

Precision Ag via Drones, XAIoT and DT

YangQuan Chen, Ph.D., Director,

MESA(Mechatronics, Embedded Systems and Automation)**LAB**

ME/EECS/SNRI/HSRI/CITRIS, School of Engineering,

University of California, Merced

<http://mechatronics.ucmerced.edu> <http://methane.ucmerced.edu/>

March 20th, 2025, Thursday

CITRIS UC MERCED F3 AG BAG



- Dr. Leigh Bernacci, VISTA
- Alli Sweigard, VISTA F3
- Prof. Erin Hestir, CITRIS UCM
- ...
- MESA Lab former and current Ph.D. students: Dr. Brandon Stark, Dr. Tiebiao Zhao, Dr. Haoyu Niu, Dr. Derek Hollenbeck, Dr. Di An, Mr. Shiang Cao
- USDA ARS Dr. Dong Wang,
- UCANR Kearny Dr. Andreas Westphal
- UCCE Merced David Doll
- UCM: Josh Viers, Gerardo Diaz, Jian-Qiao Sun, Reza Ehsani, Holley Moyes

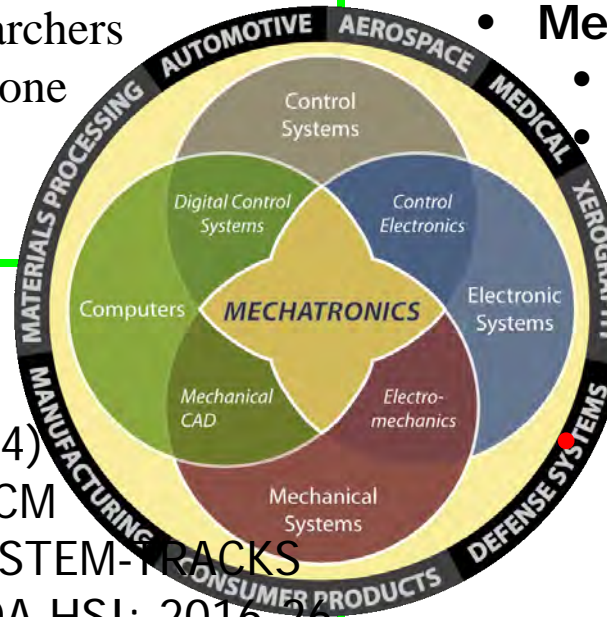
Mechatronics, Embedded Systems and Automation Lab

Real solutions for sustainability!

Established Aug. 2012 @ Castle, 4,500+ sq ft
6 Ph.D./5+ undergraduate researchers
2 visiting scholars || 10 Ph.D. done
@ UCM, 9 @ USU

Education and Outreach Activities:

- Eng Service Learning(Sp14)
- AIAA Student Branch @UCM
- Robots-n-Ribs|MESABox! STEM-TRACKS TEAM-E; UAS4STEM. USDA HSI: 2016-26
- ME142 Mechatronics (take-home labs)
- ME143 Unmanned Aerial Systems
- ME152 Digital Twins
- ME280 Fractional Order Mechanics
- ME/EECS210 Linear Multivariable Control
- ME211 Nonlinear Control
- ME212 Robustness and Optimality



Research Areas of Excellence:

