Hurtige og ikke-destruktive mark-fænotypingsmetoder

– hvad har vi lært af otte års udviklingsarbejde med forædlerne?

Jesper Svensgaard (jesv@plen.ku.dk) og
Jesper Cairo Westergaard (jcw@plen.ku.dk)

KØBENHAVNS UNIVERSITET

DANESPO

DLF SEEDS & SCIENCE

Graminor

Lantmännen

Norwegian University of Life Sciences

Sejet plant breeding

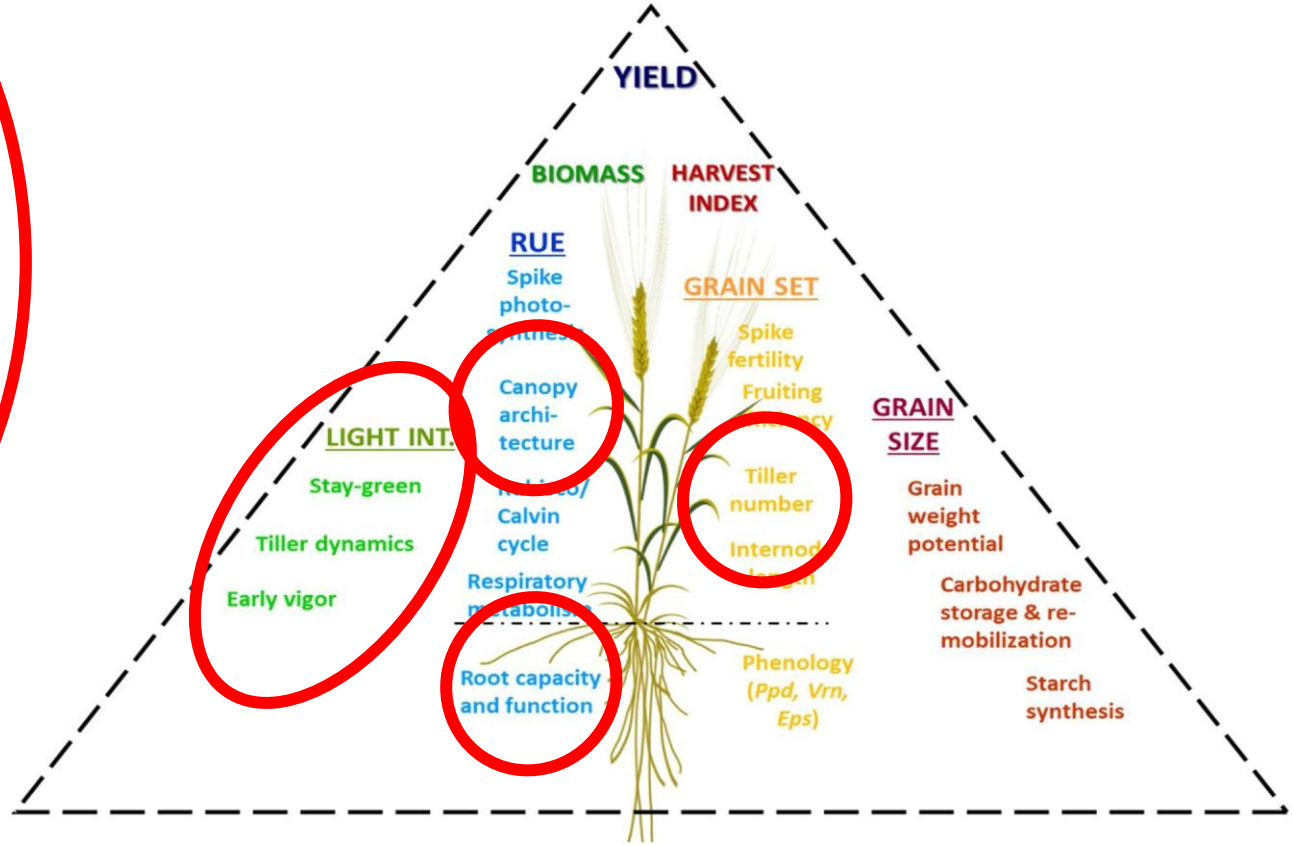
Swedish University of Agricultural Sciences

UNIVERSITY OF COPENHAGEN

Funded by:

NordGen

Hurtige og non-destruktive fænotyping-metoder??



Reynolds, Matthew, et al. "Breeder friendly phenotyping." *Plant Science* 295 (2020): 110396.

Hurtige og non-destruktive fænotyping-metoder??

Trait	Precision	Application timeline/project	Methods
Germination homogeneity, counting plants *(Potato, cereals)*	High	***/(6P-1, 6P-2)	Crop coverage (green pixels), RGB, VIS/NIR, segmentation/classification algorithms
Vigor/Early development *(cereals, grasses, potato)*	High	***/(6P-1, 6P-2)	Crop coverage (green pixels) + simple vegetation index#, Dynamic growth curves, RGB, VIS/NIR##
Biomass accumulation *(cereals, grasses)*	high	***/(6P-1, 6P-2)	Crop coverage (green pixels) + simple vegetation index, Dynamic growth curves, RGB, VIS/NIR
Growth rate, Green biomass accumulation rate *(cereals, grasses)*	High	***/(6P-1, 6P-2)	Crop coverage (green pixels) + simple vegetation index, Dynamic growth curves, RGB, VIS/NIR
Winter hardiness *(cereals, grasses)*	High	***/(6P-1, 6P2)	Crop coverage (green pixels), vegetation Index, RGB, VIS/NIR
Spatial biomass homogeneity *(cereals, grasses, potato)*	High	***/(6P-1, 6P-2)	Crop coverage (green pixels) + simple vegetation index, RGB, VIS/NIR
Crop structures, number of ears, height, volume) *(cereals, grasses)*	High	***/(6P-2)	Advanced photogrammetry, RGB, VIS/NIR
Biotic/Abiotic Stress *(cereals, grasses, potato)*	Medium	**/(6P-2)	Specific vegetation indices, leaf temperature, RGB, VIS/NIR, Hyperspectral, Thermal###
Timing of maturity/heading *(cereals, grasses, potato)*	Medium	**(*)/(6P-2)	Specific vegetation indices, multivariate image analysis, RGB, VIS/NIR, Thermal
Nitrogen Use efficiency (NUE) (Cereals)	Medium	*/(6P-2)	Specific vegetation indices, Dynamic relative content, VIS/NIR

Reynolds, Matthew, et al. "Breeder friendly phenotyping." *Plant Science* 295 (2020): 110396.

