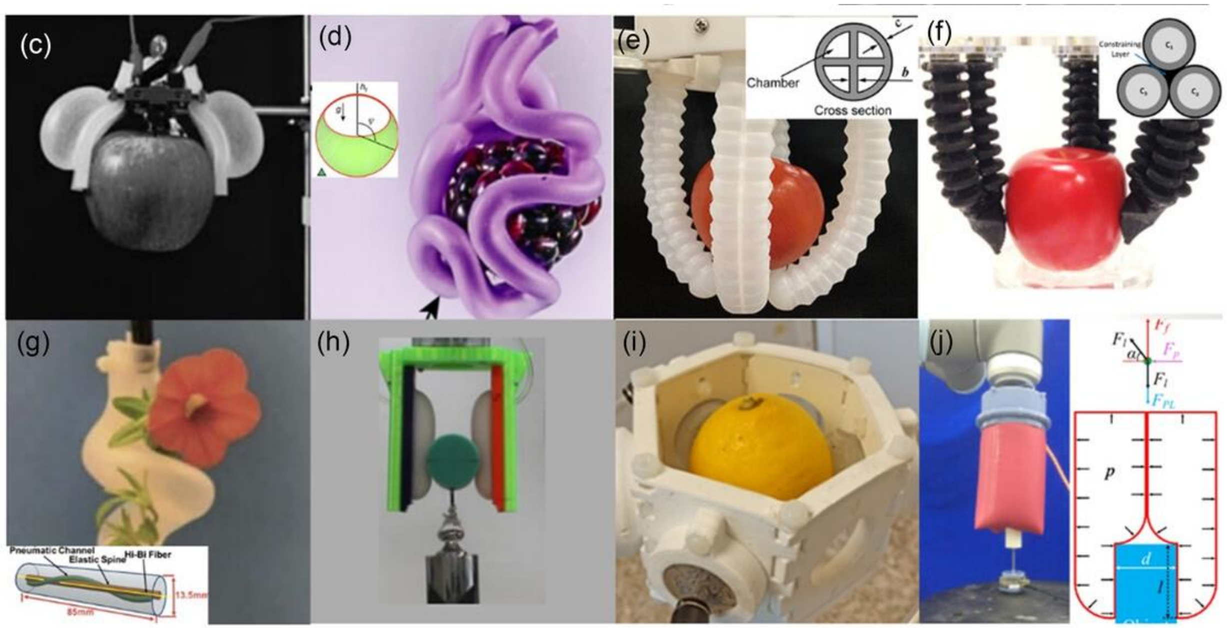


Image: Dall-E

Harvest – Soft grippers

- Soft grippers
  - Uses *soft robotics*
  - Material of the end effector is soft
    - *Compliant*
  - Reduces hard, rigid structures
  - Lowers chance of bruising on fruit

- Adapts to different
  - Forces
  - Shapes
  - Sizes



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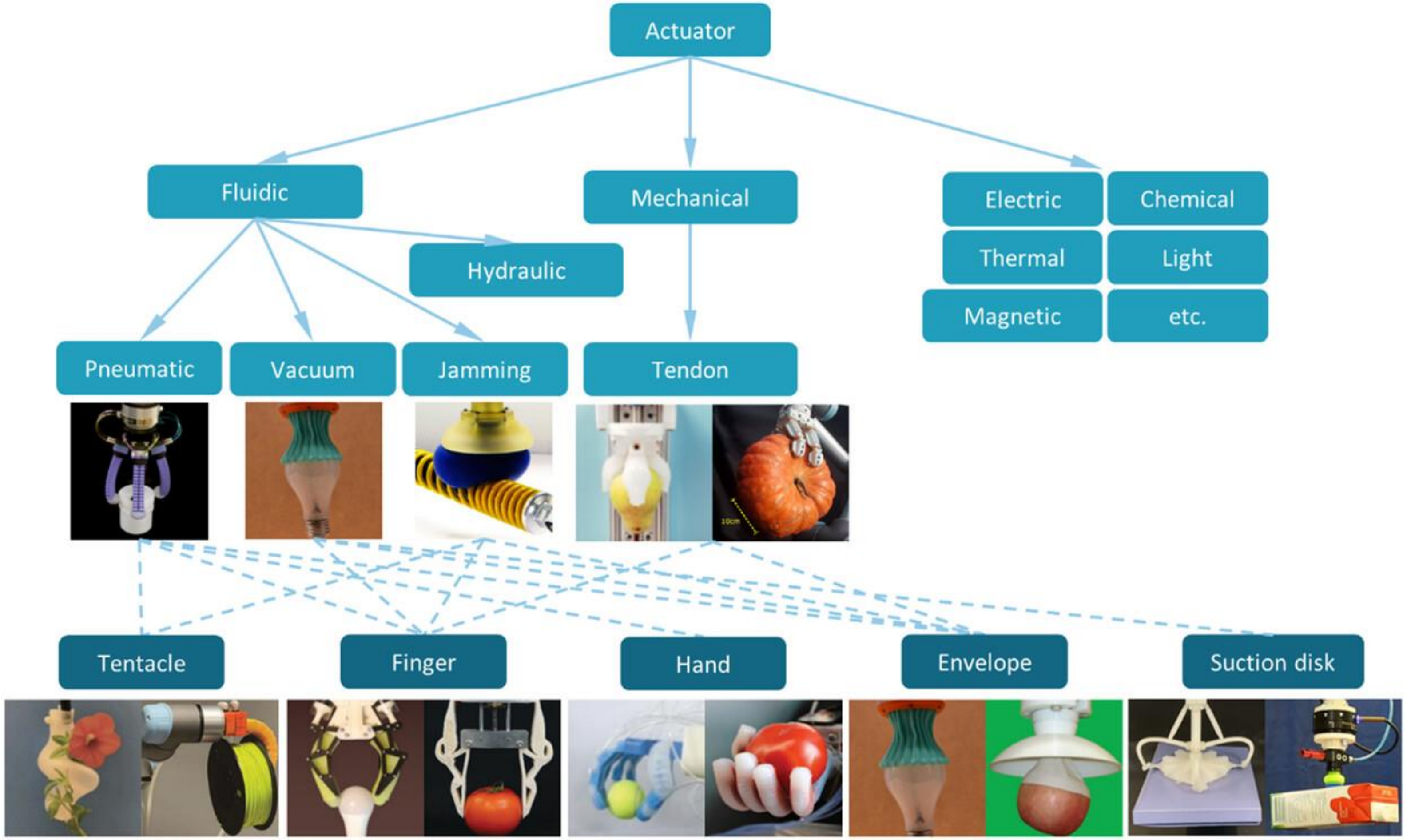
1) Feng, Qingchun. "End-Effector Technologies." *Fundamentals of Agricultural and Field Robotics* (2021): 191-212.

Harvest – Soft grippers (2)

- Pneumatic
  - Air
  - E.g., balloon
- Vacuum
  - No air
  - E.g., balloon filled with foam
- Jamming
  - Vacuum pouch filled with particles
  - E.g., balloon filled with coffee
- Tendon
  - Strings driven elsewhere



1) Liu Y, Hou J, Li C, Wang X. Intelligent soft robotic grippers for agricultural and food product handling: A brief review with a focus on design and control. Advanced Intelligent Systems. 2023 Dec;5(12):2300233.

Harvest – Soft grippers (2)

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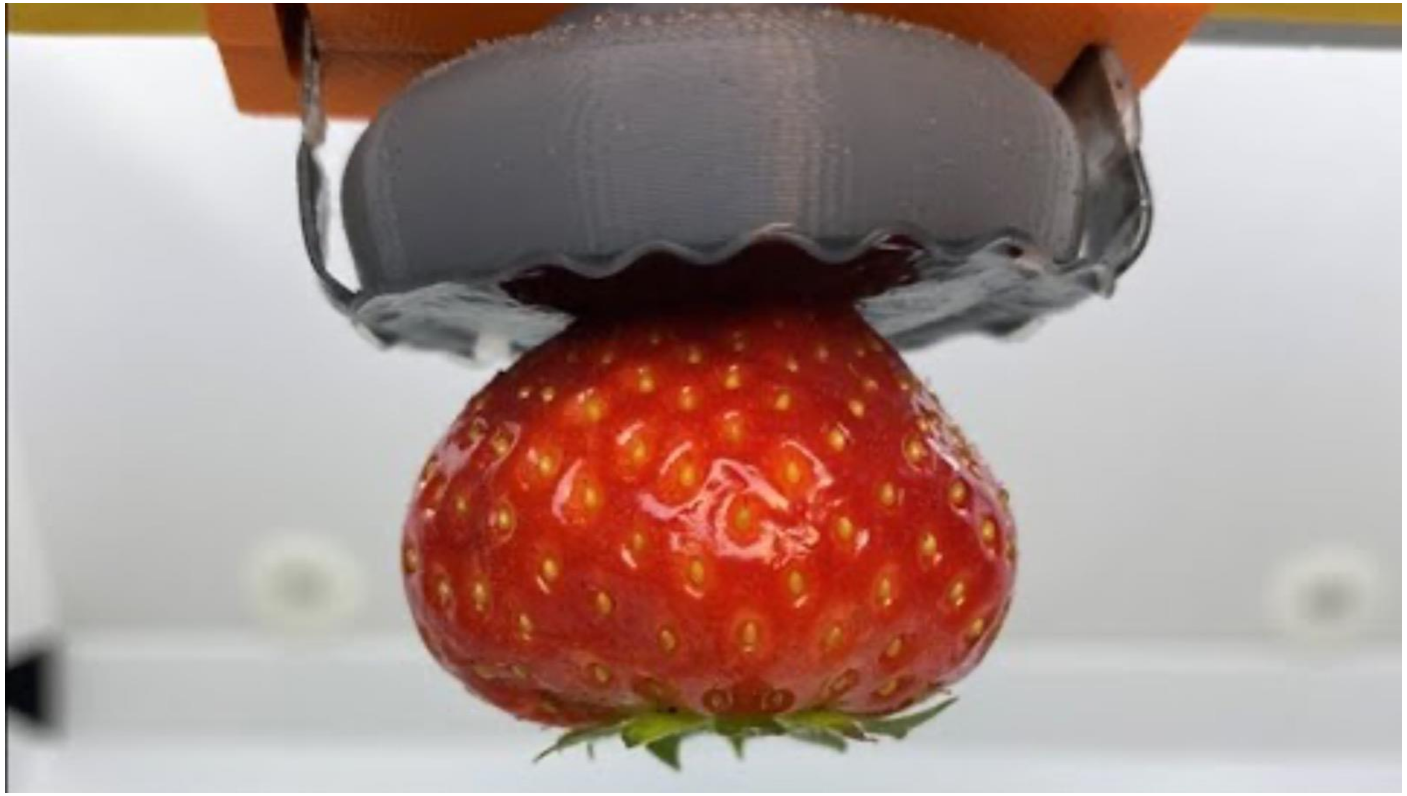

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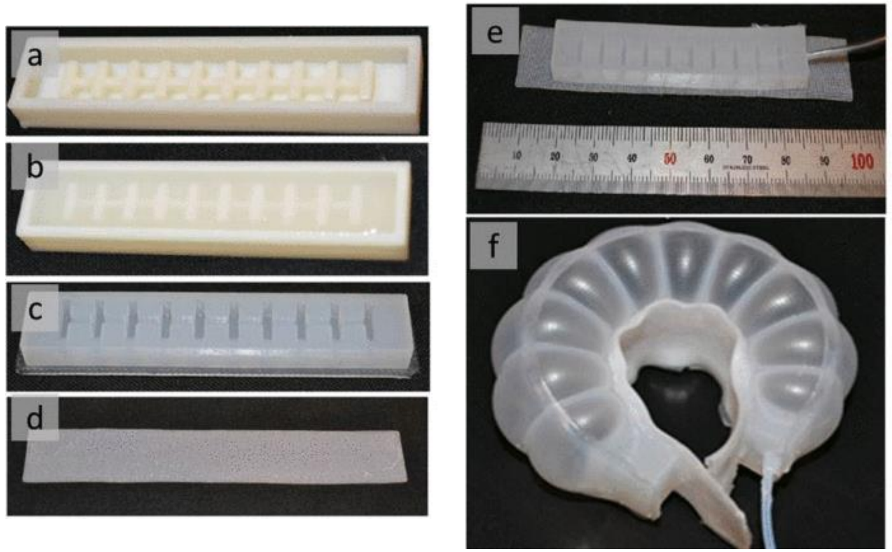
1) Liu Y, Hou J, Li C, Wang X. Intelligent soft robotic grippers for agricultural and food product handling: A brief review with a focus on design and control. Advanced Intelligent Systems. 2023 Dec;5(12):2300233.