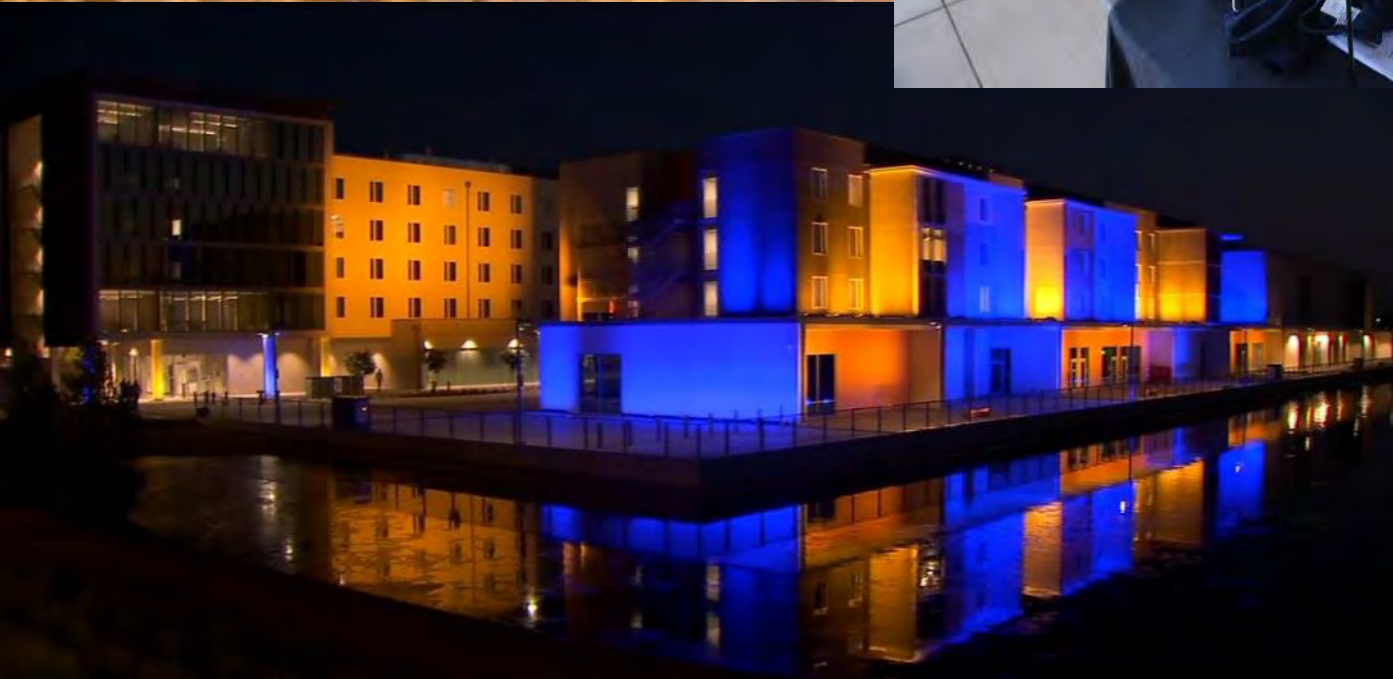
(ISI H-index=77, Google H=104; (58647) i10=679, HCR-2018-21)

- Unmanned Aerial Systems & UAV-based Personal Remote Sensing (PRS)
- Cyber-Physical Systems (CPS)
 - Mechatronics
 - Applied Fractional Calculus
 - Modeling and Control of Renewable Energy Systems

Projects Related to San Joaquin Valley:

Energy [Solar/wind energy, Building efficiency (HVAC lighting), smart grids integration, NG pipelines]

- **Water** (Water/soil salinity management, water sampling UAVs)
- **Precision Ag/Environment** (Crop dynamics, optimal harvesting, pest, methane sniffing/mapping, **DH** ...)







- **Drones**
- **XAIoT**
- **Digital Twins**

- SSM (**S**ite **S**pecific **M**anagement)
- **Water**/pesticides/fertilizers etc
 - **R**ight time?
 - **R**ight amount?
 - **R**ight place?