Tabel fra oprindelig 6P ansøgning

6P – et projekt/netværk på niende år, stærkere end nogensinde

- Public Private Partnership Plant Phenotyping Project
- En forskningsdel og et netværk
- Årlige workshops og Field Days, med stor tilslutning fra alle partnere
- Projektet slutter (med financiering fra NordGen) med udgangen af 2023
- Fuldt ønske om at fortsætte med netværket, selv med egenbetaling fra partnerne (forædlere, andre firmaer og universiteter)
- Blev baseret på droner, nu også andet udstyr
- Partnerne flyver og måler selv – universiteterne tester og udvikler pipeline for dataindsamling og tolkning

https://nordicphenotyping.org/

2015 Annual NPPN Workshop

The 1st annual NPPN workshop *Plant Phenotyping in a Nordic Context* and the 1st NPPN General Assembly took place on December 7-8, 2015 at the conference center Kolle Kolle near Copenhagen.

2022 NPPN Field Day

DLF and University of Copenhagen hosted the annual NPPN Field Day on 14-15 June 2022. The program on the first day included visits to the DLF lab and greenhouses, forage trials and sensor station. On day two we visited the Department of Plant and Environmental Sciences, University of Copenhagen facilities in Taastrup.

6P started med droner

Reynolds, Matthew, et al. "Breeder friendly phenotyping." *Plant Science* 295 (2020): 110396.

Brugen af droner til mark-fænotyping

- Hurtig, “let” og non-destruktivt
- Der eksisterer flere pipelines til flyvning og data nu

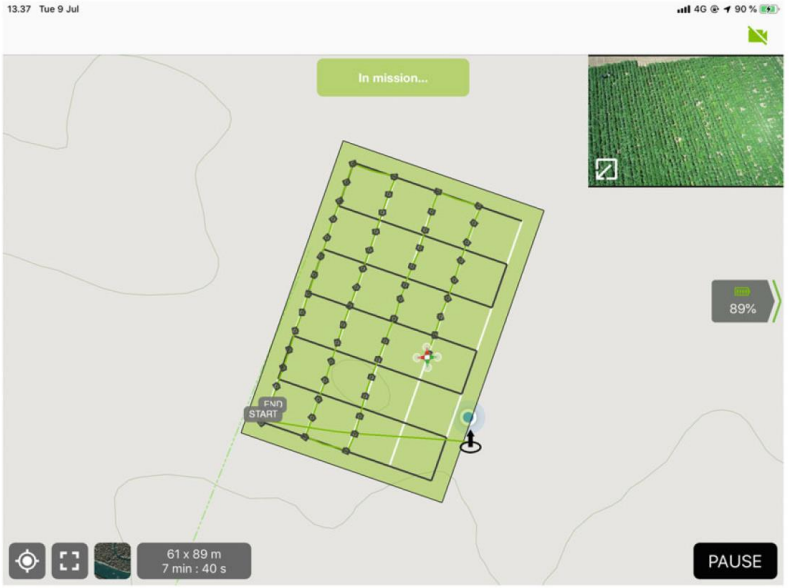


Fig. 6 Mid-mission screenshot, taken with the Pix4D software (iPad), covering an estimated area of 61 by 89 m. The drone is on the second-to-last leg of the first part of the double grid. In the upper right a live view of what the drone camera sees. Notice the off-nadir angle of the camera

Fig. 5 (**a**, Left) Mid-mission screenshot, taken with the DJI Go 4 software (iPad), 63 m above the field. The infestation is *P. infestans*. On the lower right you can see where the drone is on a map. (**b**, Right) High-resolution single shot (taken with the dedicated remote control button; can also be taken in the app with a press on the screen)

From chapter 13, Gao, Westergaard, and Alexandersson, in book: Dobnik, David & Gruden, Kristina & Ramsak, Ziva & Coll, Anna. (2021). Solanum tuberosum Methods and Protocols: Methods and Protocols. 10.1007/978-1-0716-1609-3.

Brugen af droner til mark-fænotyping

- Høj opløsning
- Mulighed for at genkende mange relevante træk
- Udfordring: At give trækkene en værdi der er repræsentativ