Harvest – Soft grippers (3)

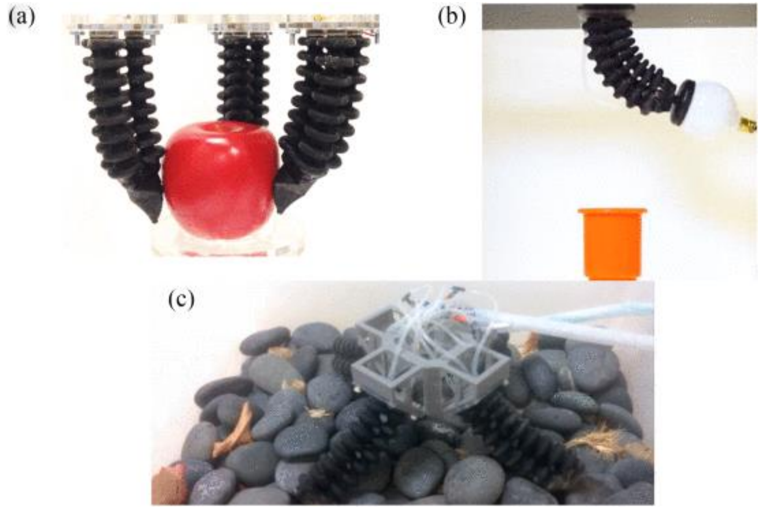
- Manufacturing soft pneumatic gripper

- Classical method
  - 3D print silicone mold
  - Fill with silicone
  - Attach strain-resisting material
  - Inflate -> bending

- Modern method
  - 3D print soft resin material



Silicone mold



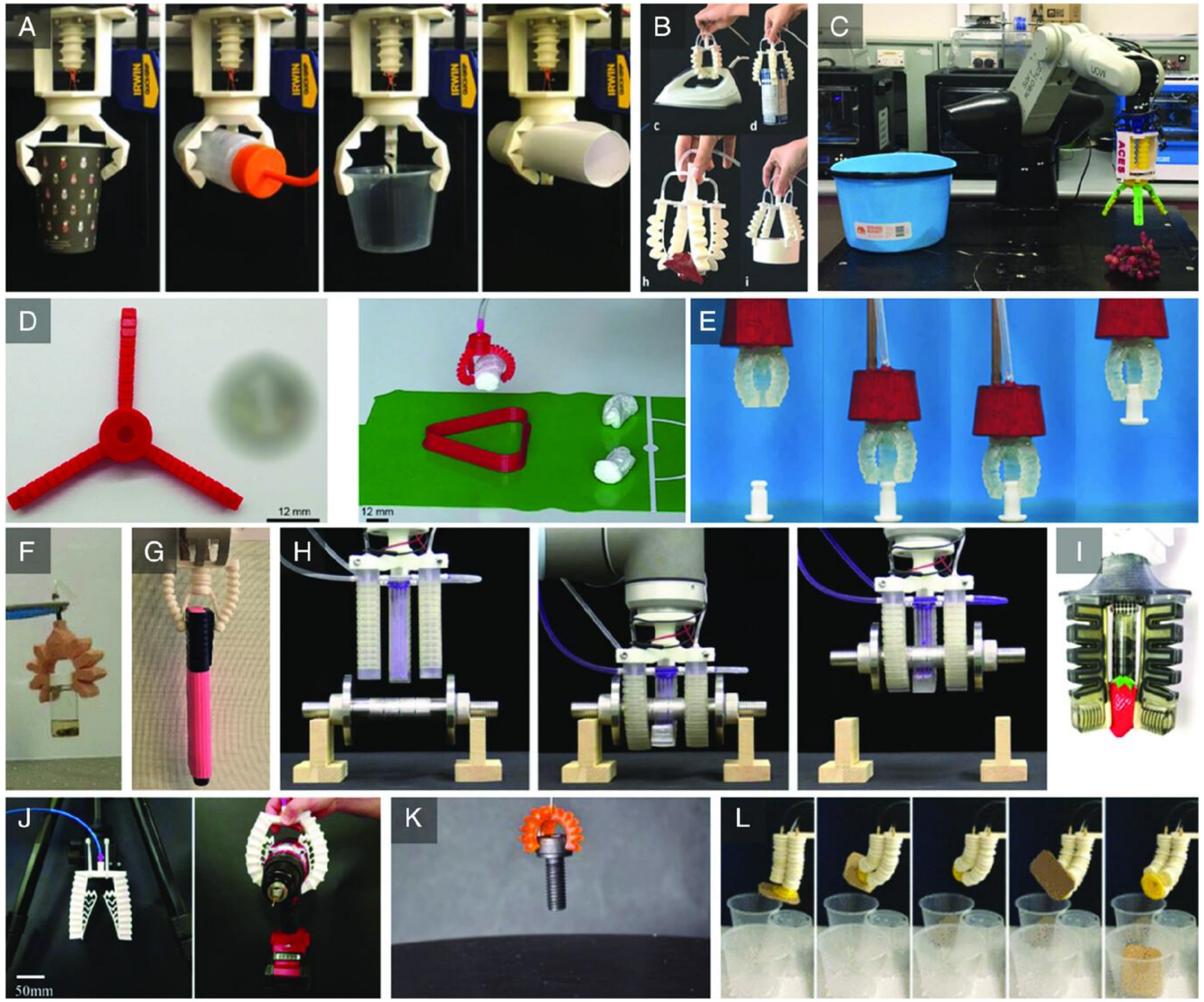
3D printed

1) Sun Y, Song YS, Paik J. Characterization of silicone rubber based soft pneumatic actuators. In2013 IEEE/RSJ International Conference on Intelligent Robots and Systems 2013 Nov 3 (pp. 4446-4453). Ieee.

Harvest – Soft grippers (4)

- Challenges
  - Controllability
  - Consistency
  - Characterisation
  - Sensing

- External hardware
  - Power supply (e.g., pumps)
  - Cable transmissions



1) Sun Y, Song YS, Paik J. Characterization of silicone rubber based soft pneumatic actuators. In2013 IEEE/RSJ International Conference on Intelligent Robots and Systems 2013 Nov 3 (pp. 4446-4453). Ieee.

Harvesting technology – AGROBOT

1) https://www.youtube.com/watch?v=M3SGScaShhw

Harvesting technology – FFRobotics

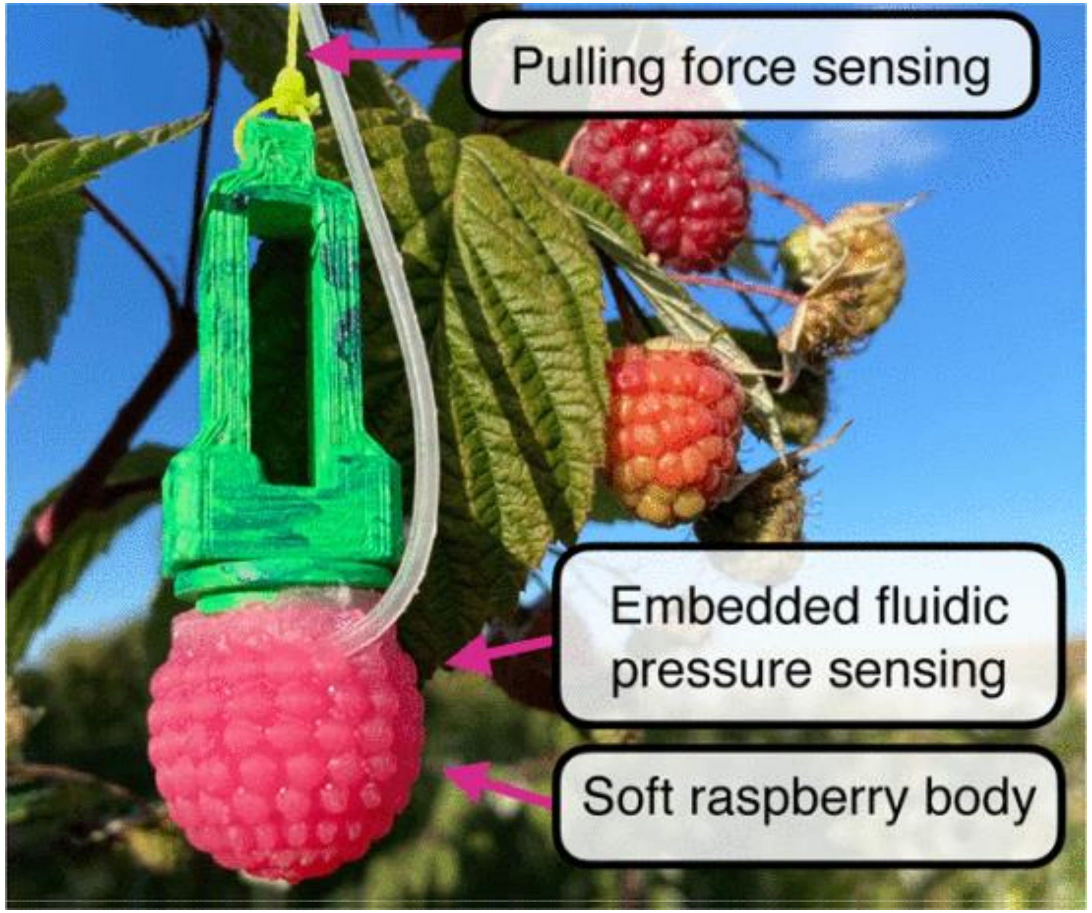
1) https://www.youtube.com/watch?v=kLmersqggOY

Harvesting technology – Cotton

1) https://www.youtube.com/watch?v=qwEGGR5b4C4

Harvesting technology – Raspberry (EPFL)

- Raspberries difficult to harvest
  - Can be crushed by end effector
- Difficult to measure force when grasping
- Built *physical twin* with sensors
  - Fake raspberry with same properties
  - Sensors inside detect forces
- Robot grasping trained on physical twin



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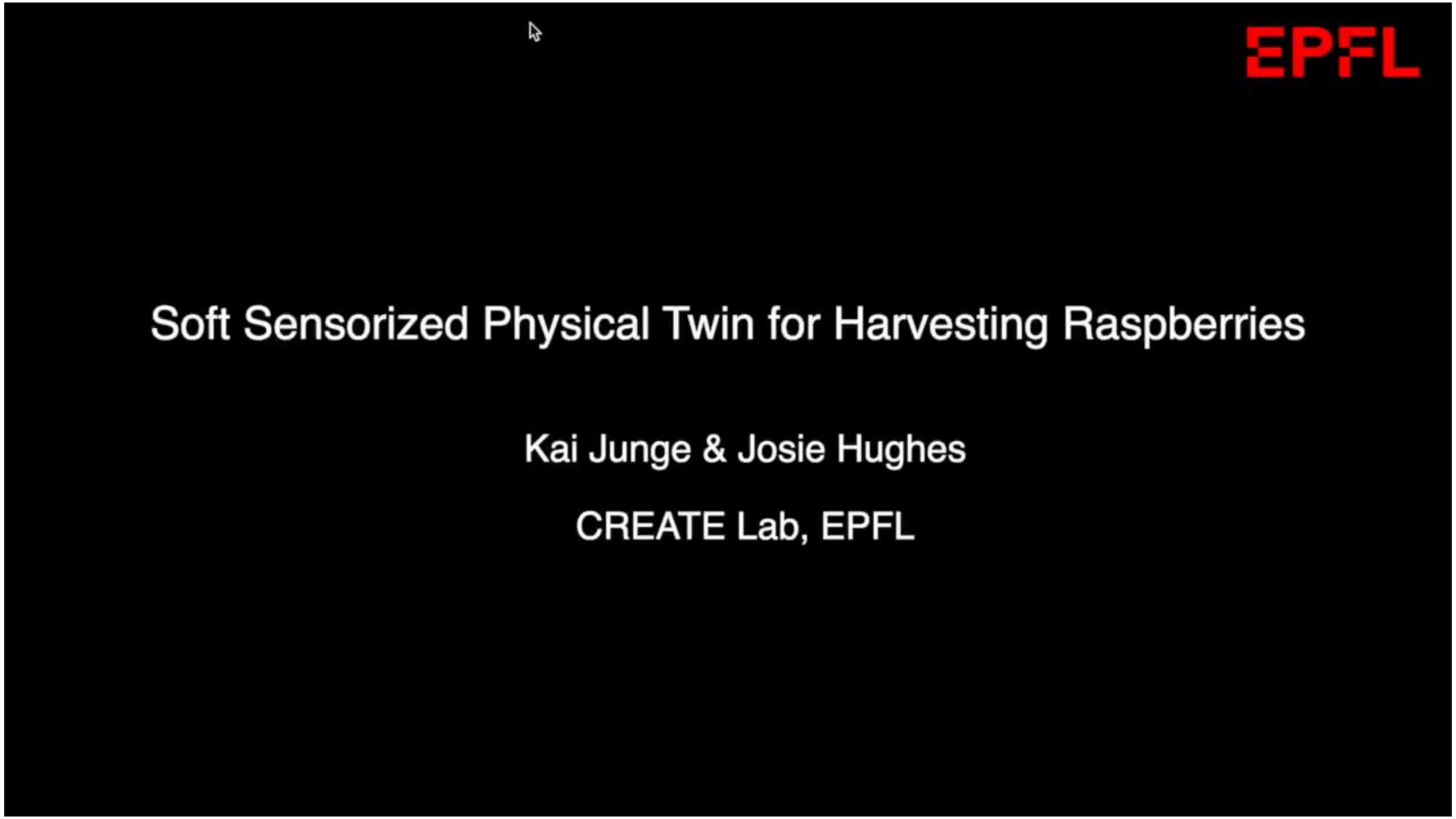
1) Junge K, Hughes J. Soft sensorized physical twin for harvesting raspberries. In2022 IEEE 5th International Conference on Soft Robotics (RoboSoft) 2022 Apr 4 (pp. 601-606). IEEE.
2) Junge K, Pires C, Hughes J. Lab2Field transfer of a robotic raspberry harvester enabled by a soft sensorized physical twin. Communications Engineering. 2023 Jun 23;2(1):40.