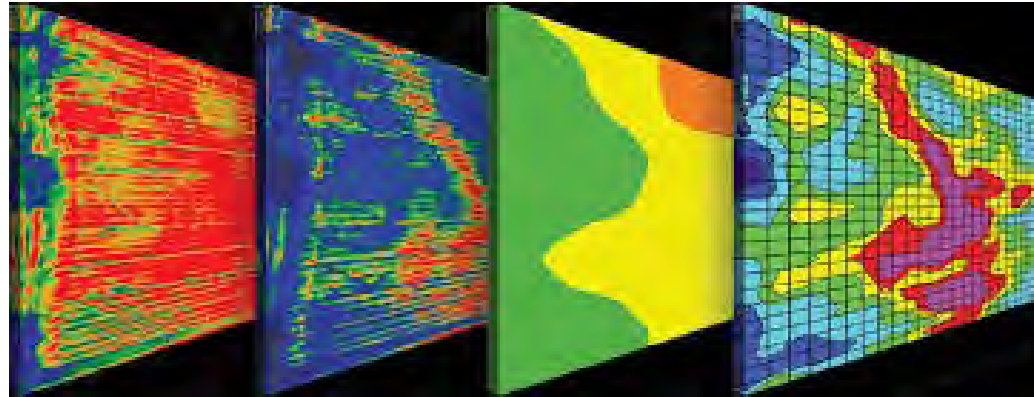
Precision Ag is A Big Data Industry

n

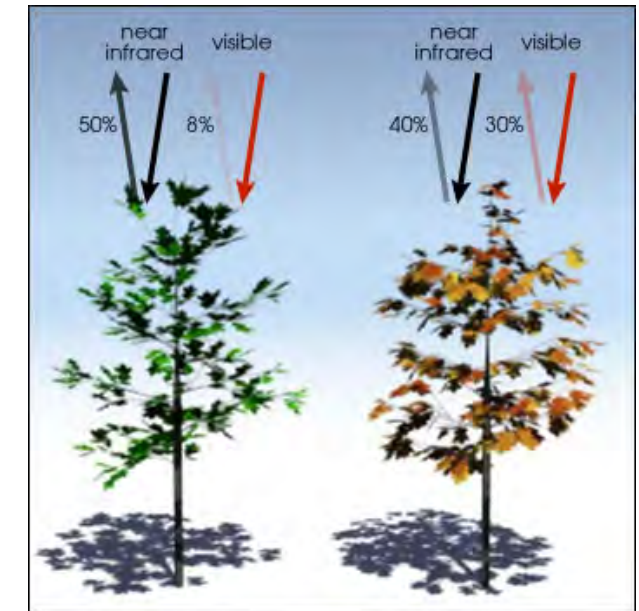
Drones are big data generators

n

Drones are mobile sensors and mobile actuators

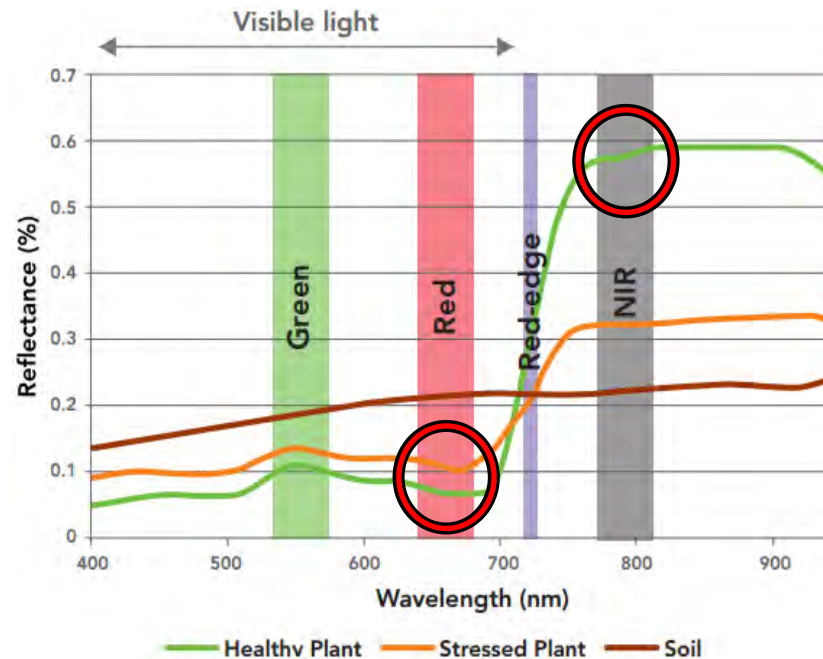