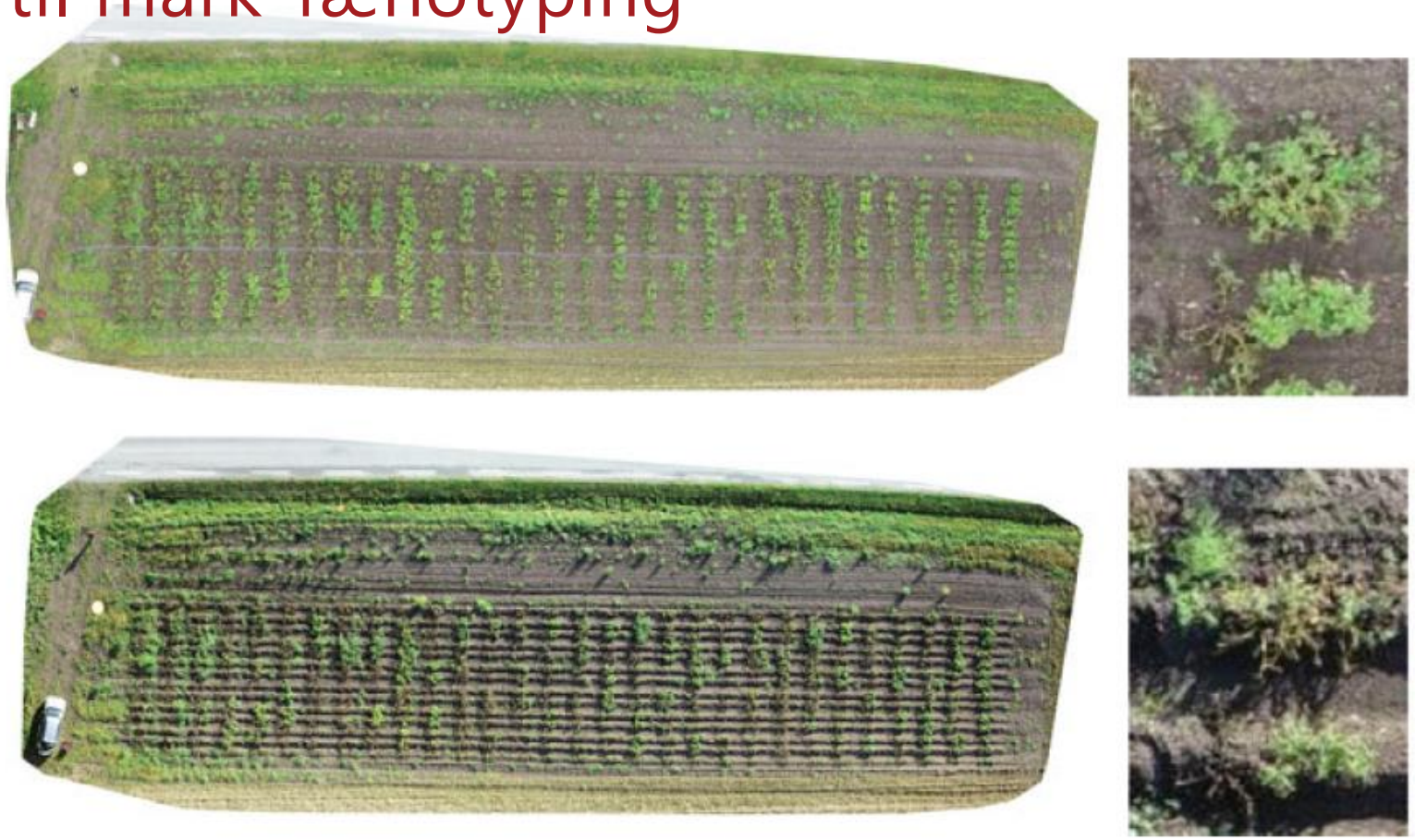
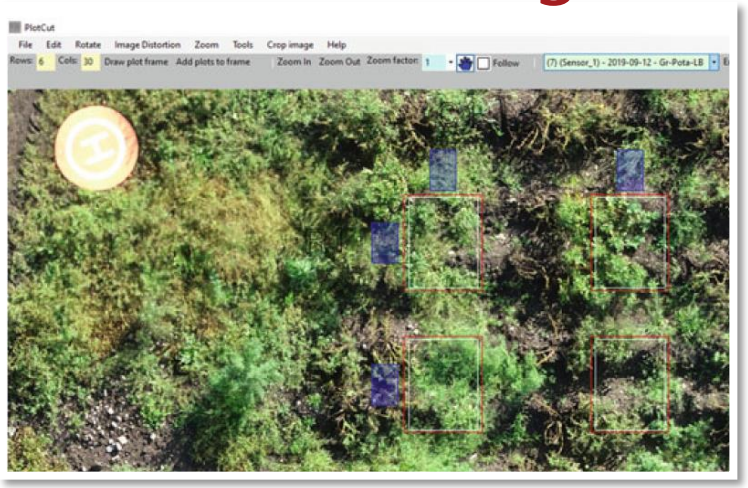


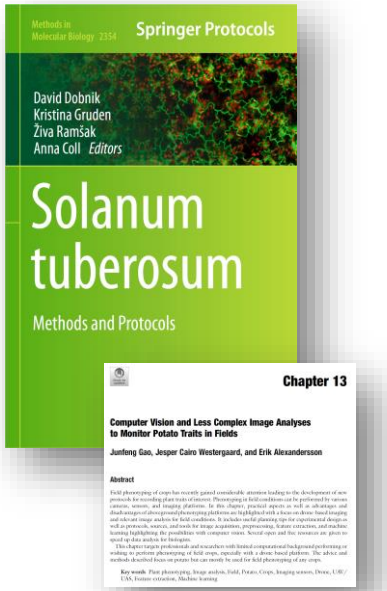
Fig. 7 Two mosaics from missions flown one week apart. Mosaics are on the left, zooms of the fourth-most right-hand columns' topmost plots is shown on the right side of the figure. In the first mosaic (topmost) the light is nicely homogenized (overcast), whereas in the second mosaic (bottom) one has very sharp shadows (due to direct sunlight) on the one side of the seedbeds. The situation on the top is always preferable for image extraction and analysis

From chapter 13, Gao, Westergaard, and Alexandersson, in book: Dobnik, David & Gruden, Kristina & Ramsak, Ziva & Coll, Anna. (2021). Solanum tuberosum Methods and Protocols: Methods and Protocols. 10.1007/978-1-0716-1609-3.