Harvesting technology – Raspberry



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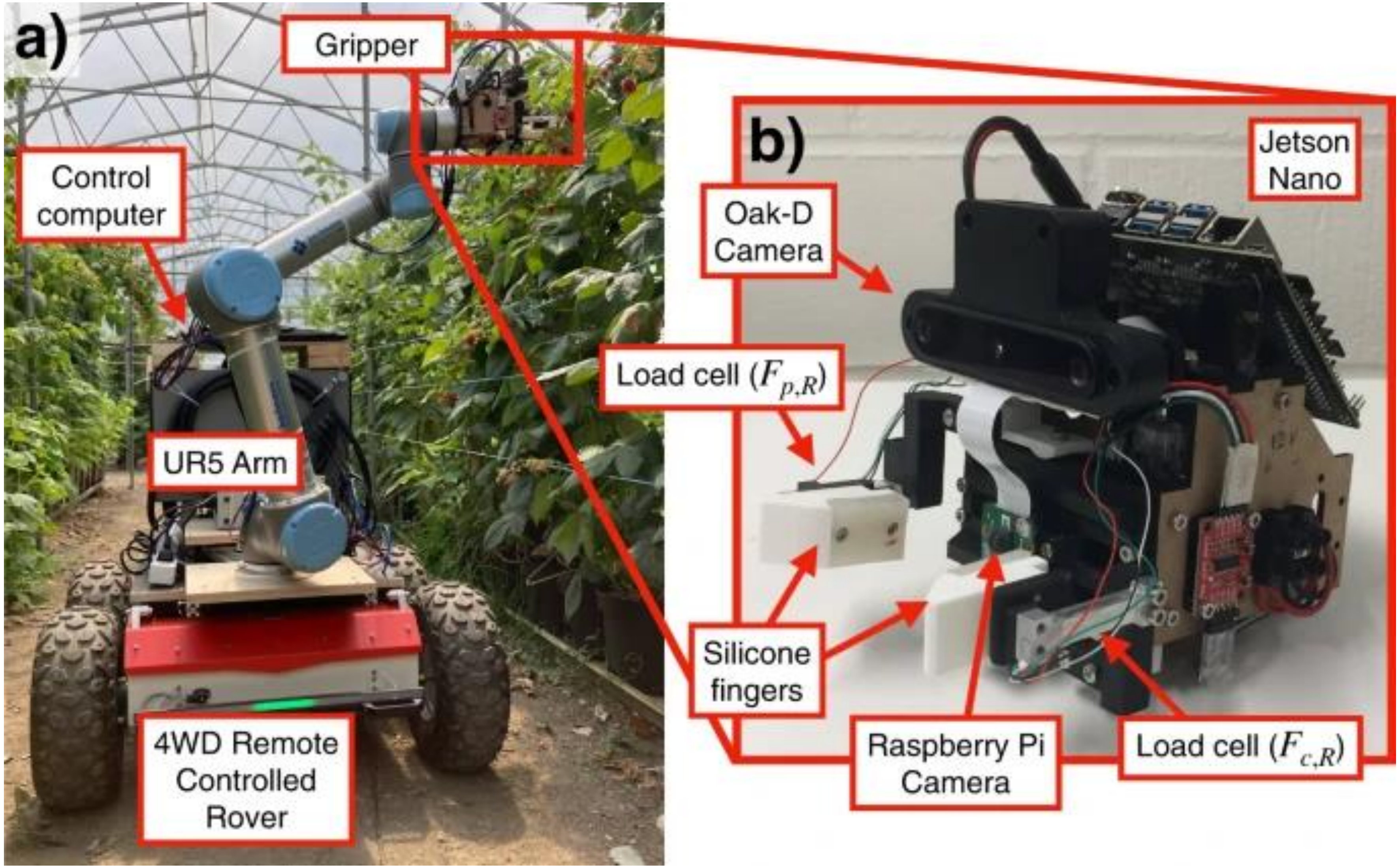
1) Junge K, Hughes J. Soft sensorized physical twin for harvesting raspberries. In2022 IEEE 5th International Conference on Soft Robotics (RoboSoft) 2022 Apr 4 (pp. 601-606). IEEE.
2) Junge K, Pires C, Hughes J. Lab2Field transfer of a robotic raspberry harvester enabled by a soft sensorized physical twin. Communications Engineering. 2023 Jun 23;2(1):40.

Harvesting technology – Raspberry



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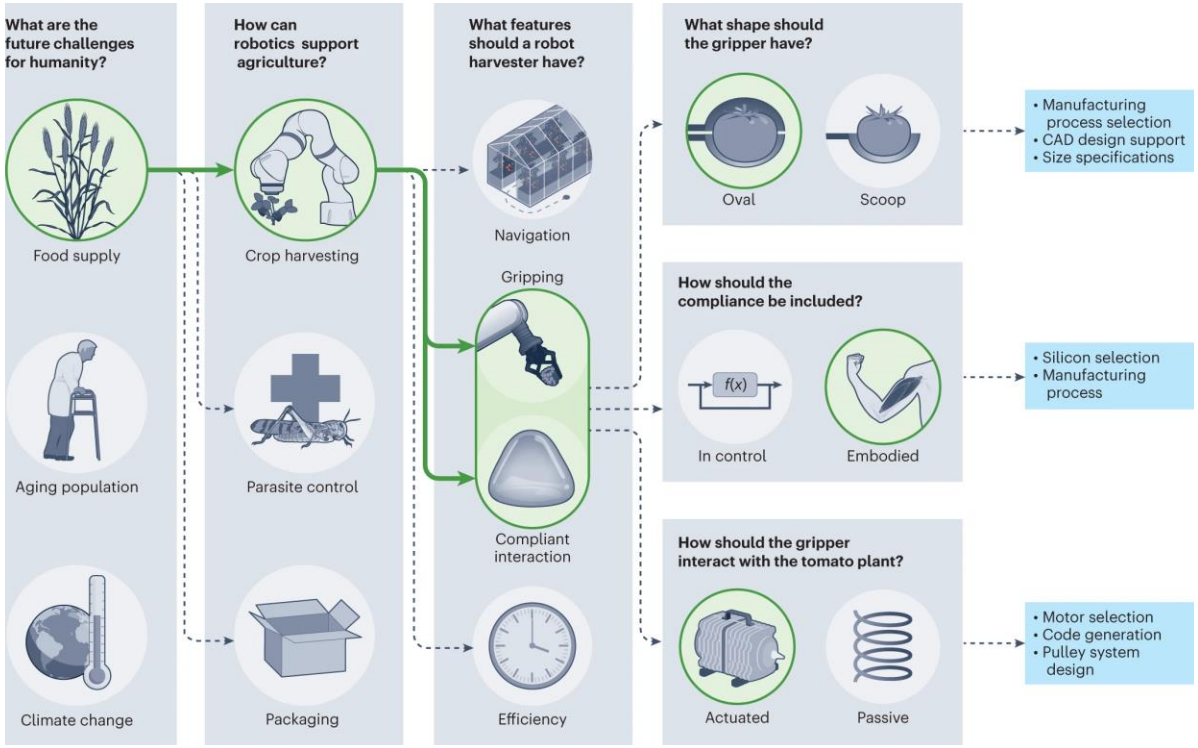
2) Junge K, Pires C, Hughes J. Lab2Field transfer of a robotic raspberry harvester enabled by a soft sensorized physical twin. Communications Engineering. 2023 Jun 23;2(1):40.

Harvesting technology – LLM gripper (EPFL)



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1) Stella F, Della Santina C, Hughes J. How can LLMs transform the robotic design process?. Nature machine intelligence. 2023 Jun;5(6):561-4.

Section: Vertical Farming

Soil compaction

- High-mass compaction damage from heavy machinery
  - Degradation to soils
  - Increased waterlogging, surface runoff, nitrous oxide emissions
  - Restricting habitat for soil fauna

- *Lighter vehicles reduce soil compaction*

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1) https://www.farmprogress.com/farming-equipment/6-tips-for-avoiding-soil-compaction
2) book

Vertical Farming

- Farms rebuilt in vertically arranged layers
  - Up to 200 times greater yield
  - Up to 250 times water reduction
  - Up to 99% less land space
- Not seasonal dependant
  - LED sources
- Not all plants thrive in this configuration
  - Best for leafy greens
  - Often hydroponic

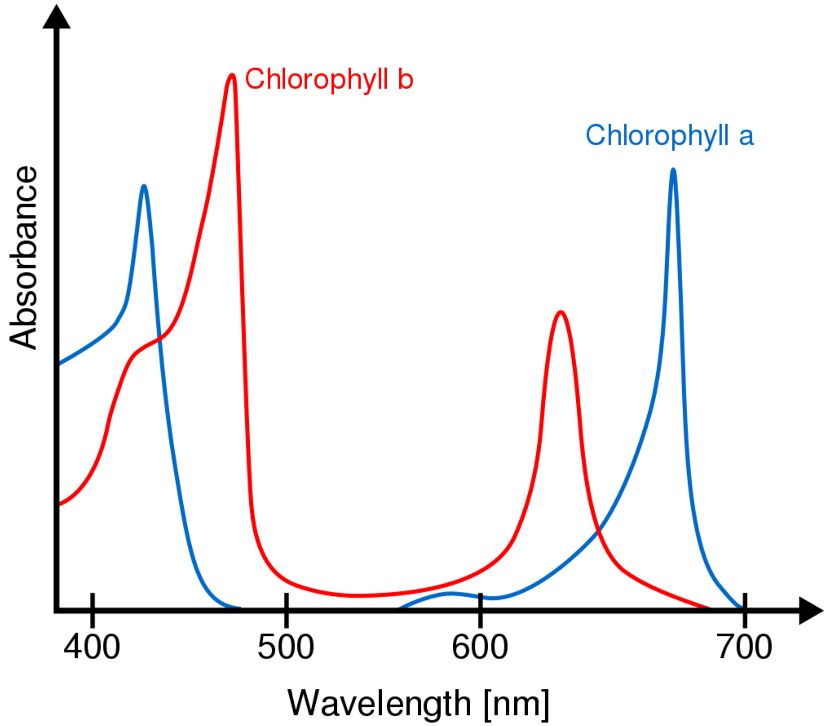
1) https://www.edengreen.com/blog-collection/what-is-vertical-farming
2) https://www.agroscope.admin.ch/agroscope/en/home/topics/economics-technology/smart-farming/vertical-farming.html

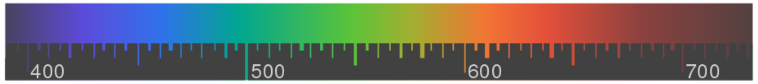
Plant response to light

- Photosynthesis
  - Sun provides white light
  - White light: all wavelengths in visible light spectrum

- Chlorophyll has uneven absorption
  - Red and blue more sensitive

- *Grow lights of only red and blue LED light save energy*





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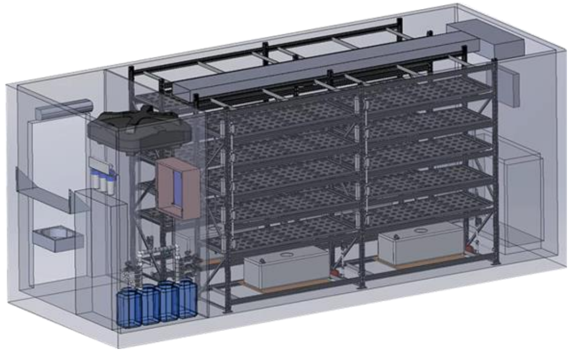
1) Parke WC, Parke WC. Light in Biology and Medicine. Biophysics: A Student's Guide to the Physics of the Life Sciences and Medicine. 2020:205-77.
2) https://en.wikipedia.org/wiki/Chlorophyll

Vertical Farming Automation

- Difficult for maintenance
  - High rows of plants
  - Compact areas

- Vertical farms can be designed specifically for manipulation
  - Similar to robots in a warehouse



ifarm vertical farm in a shipping container

1) https://ifarm.fi/ifarm_container_green

Vertical Farming – Drone inspection

1) https://ifarm.fi/ifarm_container_green

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Vertical Farming

- Vertical farm market
  - 2B investment in 2022
  - Vertical farm market worth 5B in 2023
  - ***90% drop in investment** in 1st quarter in 2024*

- Price per vegetable still to much
  - Higher labour (skilled) costs
  - High initial cost
  - Continuous (LED) cost
  - *Traditional farming cost already relatively optimised*

- Reducing cost of labour key in making viable
  - Still viable in arid markets

- Pests and disease still a problem
  - Plants share water
  - One infection infects the whole batch

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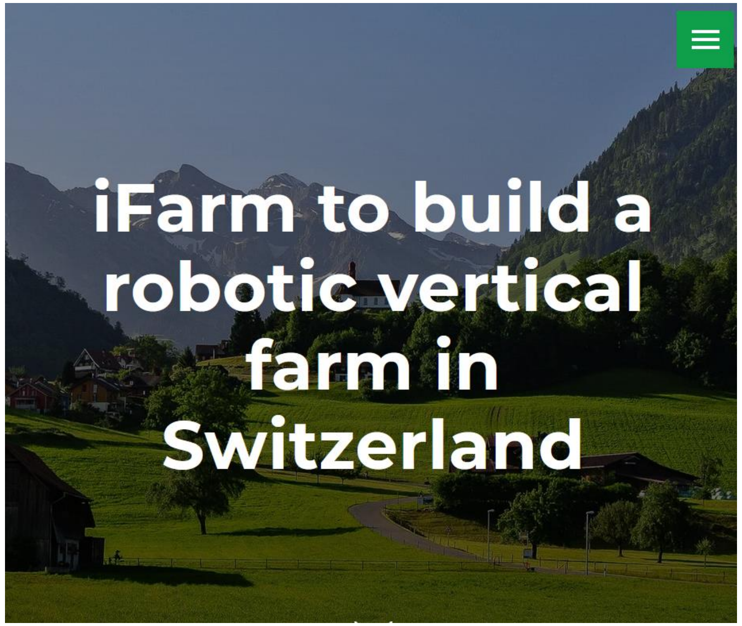
1) https://www.sciencenews.org/article/smart-lighting-vertical-farming
2) https://www.youtube.com/watch?v=8BXHu_yXVQk,

Vertical Farming – The implementation

- Example: Robotic iFarm
  - To be completed in 2025
  - **370k CHF** annual labour savings vs traditional farms