Vegetation Indices to Estimate Crop Health

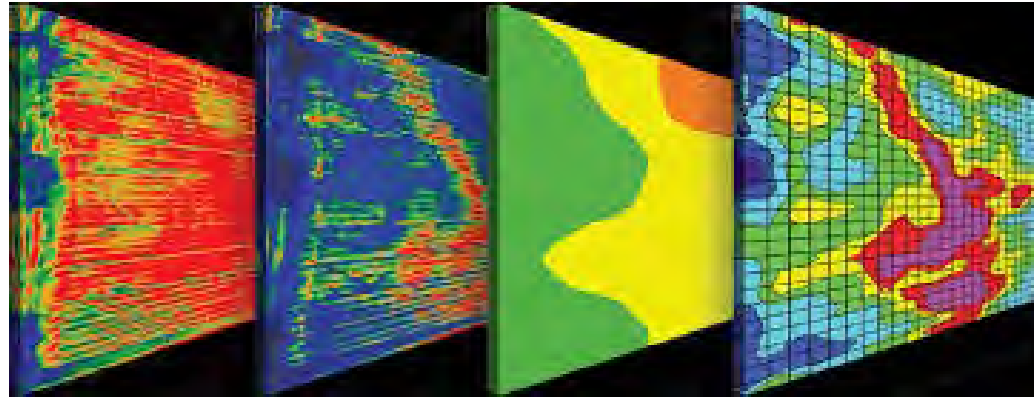


$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$$

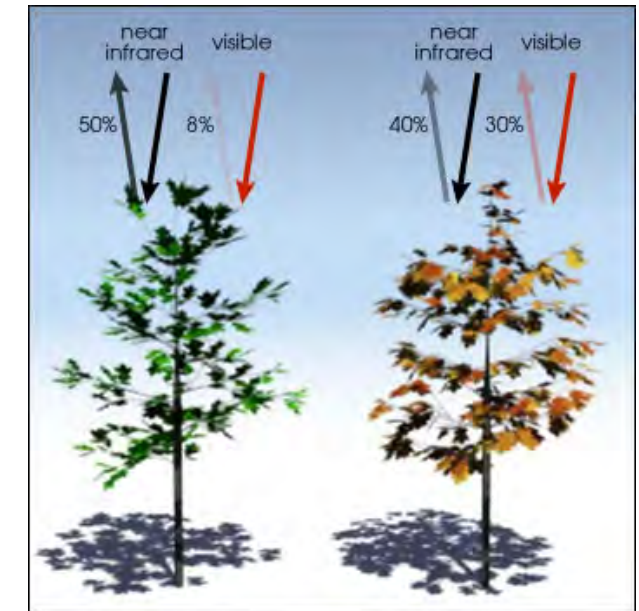
$$\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$