Vigtige udviklinger og engagement i 6P – tillid og data

- Løbende konsultenttjeneste for planteforædlerne (ude og hjemme) mht. deres brug af droner, special software til flyvning, billedbehandling og analyse, statistiske overvejelser
- Større forsøgsrunder (nogle gange flere uger) hos forædlerne med sampling, sensing og yderligere udstyrsafprøvning og protokoludvikling
- Specialflyvninger, med mere avanceret sensorer og droneplatforme. Nedgravet jordprofileringsudstyr hos forædlerne til Daisy model
- Udvikle specifik software (PlotCut v. 1., 2. og 3) som primært er baseret på forædlernes behov og deres løbende input.
- Afprøvning/vurdering af protokoller og softwareløsninger
- Artikler (fagfællebedømte), bogkapitel
- Årlige workshops og Field Days hos projektets partnere (afholdt I DK, SE, FI, NO)
- Foredrag og undervisning på workshops, konferencer og kurser





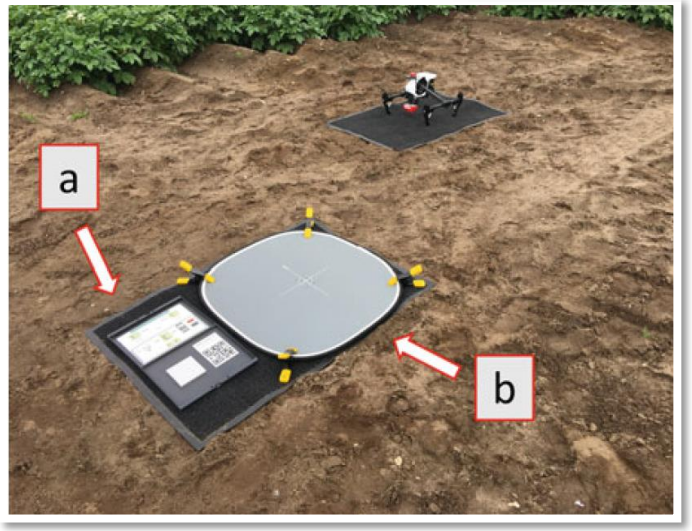


Fig. 9 Two calibration targets. (**a**) The radiometric calibration target for a MicaSense RedEdge M multispectral drone camera. (**b**) An 18% gray panel for intensity calibrations of RGB imagery. At the top of the image is seen a DJI Inspire 1 drone with the MicaSense sensor mounted including the irradiance sensor on top

Vigtige udviklinger og engagement i 6P:

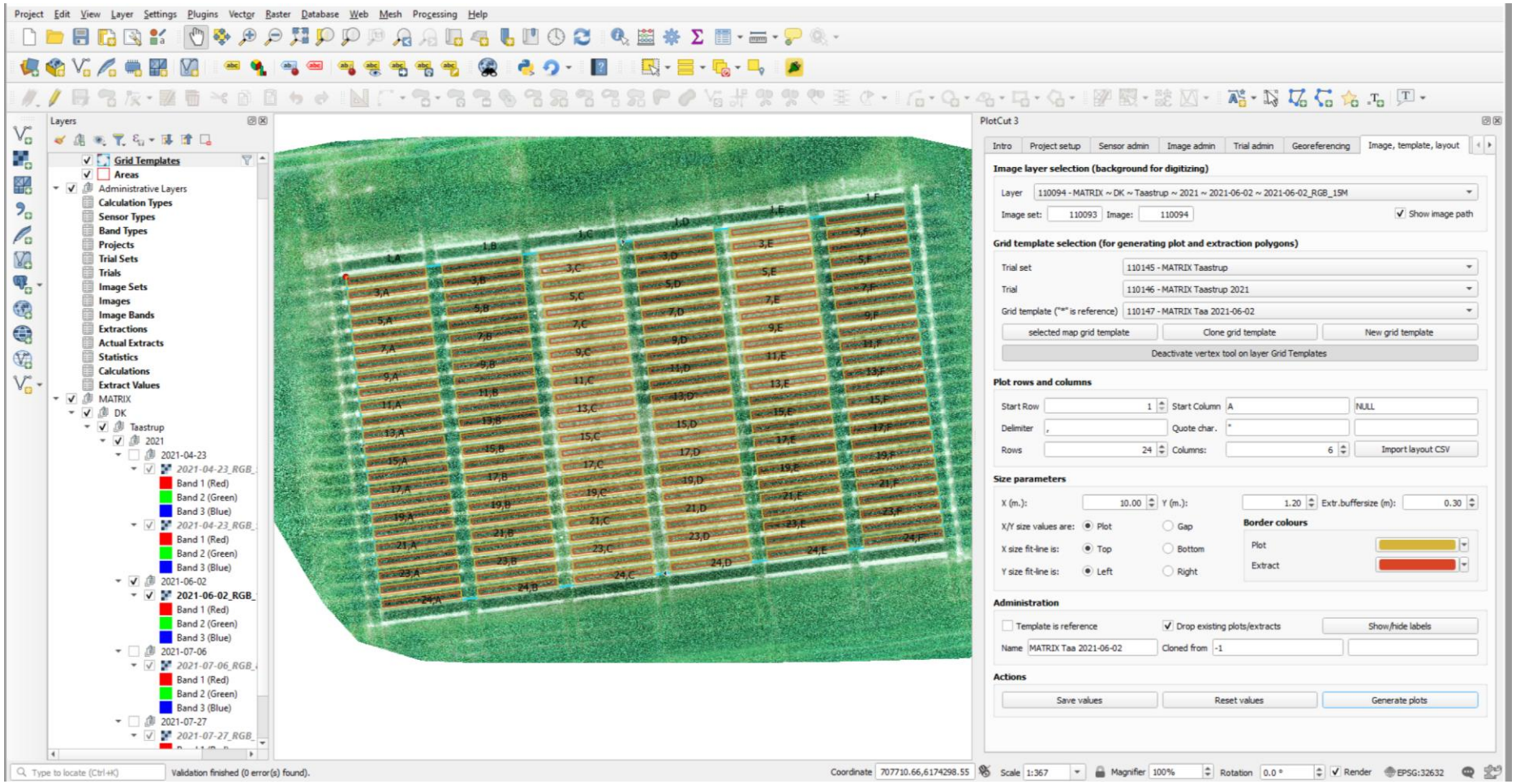
PlotCut3

A software solution created in the 6P3 project to more easily extract the relevant information from the drone images.