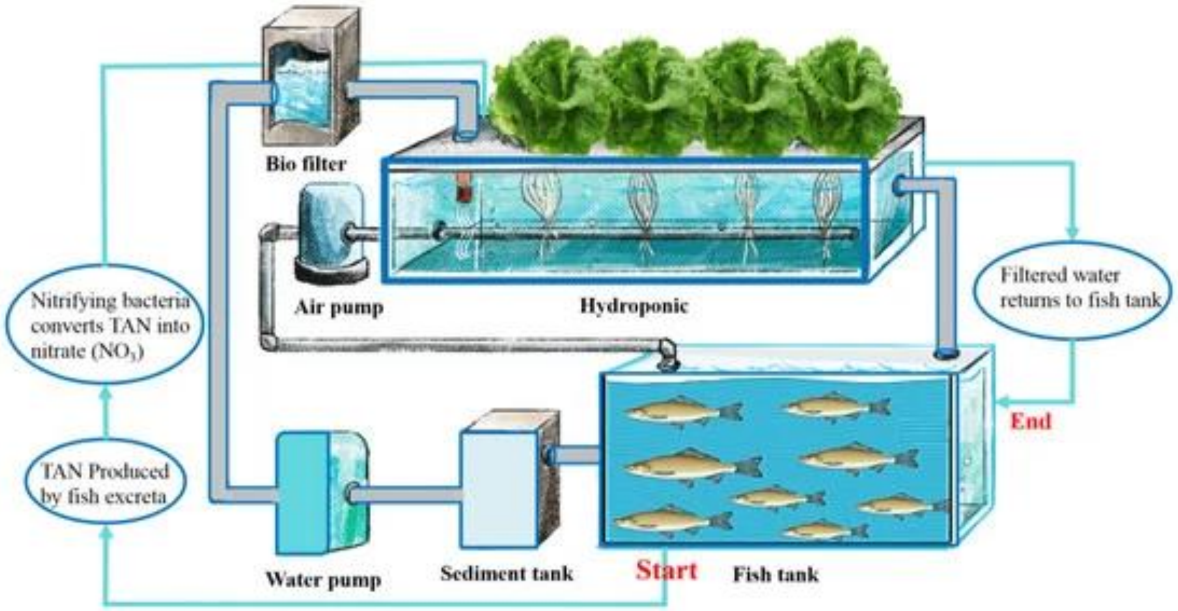
- Automated systems
  - Planting
  - Washing trays
  - Cutting plants

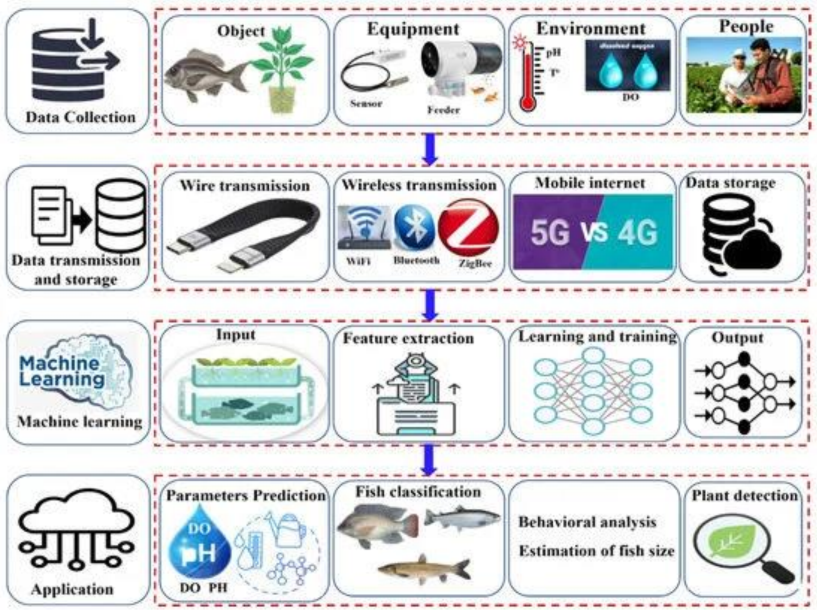
- Manual labour
  - Equipment maintenance
  - Disinfection

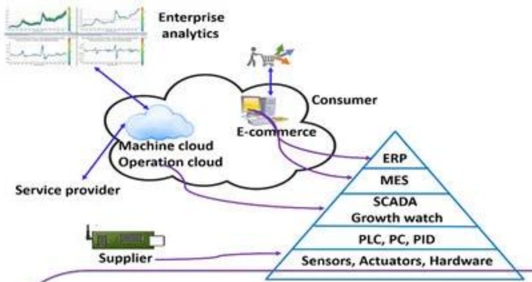


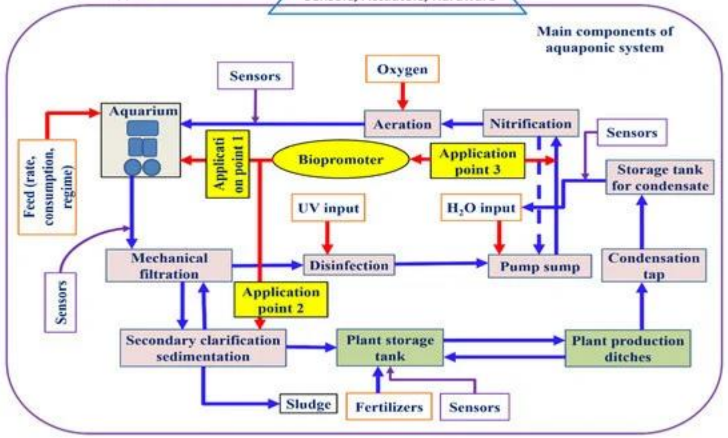
1) https://ifarm.fi/blog/vertical-farm-in-switzerland

Aquaponics









1) https://www.mdpi.com/2227-9040/10/8/303

Section: Livestock and Aquaculture

Standards and risks in mass farming

- Mass farming methods cause livestock stress
  - Confinement
  - Modification (e.g., dehorning)
  - Metabolic demands (e.g., accelerated growth)

- Increased risk of disease
  - Loss of genetic diversity
  - Stress
  - Close confinement

- Increased risk of disease transfer
  - Animal to animal
  - Animal to human

- *Future of livestock impacted by resource scarcity and climate change*

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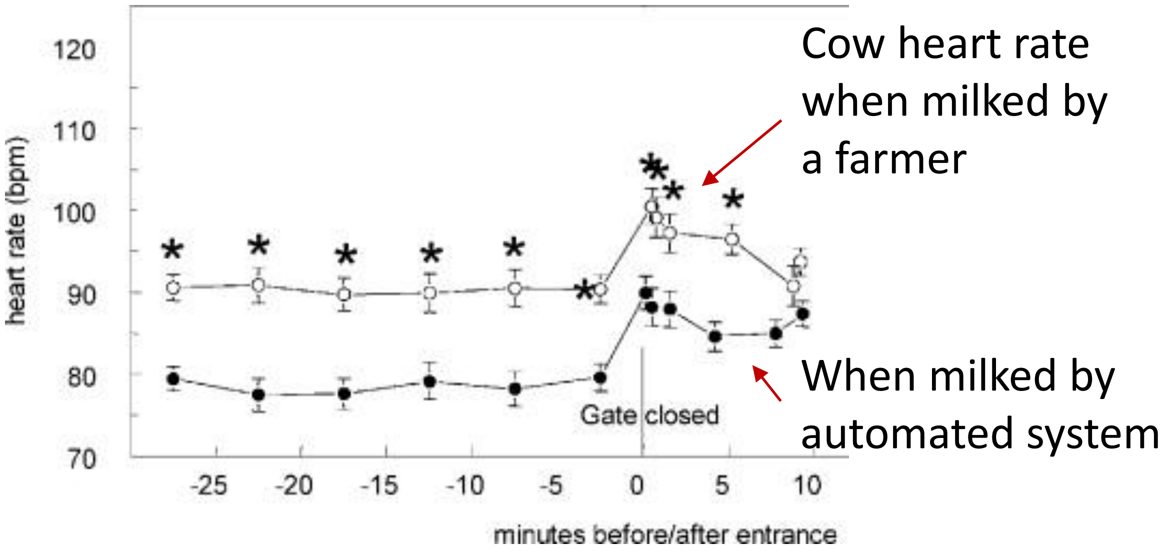
1) https://www.researchgate.net/profile/David-Roland-Holst/publication/43521028_Industrial_livestock_production_and_global_health_risks/links/0046351dcaa4030cc5000000/Industrial-livestock-production-and-global-health-risks.pdf
2) https://royalsocietypublishing.org/doi/full/10.1098/rstb.2010.0134
3) https://www.tandfonline.com/doi/full/10.1080/10408410701647594#d1e1298
4) https://geneticliteracyproject.org/2017/07/26/megafarms-us-model-large-scale-livestock-farming-model-offer-efficiency-consequences/
5) https://www.greenpeace.org/international/story/49981/myth-industrial-agriculture-food-climate-health/

Challenges in livestock management

- Animal stress and health has been correlated to farmer stress

- Early detection of disease requires close monitoring of animals
  - Classical stress / animal disease indicators slow
    - E.g., egg production
  - Classically labour intensive, manual work

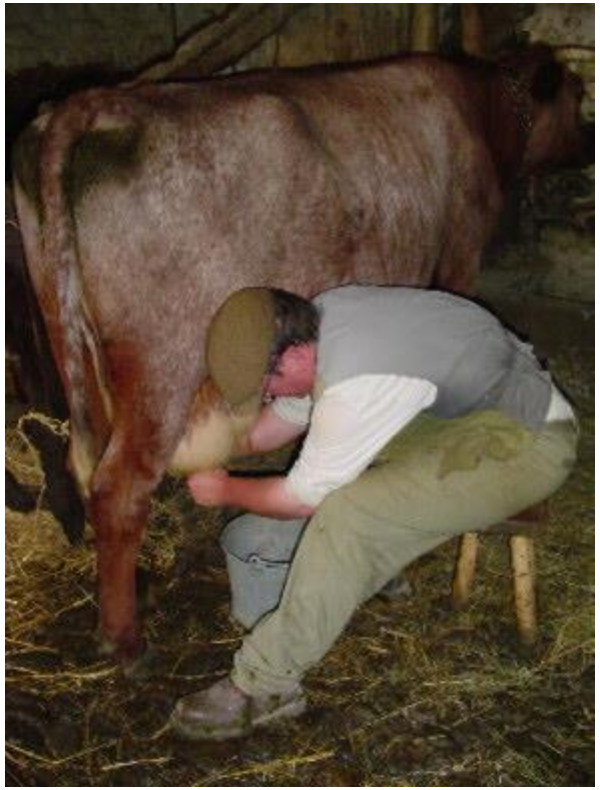
- Milking adds stress to cows
  - Standards to keep stress below a specific level



1) https://www.cambridge.org/core/journals/animal-welfare/article/connecting-farmer-mental-health-with-cow-health-and-welfare-on-dairy-farms-using-robotic-milking-systems/94FA6C8B2C586A04D69503A852CF0F0E
2) https://www.sciencedirect.com/science/article/pii/S0020025516312658\
3) https://www.sciencedirect.com/science/article/pii/S0022030202744093

Farm health during milking

- Injuries caused by cattle
  - USA: 40 fatal injuries in 2022
  - USA: 4.1 nonfatal injuries per 100 workers in 2021
- Long term health
  - Chronic musculoskeletal from milking
  - Respiratory diseases



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1) https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2016.00147/full
2) https://www.bls.gov/iif/nonfatal-injuries-and-illnesses-tables/table-1-injury-and-illness-rates-by-industry-2021-national.htm
3) https://en.wikipedia.org/wiki/Dairy

Livestock – Automated Milking

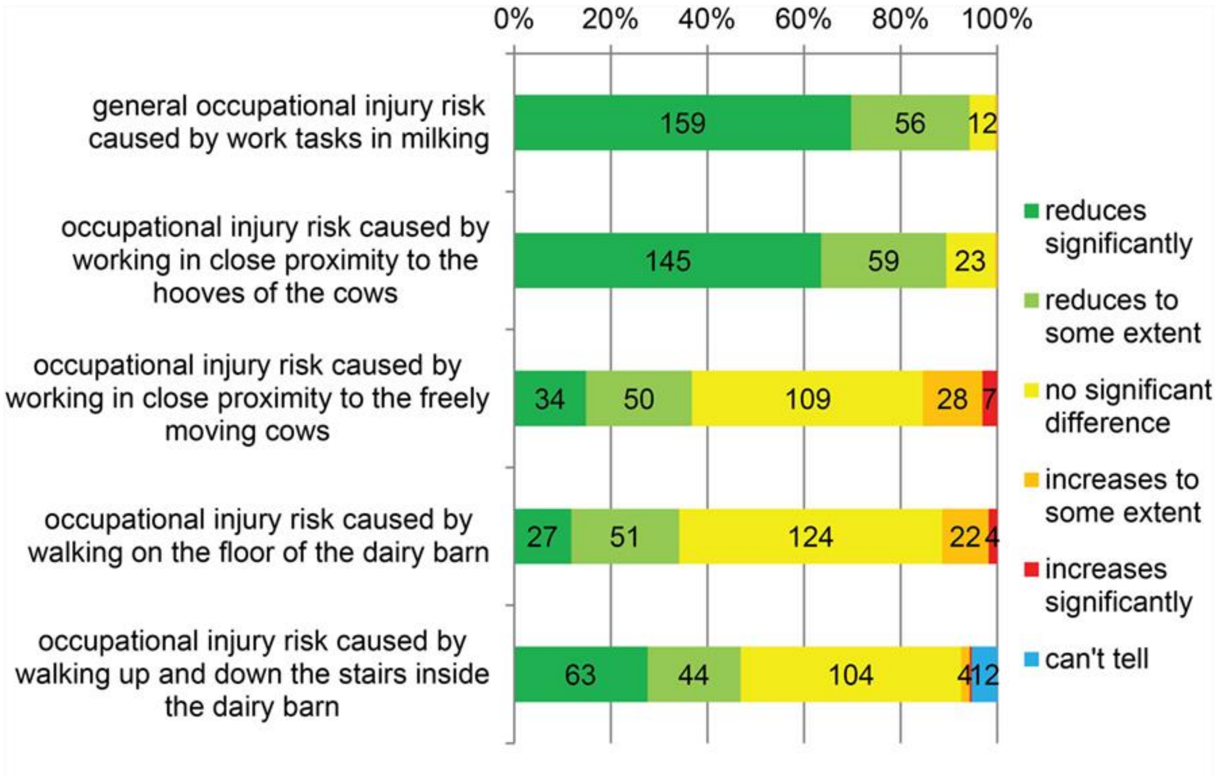
- Milking automation
  - Cows choose when to be milked
- Tracking cow health while milking
  - Quality control of milk
  - Health parameters of cow
- *Being milked by a robot is much less stressful for the cow than being milked by a stressed human*