Precision Ag via Drones, XAIoT, Digital Twins

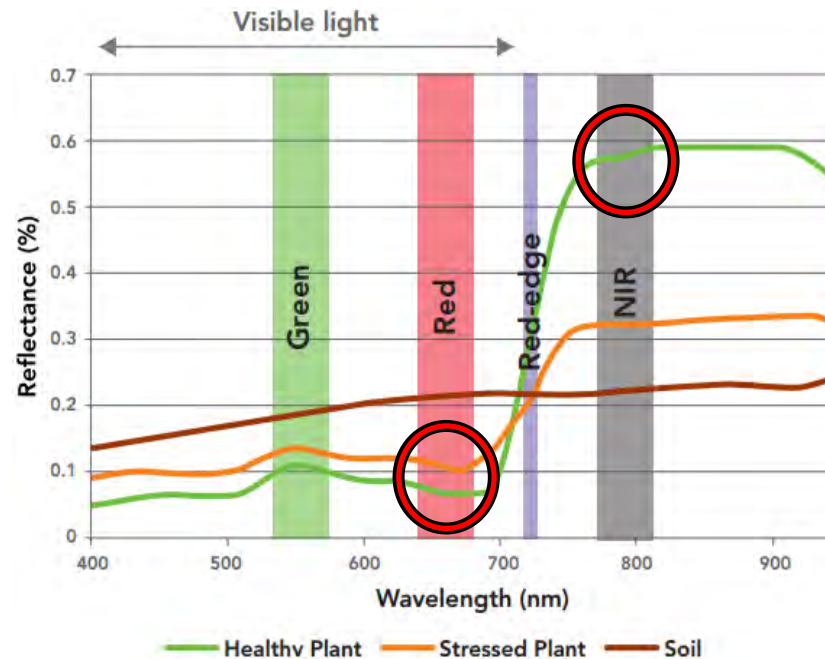


Vegetation Indices to Estimate Crop Health

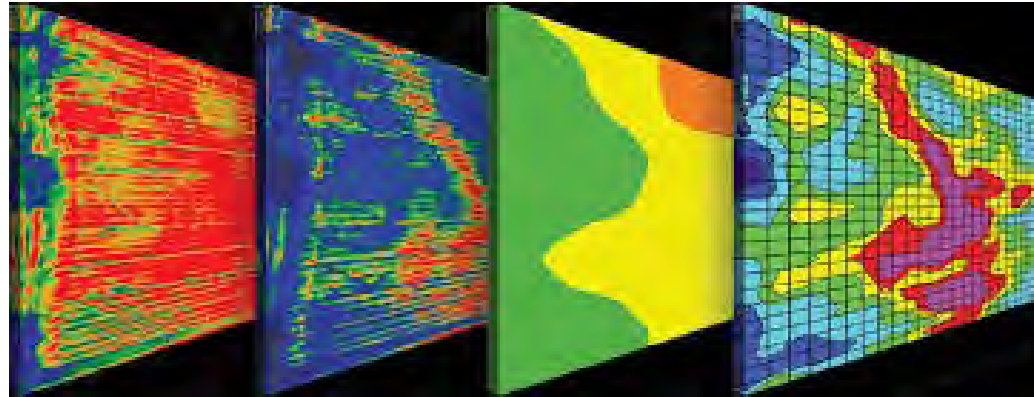


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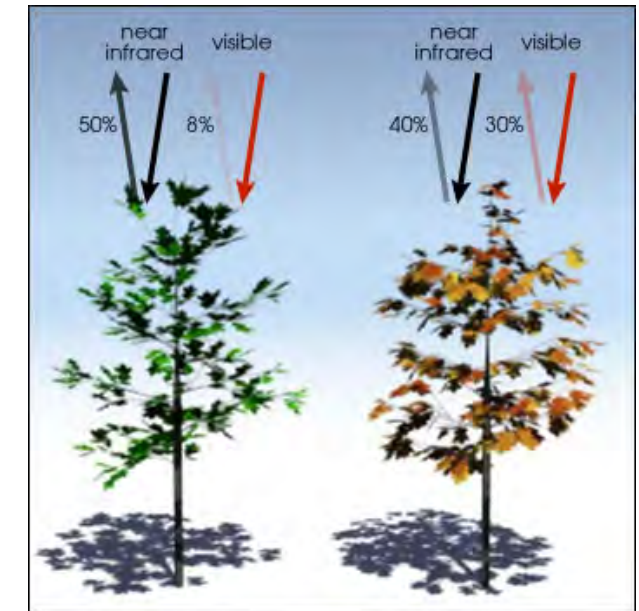
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Precision Ag via Drones, XAIoT, Digital Twins