Especially important when one has many repeated flights over the same field.

- Easy creation of extraction templates
- Reuse of the templates
- Free (for the project partners) and open-source
- During 2023 a paper will be written on it and it will be released to the public, free.

PlotCut3 is built as a QGIS plugin and is using PostgreSQL as the database, and PostGIS extension



Resultater der viser potentialer og udfordringer

↓ 2022 slide from 6P3 work package leader Erik Alexanderson, SLU Alnarp.

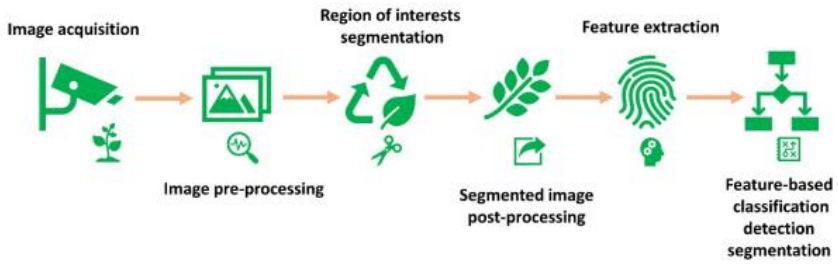
Using simple RGB images handheld above the canopy

But:

- Can we replicate this from a drone?
- Get enough spatial resolution (pixels per area)
- Fly low enough and still make trustworthy ortho-mosaics?

Deep learning

Field RGB images
Encoder-Decoder SegNet-based CNN
Segmentation important
Majority voting of scales
visual scoring vs lesion detection (R2=0.655)



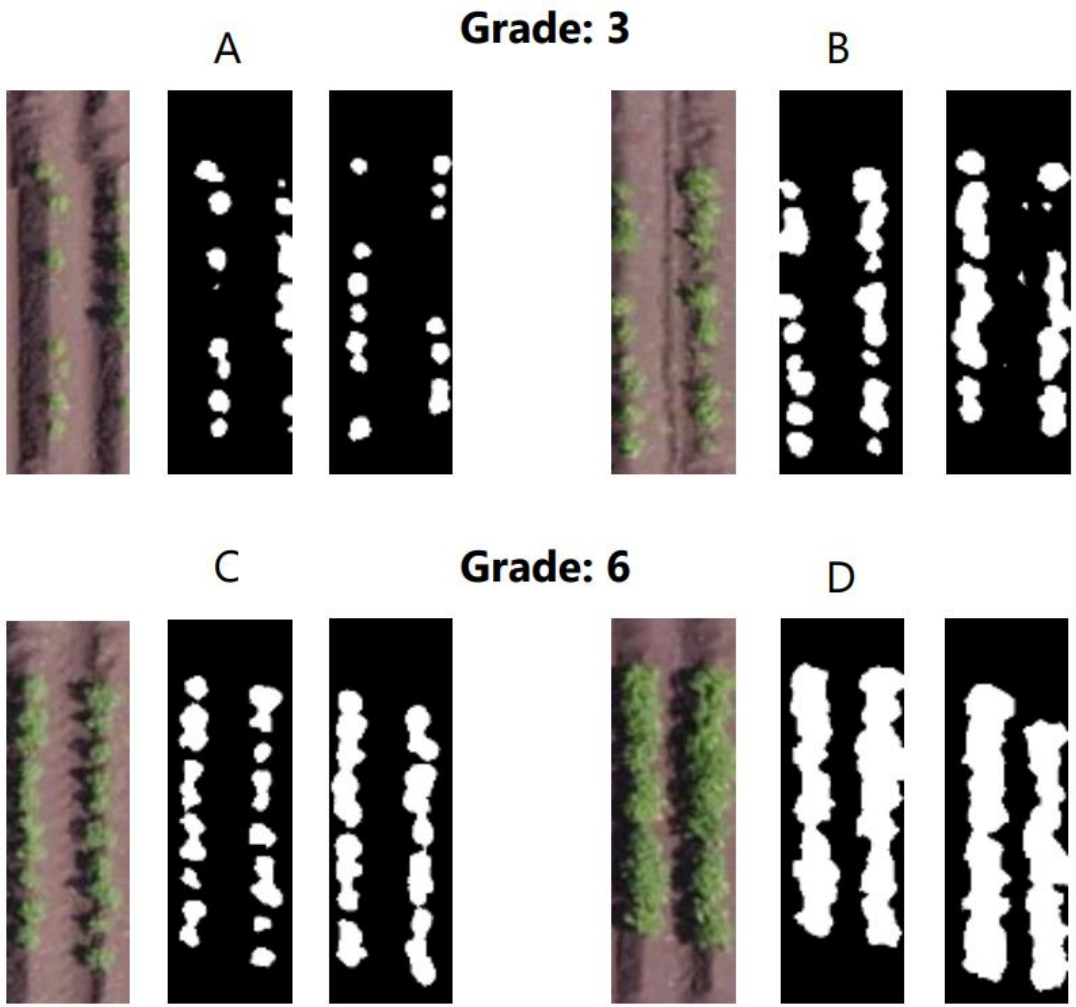
ELSEVIER
Knowledge-Based Systems
Volume 214, 28 February 2021, 106723

Automatic late blight lesion recognition and severity quantification based on field imagery of diverse potato genotypes by deep learning