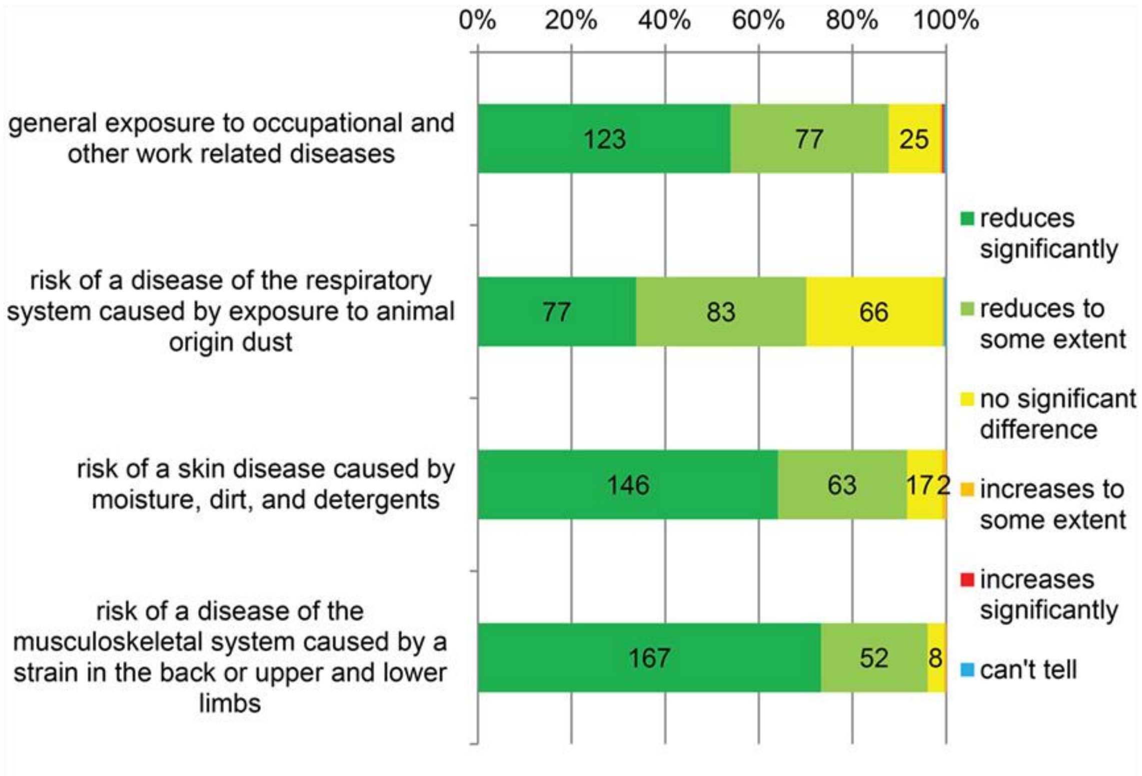
  - Andreas Pelzer

1. Milk receiver can
2. Quarter milk tubes
3. Robotic arm
4. Teat cleaning brushes
5. Scanning laser
6. Milk sensor
7. Feed dispenser (hidden)
8. Milk meter
9. AMS control panel
10. Robotic arm control panel

1) https://www.dairynz.co.nz/milking/new-dairy-technology/automatic-milking-systems/

Automatic milking vs conventional milking





Survey of 228 Finnish farms after installing automatic milking

1) https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2016.00147/full#B4

Livestock – Quality of life

- Reduction of labour through repetitive tasks
  - Milking, feeding, mucking out

- Quality of life - Farmer
  - Adjust working hours away from early mornings and weekends

1) https://umash.umn.edu/spotlight-preventing-repetitive-motion-injuries-on-the-farm/

Livestock – Innovations

- Automate livestock distribution based on nutrition (individually)
- Monitoring of air quality in livestock buildings through moving sensor
- Automate manure handling in barns
- Automated disinfection for livestock breeding
    - Automated medicine spraying for poultry house

1) https://dairy.unl.edu/automatic-milking-systems-good-bad-and-unknown/
2) Attard G. Robots in Livestock Management. InEncyclopedia of Smart Agriculture Technologies 2023 Apr 25 (pp. 1-12). Cham: Springer International Publishing.
3) Feng QC, Wang X. Design of disinfection robot for livestock breeding. Procedia Computer Science. 2020 Jan 1;166:310-4.
4) Qingchun FE, Xiu WA, Quan QI, Chunfeng ZH, Bin LI, Ruifeng XU, Liping CH. Design and test of disinfection robot for livestock and poultry house. Smart agriculture. 2020 Dec 30;2(4):79.

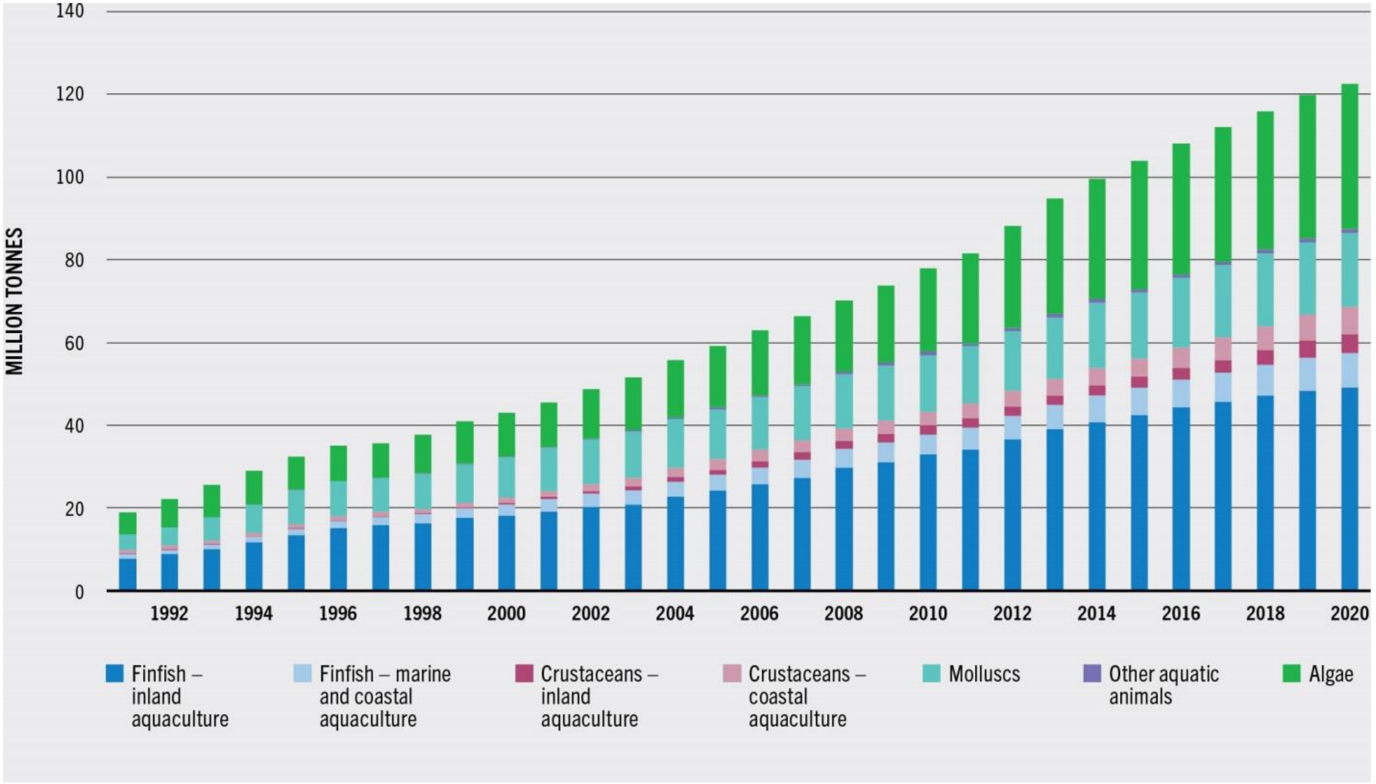
Livestock innovations: VR googles

1) https://www.youtube.com/watch?v=EOyImm0IVPE

Aquaculture

- Controlled cultivation of aquatic organisms
  - I.e., aqua-farming

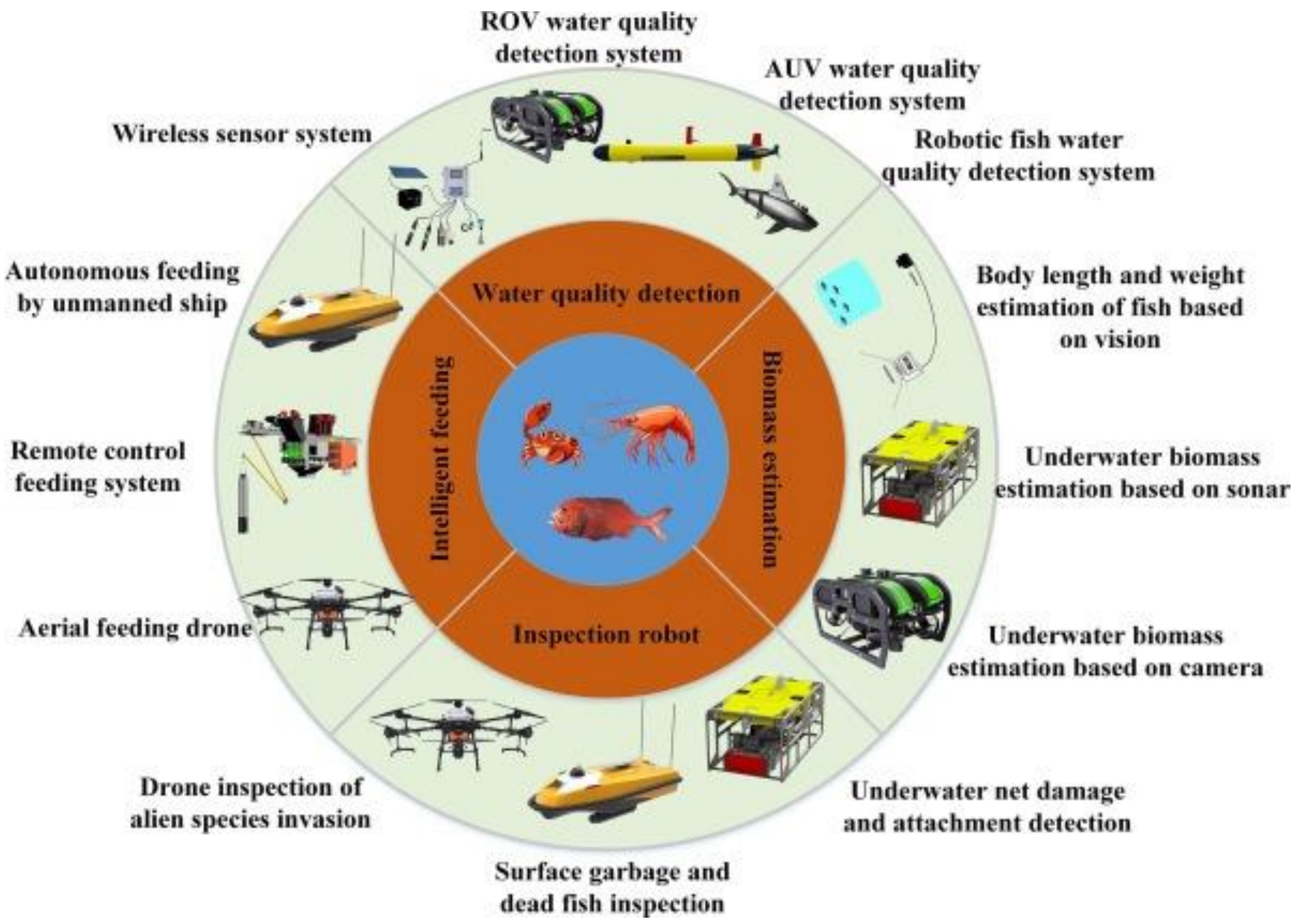
- Cultivated organisms:
  - Fish
  - Crustaceans
  - Molluscs
  - Algae
  - Aquatic plants (e.g. lotus)
  - Seaweed (also for carbon sequestration)



1) https://en.wikipedia.org/wiki/Aquaculture
2) https://openknowledge.fao.org/server/api/core/bitstreams/9df19f53-b931-4d04-acd3-58a71c6b1a5b/content/sofia/2022/aquaculture-production.html
3) https://onlinelibrary.wiley.com/doi/10.1002/csr.3098

Aquaculture – Robot applications

- Water quality
- Intelligent feeding
- Biomass estimation
- Inspection



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1) Wu Y, Duan Y, Wei Y, An D, Liu J. Application of intelligent and unmanned equipment in aquaculture: A review. Computers and Electronics in Agriculture. 2022 Aug 1;199:107201.