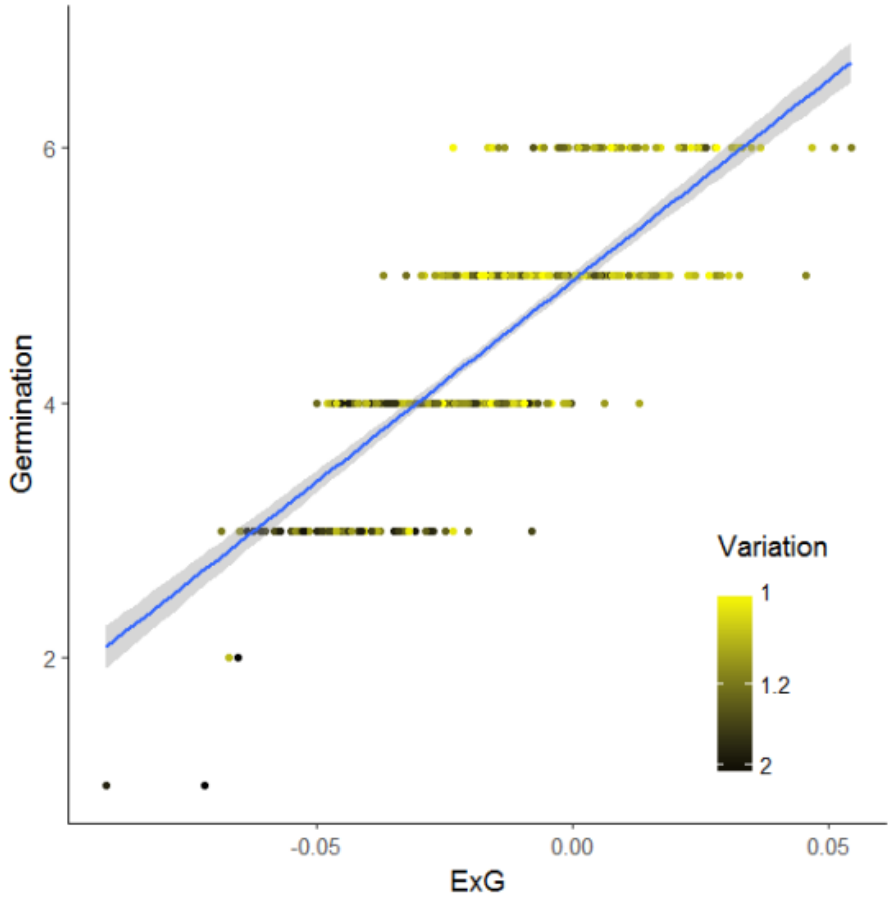
Junfeng Gao [a], Jesper Cairo Westergaard [b], Ea Høegh Riis Sundmark [c], Merethe Bagge [c], Erland Liljeroth [d], Erik Alexandersson [d]

[a] Lincoln Agri-Robotics, Lincoln Institute for Agri-Food Technology, University of Lincoln, Lincoln, UK
[b] Department of Plant and Environmental Sciences, University of Copenhagen, Taastrup, Denmark
[c] Danespo Breeding Company, Give, Denmark
[d] Department of Plant Protection Biology, Swedish University of Agricultural Sciences, Alnarp, Sweden

Resultater der viser potentialer og udfordringer



Variation in germination

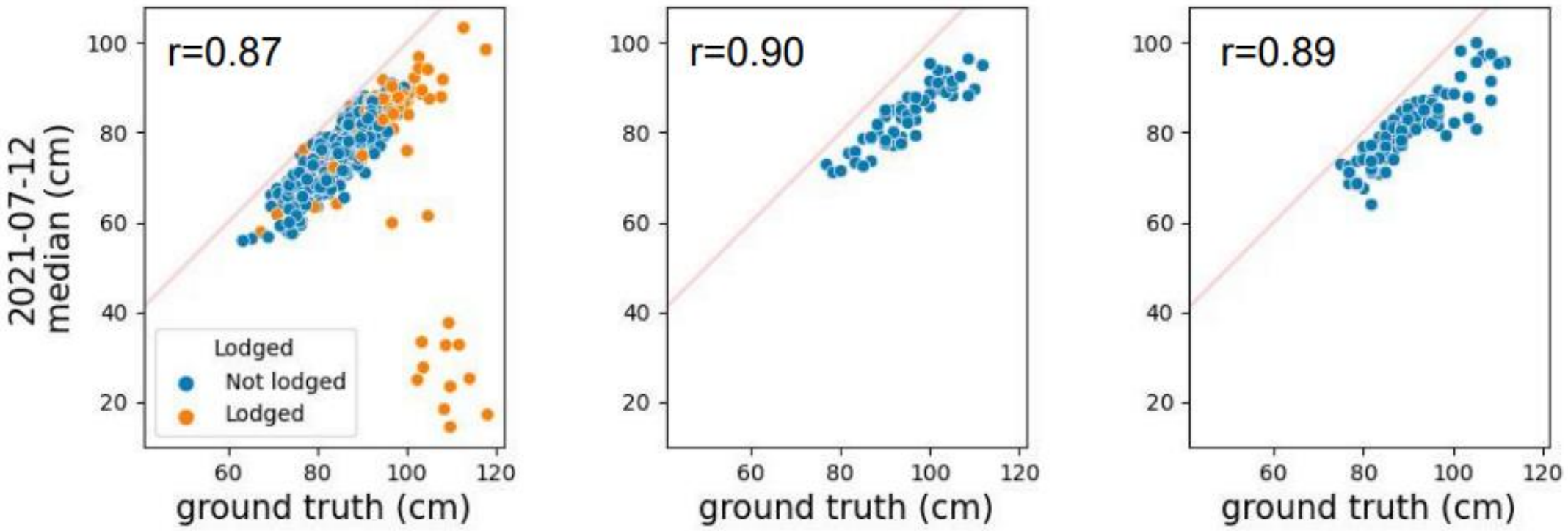


Resultater der viser potentialer og udfordringer

↓ 2022 slide from 6P3 work package leader Morten Lillemo, NMBU. Data from Henrik Lassegård master thesis, Dec 2021

Plantehøjde: Estimering fra dronebilleder

- Comparison with ground truth in 3 different trials
- Median values show good correlations, but underestimates true plant height



Resultater der viser potentialer og udfordringer

↓ 2022 slide from 6P3 work package leader Morten Lillemo, NMBU.