Aquaculture – Salmon farming

Number of aquaculture sites in Norway

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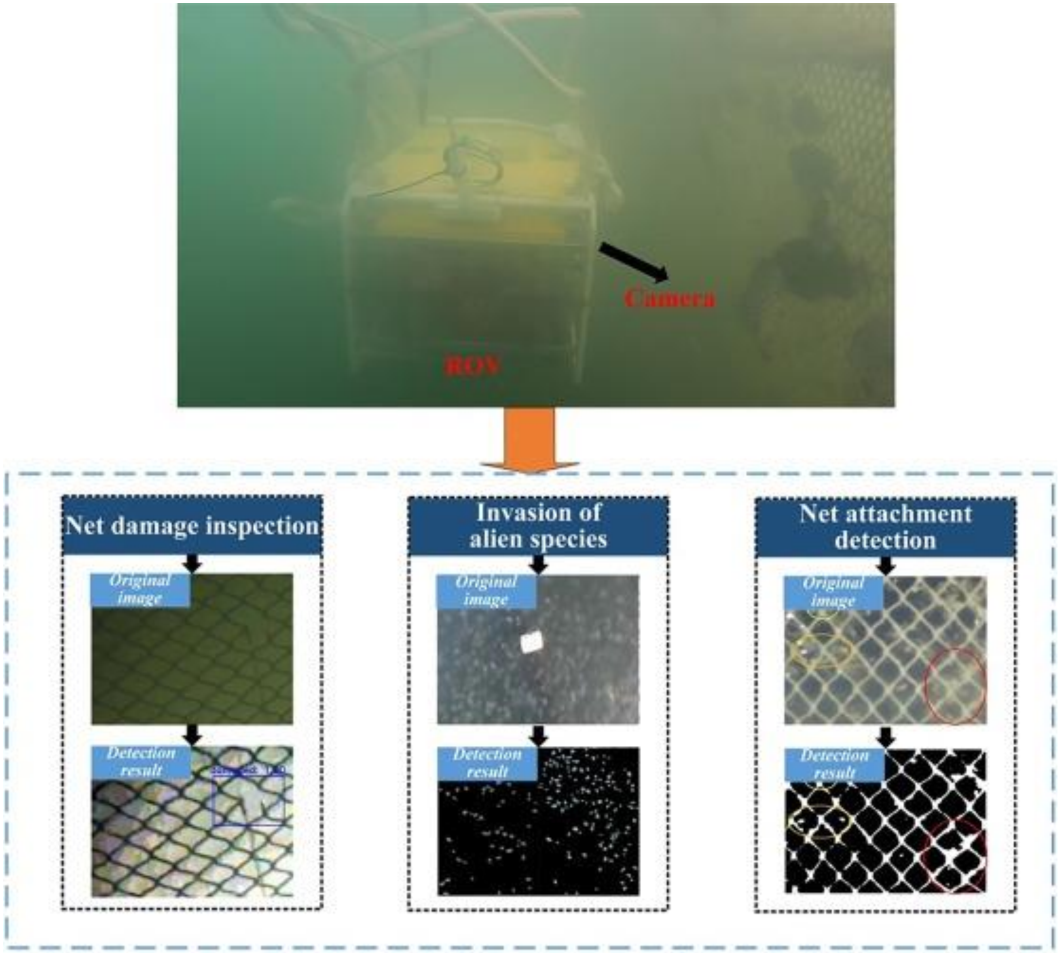
1) https://thefishsite.com/articles/what-is-on-salmon-aquacultures-tech-horizon-norway-development-license
2) Wang CD, Olsen Y. Quantifying regional feed utilization, production and nutrient waste emission of Norwegian salmon cage aquaculture. Aquaculture Environment Interactions. 2023 Aug 3;15:231-49.

Aquaculture – Nets

- Holes in nets
  - Large government penalty for escaping fish
  - Other creatures can enter
  - Currently, manual inspection standard

- Cleaning nets
  - Large build-up of biomass
  - Many companies with robotic cleaners
  - Slowly becoming standard



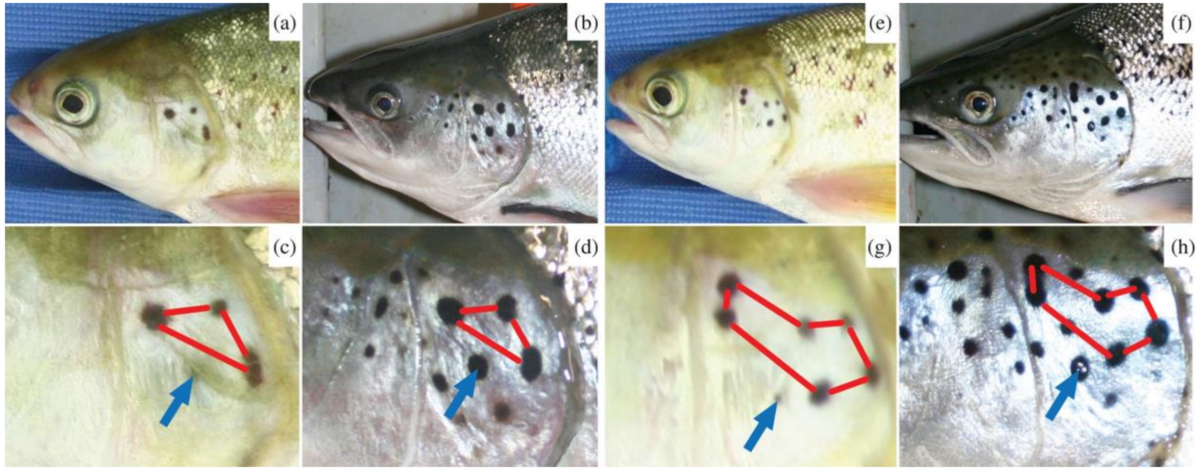
1) Wu Y, Duan Y, Wei Y, An D, Liu J. Application of intelligent and unmanned equipment in aquaculture: A review. Computers and Electronics in Agriculture. 2022 Aug 1;199:107201.

Aquaculture – Nets

1) https://www.youtube.com/watch?v=8nEmY13FB1o

Aquaculture – Salmon monitoring

- Estimate biomass
  - Sample of salmon manually fished
- Spots on salmon face unique like fingerprint
  - Use underwater vessels to track salmon
- Water quality measurements
  - Salinity, temperature, and dissolved oxygen

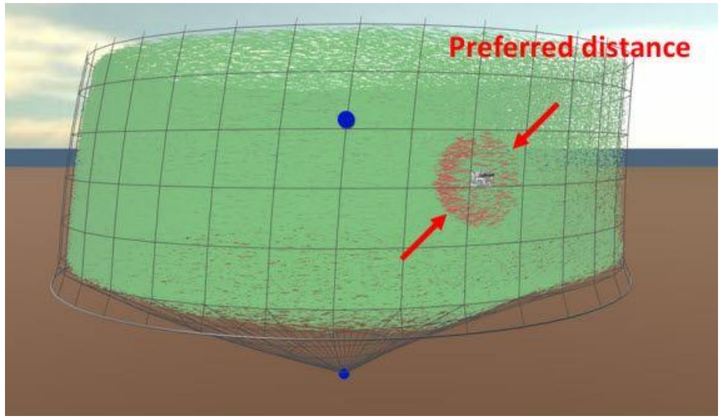


1) https://www.ntnu.no/bridge/project/development-algorithm-non-invasive-identification-salmon-individuals-using-images
2) https://onlinelibrary.wiley.com/doi/full/10.1111/jfb.13491
3) https://www.sintef.no/en/sintef-research-areas/aquaculture_technology/ (example of lab focussing on aquaculture technology)

Aquaculture – Fish stress

- Want to reduce fish stress
  - Lowers quality
  - Ethical considerations

- Robot monitoring (UUV) can stress salmon
  - Fish prefer to keep a specific distance away from robot



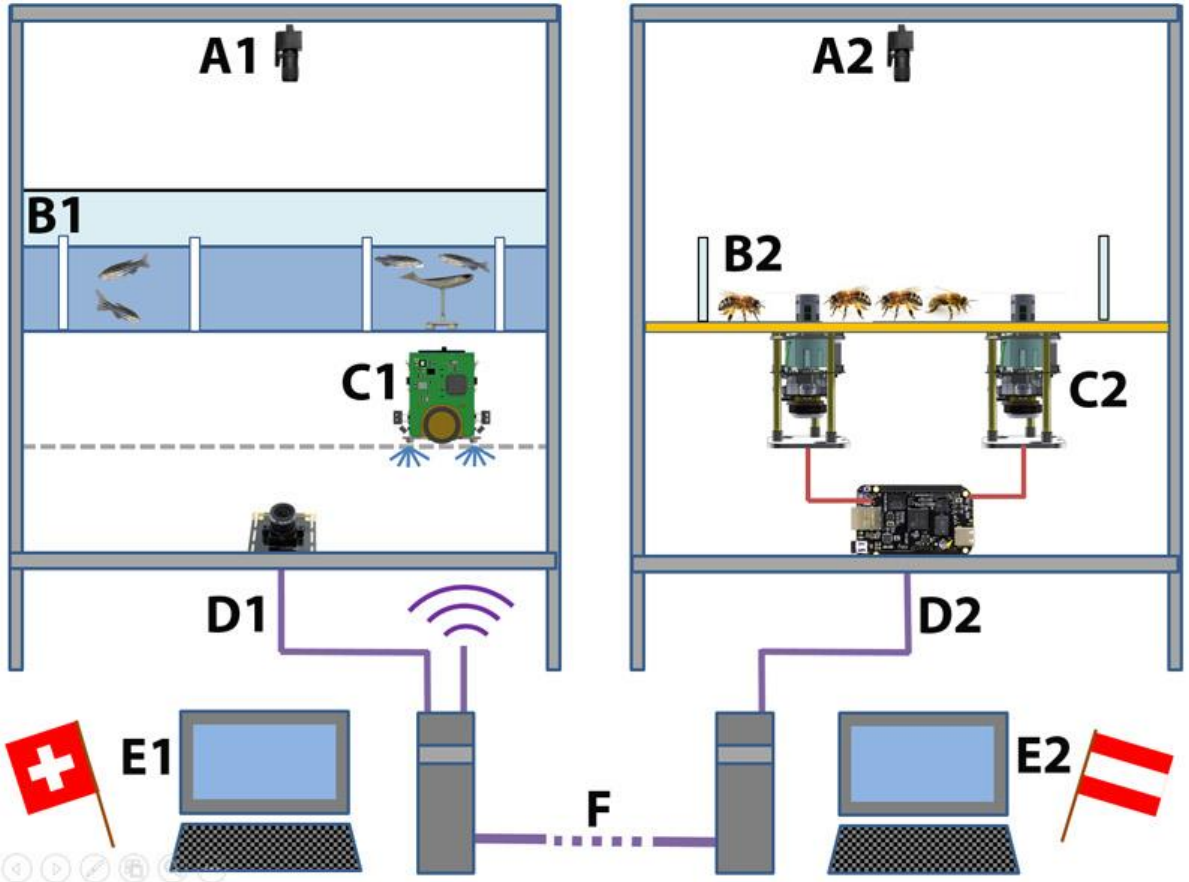
1) https://www.sintef.no/en/projects/2020/race-fish-machine-interaction/
2) https://www.mdpi.com/2410-3888/9/6/211

Aquaculture – Fish stress

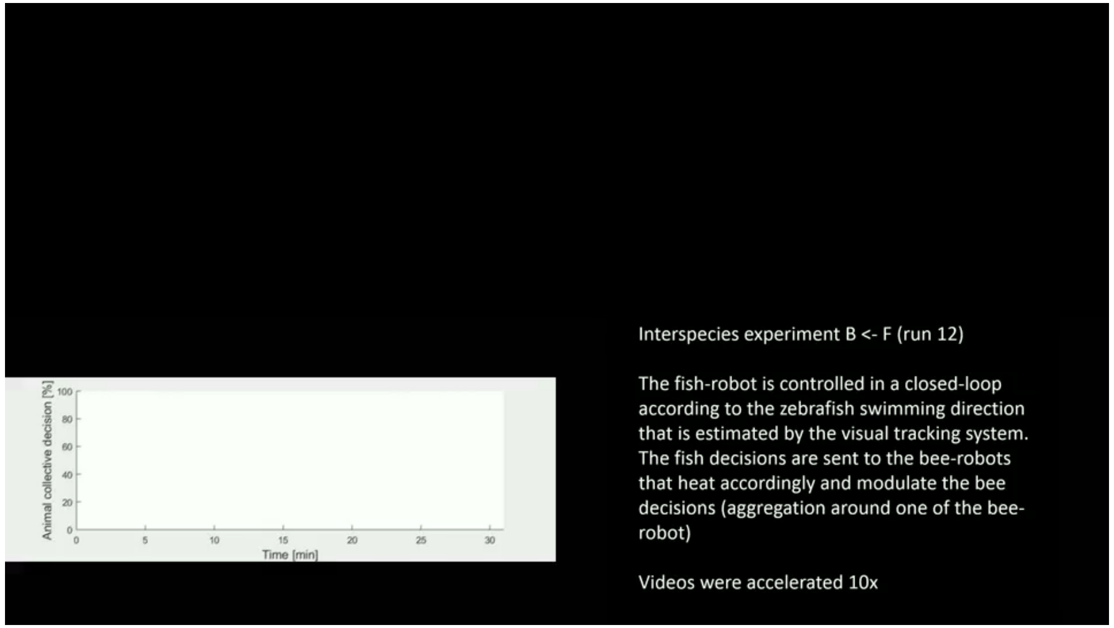
Robo-turtles in fish farms reduce fish stress

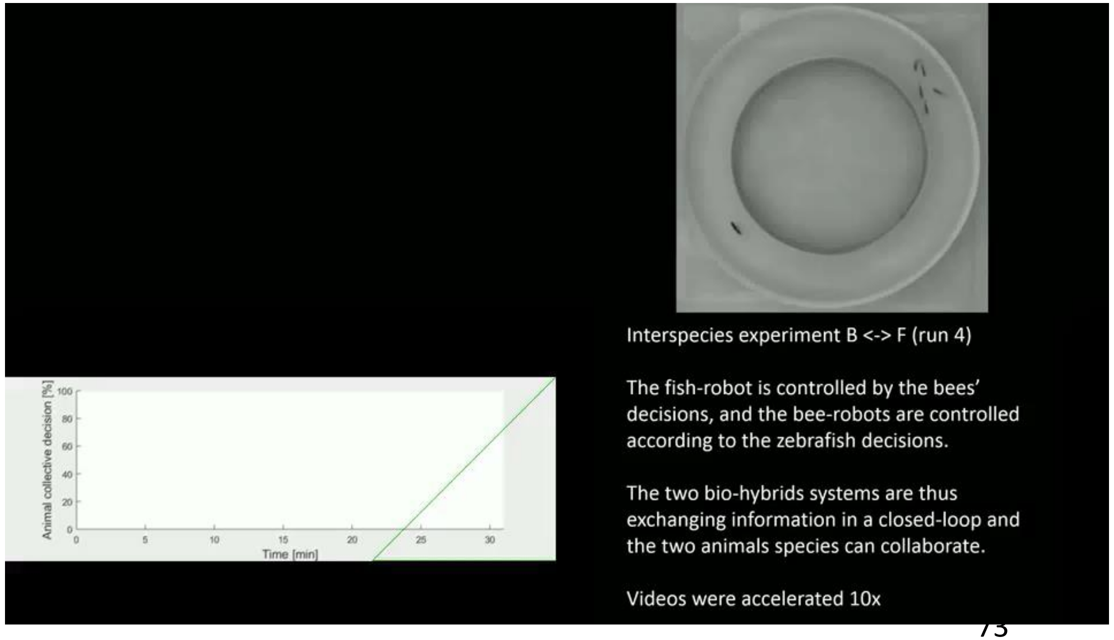
1) https://www.youtube.com/watch?v=X1MxlkFBxpQ