Tælling af aks fra dronebilleder

- Focus on head detection using low-altitude UAV flights
- Testing of 8 m altitude flights in 2021, RGB imaging with Phantom 4:

- Collaboration with the Global Wheat Head Detection Challenge

AAAS
Plant Phenomics
Volume 2021, Article ID 9846158, 9 pages
https://doi.org/10.34133/2021/9846158

Plant Phenomics
A SCIENCE PARTNER JOURNAL

Database/Software Article

Global Wheat Head Detection 2021: An Improved Dataset for Benchmarking Wheat Head Detection Methods

Etienne David,[1,2] Mario Serouart,[1,2] Daniel Smith,[3] Simon Madec,[1,3] Kaaviya Velumani,[2,4] Shouyang Liu,[5] Xu Wang,[6] Francisco Pinto,[7] Shahameh Shafiee,[8] Izzat S. A. Tahir,[9] Hisashi Tsujimoto,[10] Shuhei Nasuda,[11] Bangyou Zheng,[12] Norbert Kirchgessner,[13] Helge Aasen,[13] Andreas Hund,[13] Pouria Sadhegi-Tehran,[14] Koichi Nagasawa,[15] Goro Ishikawa,[16] Sébastien Dandrifosse,[17] Alexis Carlier,[17] Benjamin Dumont,[18] Benoit Mercatoris,[17] Byron Evers,[6] Ken Kuroki,[19] Haozhou Wang,[19] Masanori Ishii,[19] Minhajul A. Badhon,[20] Curtis Pozniak,[21] David Shaner LeBauer,[22] Morten Lillemo,[8] Jesse Poland,[6] Scott Chapman,[3,12] Benoit de Solan,[1] Frédéric Baret,[2] Ian Stavness,[20] and Wei Guo[19]

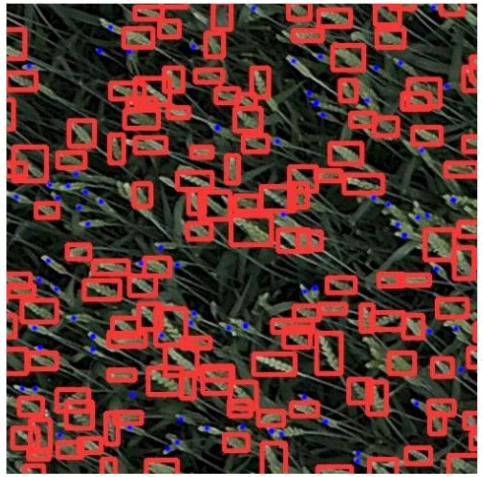
https://doi.org/10.34133/2021/9846158

Resultater der viser potentialer og udfordringer

- YOLO5 deep learning model

Image size:1024x1024
Cropped from the main image

Detected heads using YOLO5
Accuracy: up to 95%



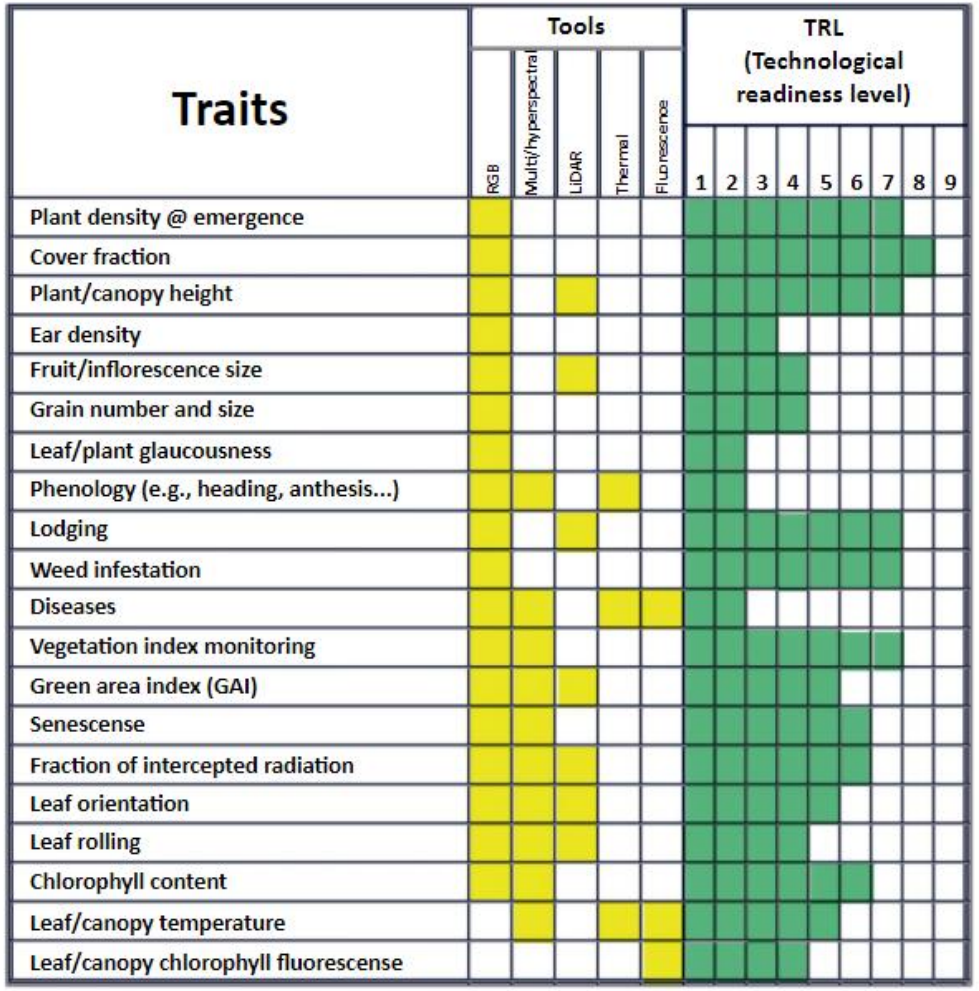
Best Accuracy = 69%

Test made at Norwegian University of Life Sciences - NMBU

Yang, Baohua, et al. "Rapid detection and counting of wheat ears in the field using YOLOv4 with attention module." *Agronomy* 11.6 (2021): 1202.

Resultater der viser potentialer og udfordringer (og nyt udstyr der kommer til)

- Plotvariation ✓
- Plantetal [✓]
- Afgrødedække/vigor ✓
- Overvintring ✓
- Vækstkurver VI og højde ✓
- Afgrødehøjde generelt [✓]
- Tælle aks [✓]
- Vurdere afmodning [✓]
- Rust i græsser ✓
- Etc



Araus, José Luis, et al. "Translating high-throughput phenotyping into genetic gain." *Trends in plant science* 23.5 (2018): 451-466.

Resultater der viser potentialer og udfordringer (og nyt udstyr der kommer til)

- Plotvariation ✓
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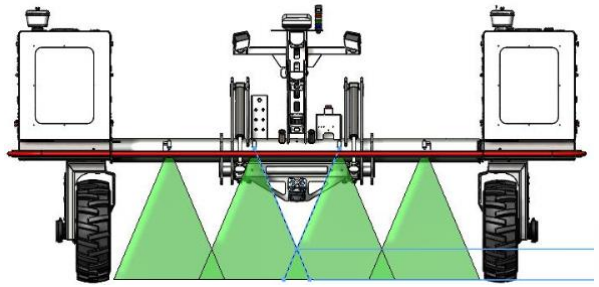
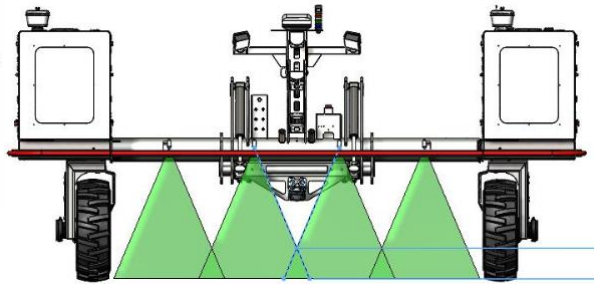


Og hvad har vi så lært (på dronesiden) i 6P?

- Software design and dissemination
  - Continuously involve the breeders for the design and testing
  - Be upfront about what is prioritized high versus what may never be in the feature set
  - When new versions are released, set aside the time to hold extra web meetings to provide help
- Go out and visit the breeders many times
  - Once or twice before and during the season
  - To understand what challenges and limits them. And to build up trust
  - And who is right – the breeder or the instrument data – challenge the setup
- Use the easy and cheaper drone, camera etc when possible (e.g., RGB sensor versus multispectral); the simpler flight mission software – don't get it perfect, get it done
- If an imaging flight is needed every seven days, plan for one every four
- Process (even if just a quick, low resolution) the drone images on same or next day to catch any errors (e.g., insufficient image overlap due to hard winds, ruining the mosaic'ing process)
- Generally speaking: **The KISS concept whenever possible** "Keep It Simple, Silly"
  - We can do and test a lot, nice for publications, but focus on what is needed
- We can produce good data, how to assure quality of data + integration into breeding program

Næste projekter – IMFABA og Halm til det hele



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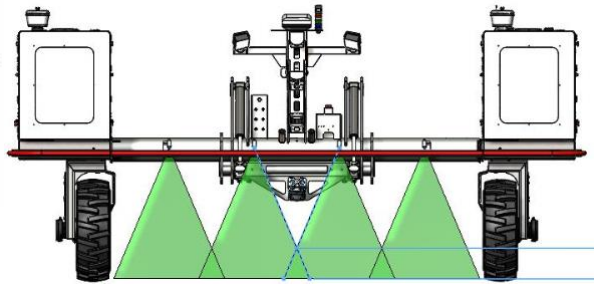
Næste projekter – IMFABA og Halm til det hele



Tørke I hestebønner
- Afgrødehøjde
- Afmodning (VI)
- Bladtemperatur (vanskelig)
- Stomata konduktans (Håndholdt)

Halmudbytte I forædlingsmateriale
- 3D modeller på volume og afgrødehøjde (drone)
- Tælle planter, tælle aks
- Tælle og vurdere stub

Data-science en vigtig del nu

Næste udviklingstrin – AI, nye kameraer, specifikke traits

- Sensor fusion: Samle flere sensortyper og forskellige spatielle samplingsniveauer (proximalt/markrobot, droner, satelliter) for samme mark.
  - Så vi kan undersøge for diverse afgrøder hvornår er det nemmeste "godt nok" til at opnå beslutningsstøtte og hvornår er det i stedet værd eller ligefrem nødvendigt, at bruge det mere tidskrævende og/eller dyre udstyr. Kameraer der kan se “igennem” ting
- Opbygge forsøgs- og produktikonsmark datasæt der er "åbne"
  - Åbne = Free and Open Source data. Koster ikke noget og er i standard formater.
  - Til brug i AI (Deep Learning etc.) undersøgelser og applikationer med partnere
  - Tilgængeligt fra vore eller andre servere. Dataplacering dissimineret offentligt.
  - Fordi: Der er data "derude" som er produceret i samarbejde mellem planteavlere, universiteter og firmaer, men det er delvist ejet og kontrolleret af firmaer der slet ikke eller kun delvist giver adgang.
- Data-science fokus tak. Data-science i sundhed over i landbrug. Digitale tvillinger

Tak for opmærksomheden – spørgsmål?