Mixed societies (interspecies interaction)



1) https://www.science.org/doi/10.1126/scirobotics.aau7897

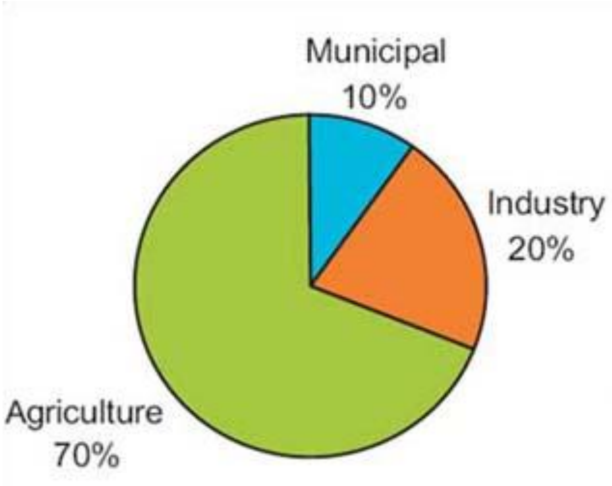




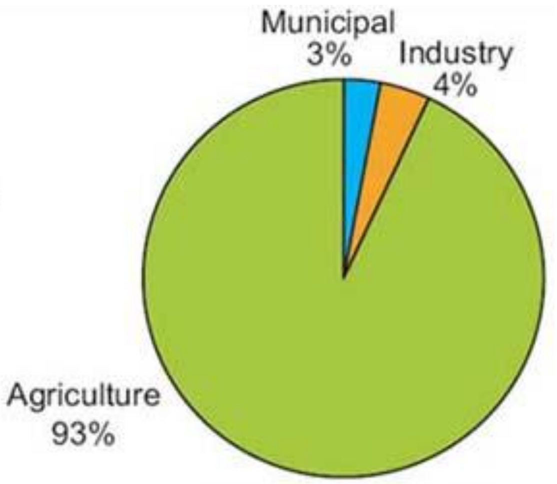
Section: Precision agriculture

Water and chemicals

- Agriculture uses 70% of global fresh water supplies
- Diffuse pollution from run-off contaminates water supplies
- Robotics can reduce water supply and field run-off through **precision agriculture**



Water withdrawal from fresh water



Water consumption (the portion permanently lost from source after withdrawal)

1) https://www.fao.org/4/y5582e/y5582e04.htm

EU Farm to Fork strategy

- EU strategy on improving food quality and agriculture

- *Two major targets:*
  - Target 1: to reduce by 50% the use and risk of **chemical pesticides** by 2030
  - Target 2: to reduce by 50% the use of more **hazardous pesticides (called ‘candidates for substitution’)** by 2030

1) https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides/farm-fork-targets-progress_en

Precision agriculture

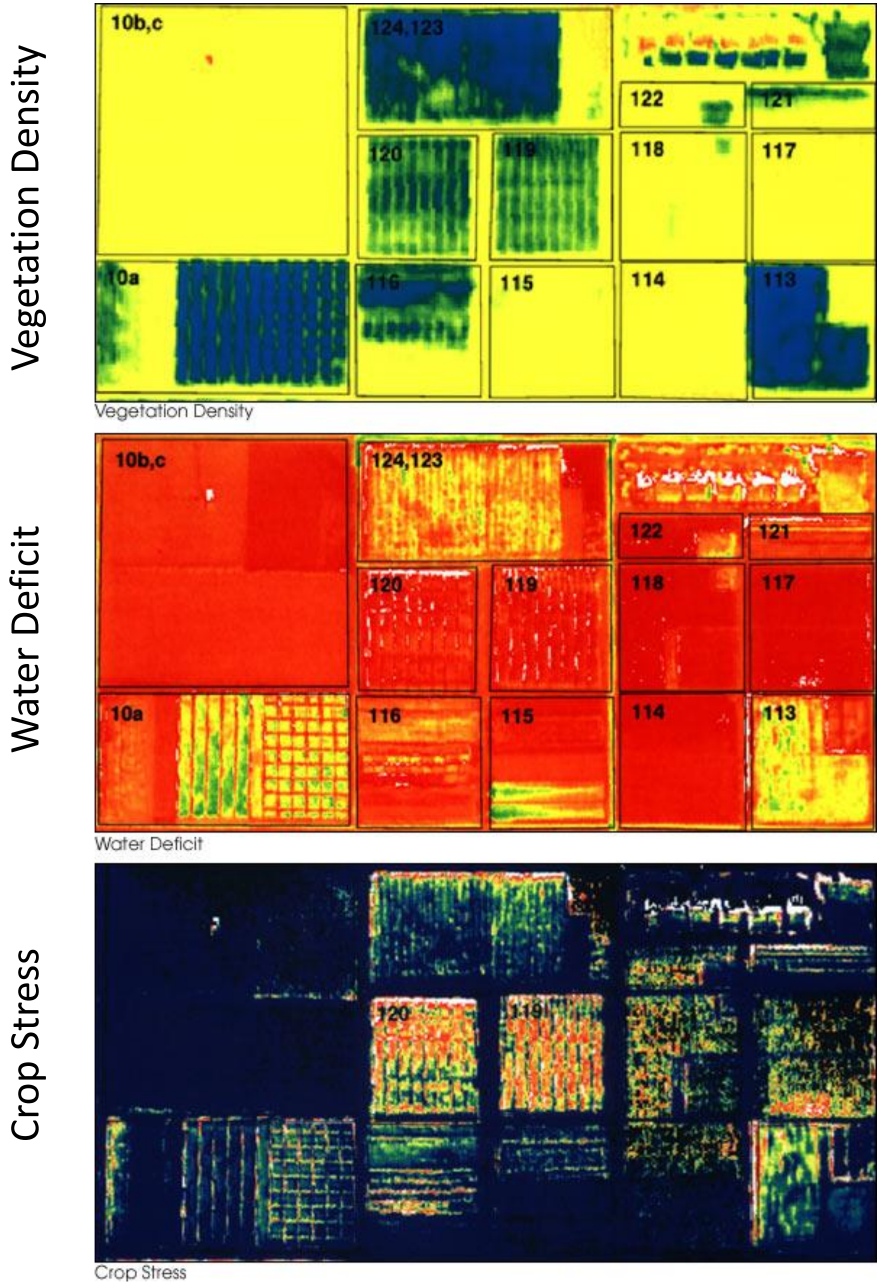
- Definition: International Society of Precision agriculture

*“Precision Agriculture is a **management strategy** that gathers, **processes and analyzes** temporal, spatial and individual **plant and animal data** and combines it with other information to support management decisions according to estimated variability for **improved resource use** efficiency, productivity, quality, profitability and sustainability of agricultural production.”*

1) https://www.ispag.org/about/definition

Precision agriculture

- Measure data of a field
- Transform data into useful information
- Act, based on informed decisions
  - Precision in space
  - Precision in time

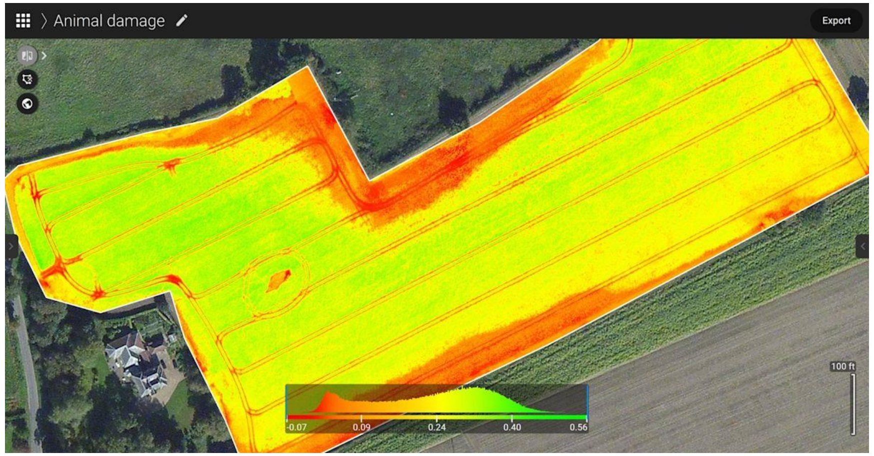


1) https://en.wikipedia.org/wiki/Precision_agriculture

Precision agriculture in space

- Decision and action based on position

- Examples:
  - Monitoring across field location
  - Selective watering across a field
  - Patch / spot spraying
  - Single plant spraying
  - Selective weeding

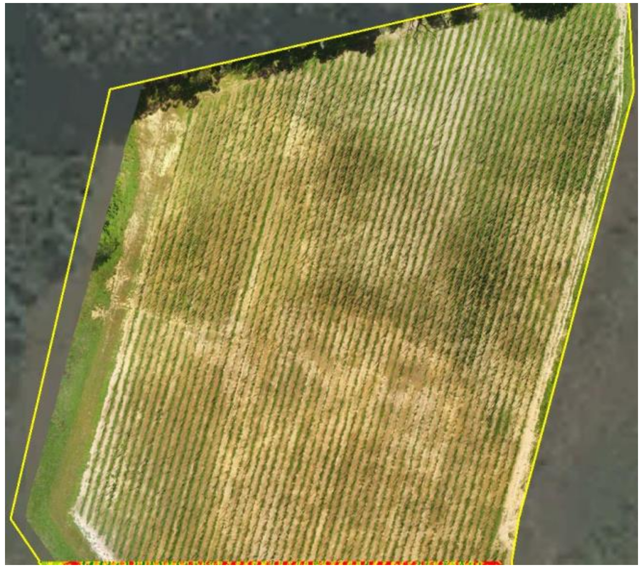


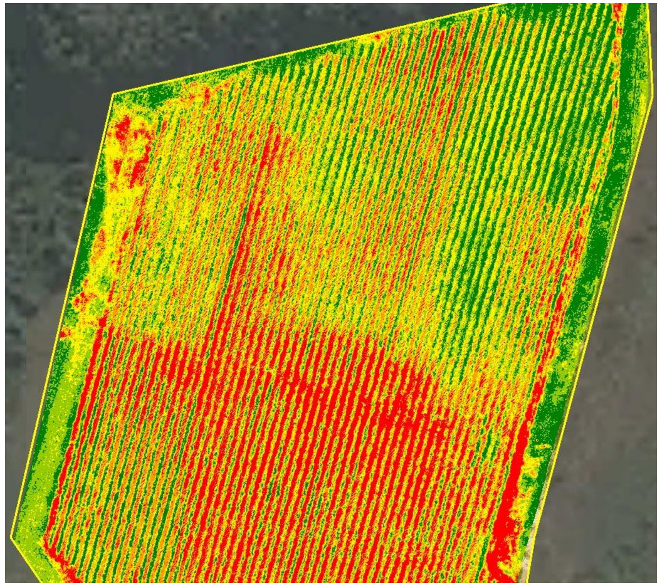
Animal damage assessment

1) https://www.pix4d.com/blog/precision-agriculture-on-demand/

Example: Precision agriculture in space (grapes)

- Drone outfitted with a near-infra-red (NIR) sensor
- Found a problem in the irrigation system
  - Farmers decided not to harvest struggling sections
  - Less stress on vines for next season
- Over-performing section of the field could be harvested early, offsetting loss





1) https://www.pix4d.com/blog/precision-farming-drone-mapping/

Robotics for crop maintenance from knowledge to action

- Targeted spraying
  - Robots for pesticide and fertilizer
- Mapping and Surveillance
  - Classical imaging
  - Multispectral imaging
- Irrigation and Water Management
  - Patrolling with moisture sensors
  - Target dry areas and direct water

1) https://droneag.farm/solutions/dji-agras-spraying-drone/
2) Agroscope, Dr. Louis Sutter

Robotics for crop maintenance

- Weeding Robots
  - Reduce pesticide use
- Pruning and trimming robots
  - Trimming green crops
- Disease and pest monitoring
  - Monitor pest pressure
  - Monitor crop health, spread

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1) https://spectrum.ieee.org/wallye-robot-
2) Agroscope, Dr. Louis Sutter

Flashing lights warning – laser weeding

(Flashing lights)– laser weeding

1) https://www.youtube.com/watch?v=X0AqgWQzrVA

Guest talk: Ecorobotix

- Guest lecture: Ecorobotix
  - Next week

- Different approach
  - Focus on farmers

NEWS & NOVELTIES | 02/18/2025

Ecorobotix Named Among Europe's Top 50 Future Unicorns

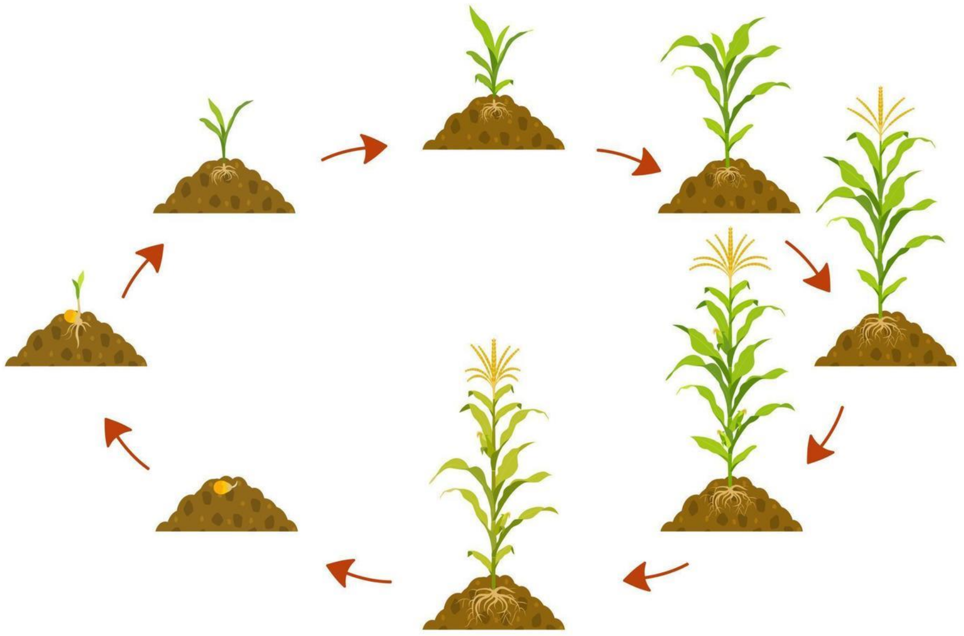
1) https://www.youtube.com/watch?v=X0AqgWQzrVA
2) https://ecorobotix.com/en/discover/news-novelties/ecorobotix-named-among-europes-top-50-future-unicorns/

Precision agriculture in time

- When to act?
  - Plant growth requires different attention
  - Water retention, stress in plants
  - When to add herbicide, insecticide

- Precision in time often requires precision in space

- Predictive models in combination with measured data



1) https://www.vecteezy.com/vector-art/7076412-cycle-growth-of-corn-in-circle-with-arrows-pointers-stages-of-crop-growth-from-seed-to-harvest

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Precision in time

- Difference between **pre-emergence** or **post emergence** of crops
  - No crop visuals

    vs
  - 3D challenges

- Green on brown
  - Green plant contrast on brown dirt

- Green on green
  - Need to separate plants
  - Requires plant identification

1) https://proofminder.com/blog/new-technology-on-the-horizon-green-on-green/

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Use case: Water status assessment

- Measuring water content in leaves

- Equipment
  - Scholander pressure chamber
  - Nitrogen tank
  - Magnifying lens

- Measurements at midday or before dawn


Scanty canopy


Lime treatment


Measuring leaf water content

1) Book

Use case: Water status assessment

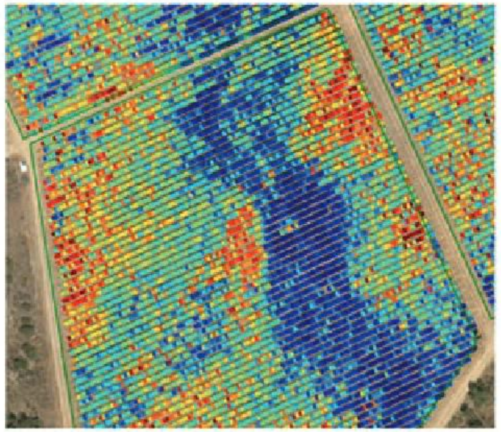
- Leaves close stomata to respond to water stress
  - Closed stomata -> Higher leaf temperature
- Other parameters
  - Sun-side vs shade side
  - Inclination of leaves
- *Measuring temperature in space and time can give insights to stress levels of plants*


VineScout monitoring robot

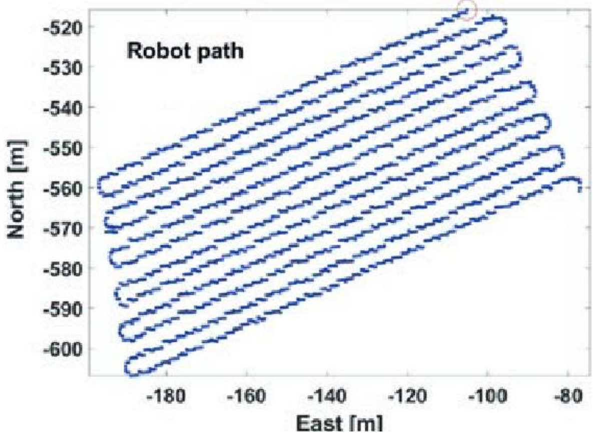
1) Book

Use case: Water status assessment

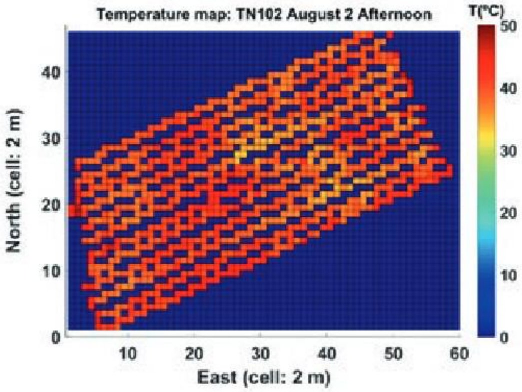
- Robot navigated through vineyards
- Measured canopy temperature
  - Infrared radiometer
- NDVI
  - Differences in vine vigour
  - Edges of either side worse



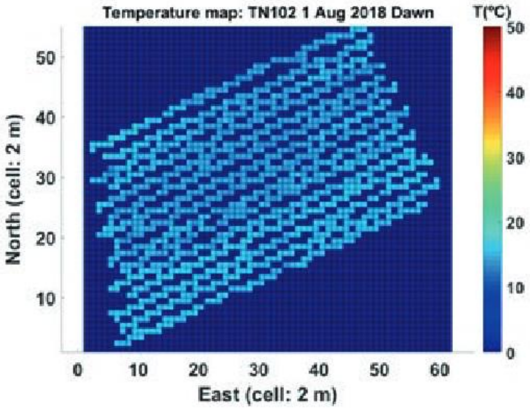
Normalized difference vegetation index (NDVI)



Robot path



Temperature in afternoon

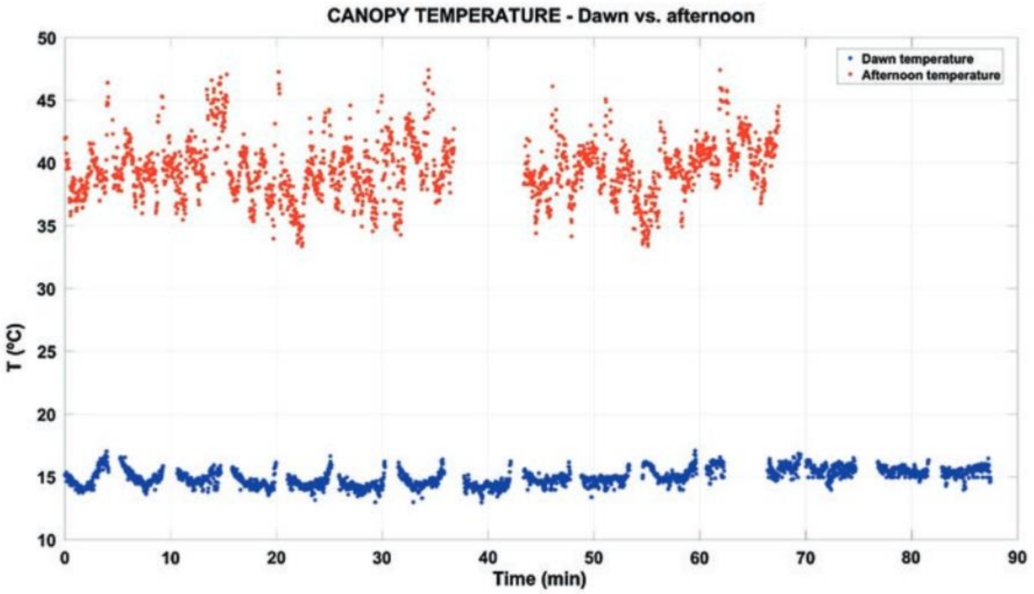


Temperature at dawn

1) Book

Use case: Water status assessment

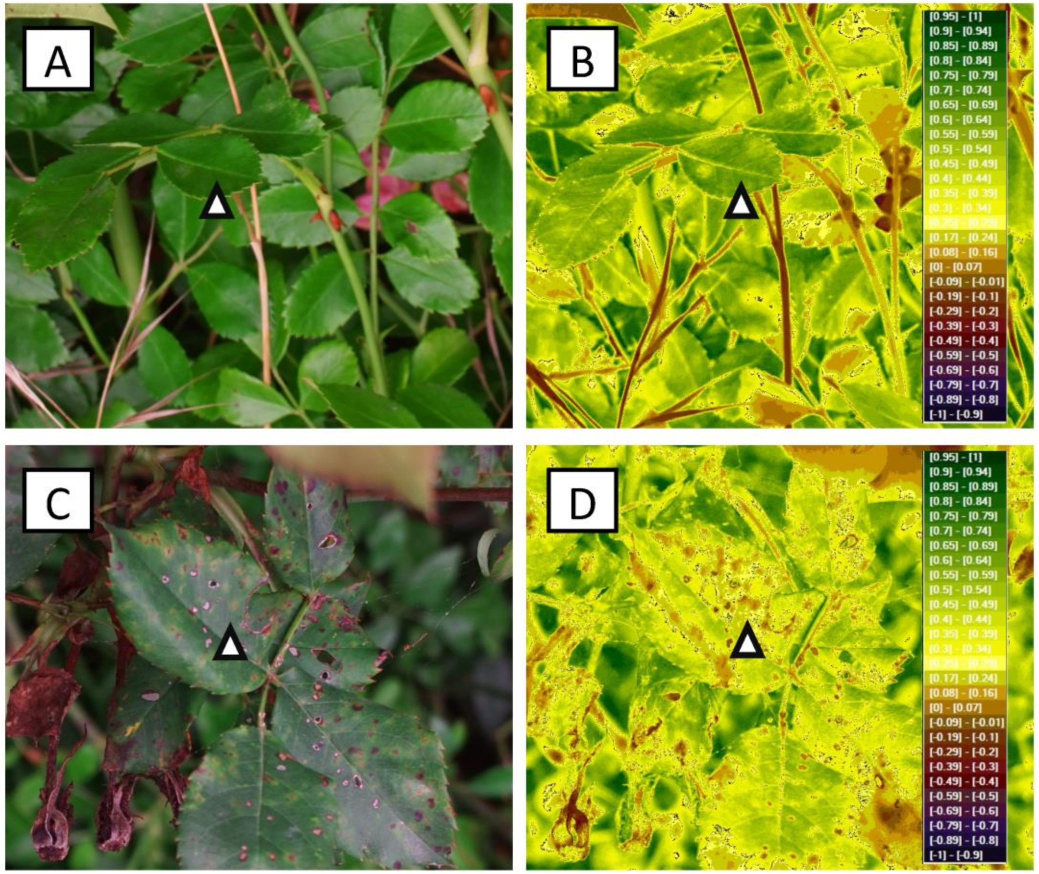
- Plotted over time
  - Measurements across each row
- Findings:
  - Significant dispersion in afternoon temperatures
- Centre of the vineyard several degrees colder at dawn
  - Temperature difference disappears after an hour
- Centre forms “basin” which buffers temperature



1) Book

Challenges in precision agriculture

- Fungi
  - If you can see fungi on the plant; it's too late!
  - Requires detailed spectral analysis
- Insects
  - Insects move
  - Insects hide under plant leaves
  - Requires real-time advanced detection



1) Traversari S, Cacini S, Galieni A, Nesi B, Nicastro N, Pane C. Precision agriculture digital technologies for sustainable fungal disease management of ornamental plants. Sustainability. 2021 Mar 26;13(7):3707.

Section: Challenges and ethical considerations

What are the main ethical concerns?

1. Go to **wooclap.com**
2. Enter the event code in the top banner

Event code
YYNHBJ

Ethical considerations

- Movement towards migrant labour
  - 65,000 in agriculture in the UK
    - Brexit slowed migration
  - *While robotics can improve safety, they can impact the livelihood of vulnerable people*

- Data ownership
  - Big data obtained from robotic monitoring
    - Deep learning for plant analysis

- Liability
  - Who is responsible if robotic solution fails?

1) Whitepaper (ref at start)
2) https://www.parvalux.com/how-robots-are-used-in-agriculture/

Challenge: Gradual tech adaptation

- Farmer's skills
  - Average age of UK farmer is 58

- Farmers are experts with their machines
  - Typically hands-on
  - Very busy

- New technology needs to improve the farmer
  - *Will have a talk next week from a company that pivoted strategy to adapt to farmer's needs*

1) Whitepaper
2) Image: https://www.imdb.com/title/tt10541088/

Challenge: Cost per yield

- Yield estimation
  - How much profit will the field make?

- Economics, cost per yield:
  - Initial cost (seeds)
  - Maintenance (operational)
  - Error (damage)

-> Robotics can risk additional costs on all three

ENV-530 Sustainability Robotics

1) A Systematic Literature Review on Crop Yield Prediction with Deep Learning and Remote Sensing https://www.mdpi.com/2072-4292/14/9/1990
2) https://www.savills.co.uk/research_articles/229130/329236-0

Technical limitations

- Detection
  - Large computation power
- Power
  - Battery capabilities
  - Alternative energy sources
- Maintenance
  - Difficult to fix
- Regulations and risk

1) https://roboticsbiz.com/robotics-in-agriculture-advantages-and-disadvantages/
2) https://www.ftc.gov/news-events/news/press-releases/2025/01/ftc-states-sue-deere-company-protect-farmers-unfair-corporate-tactics-high-repair-costs

Lecture goals revisited

- Explore critical challenges in agriculture that robotics can address
  - Climate change, labour shortages, safety, pest / disease control
- Learn what ways a robot can harvest plants
  - End effectors for specific plants
- Understand how robotics can improve livestock management
  - Reduce animal stress, automated cleaning
- Identify what is automated farming and what it entails
  - Robots interacting directly with farms
- Understand what is precision agriculture
  - Data integrated into farm management; precision in space and time
- Be able to discuss ethical considerations from robotics in agriculture
  - Big data, farmer adaption, regulations