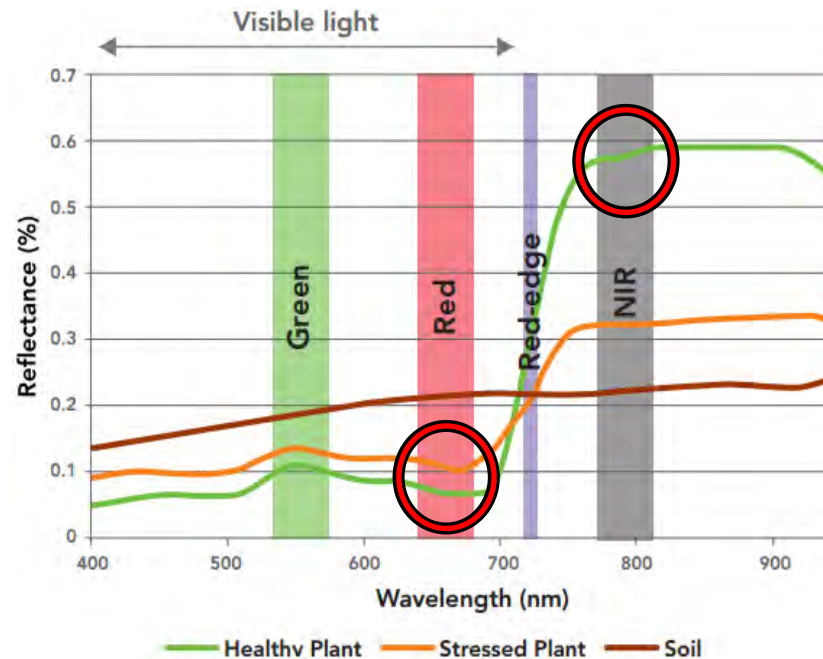


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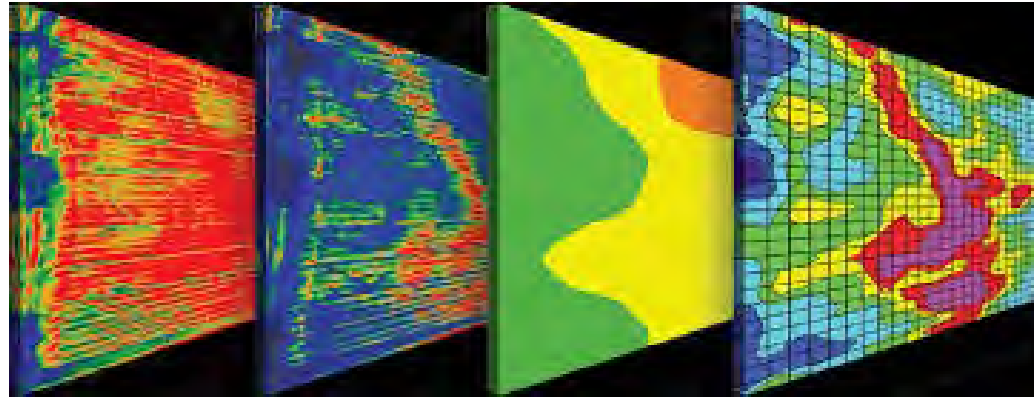


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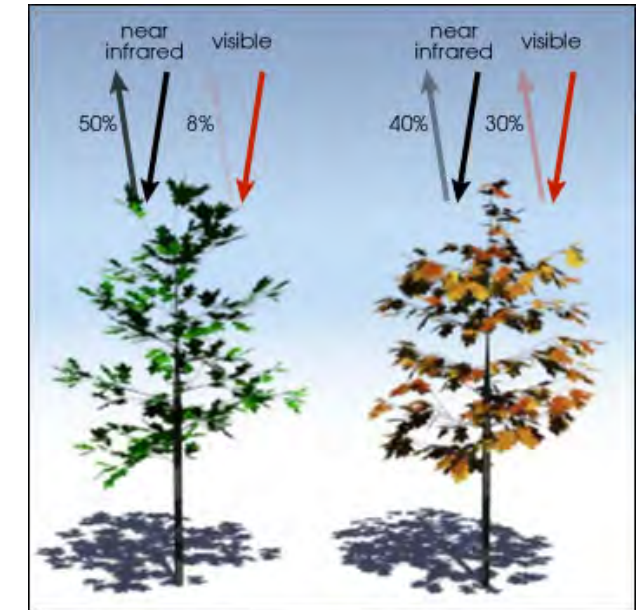
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Precision Ag via Drones, XAIoT, Digital Twins

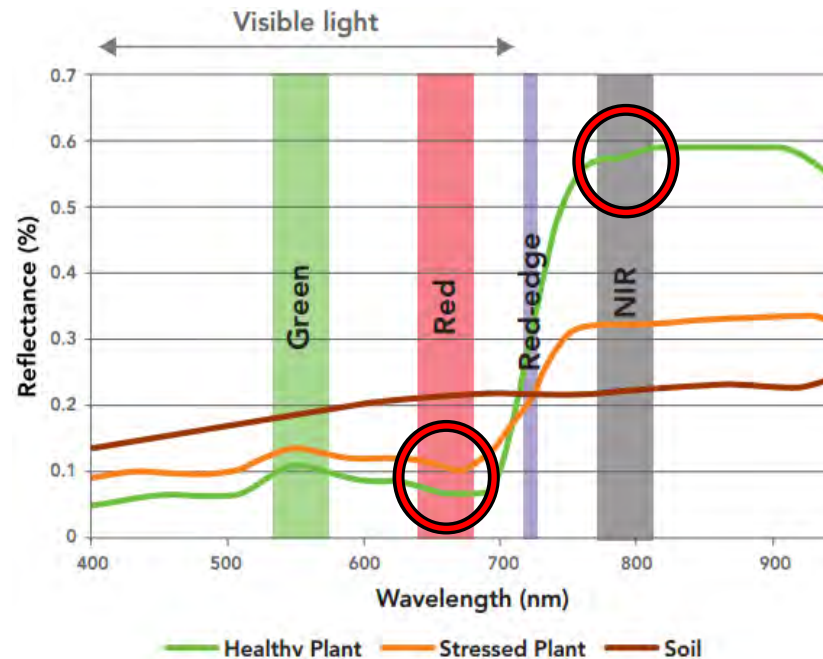


Vegetation Indices to Estimate Crop Health

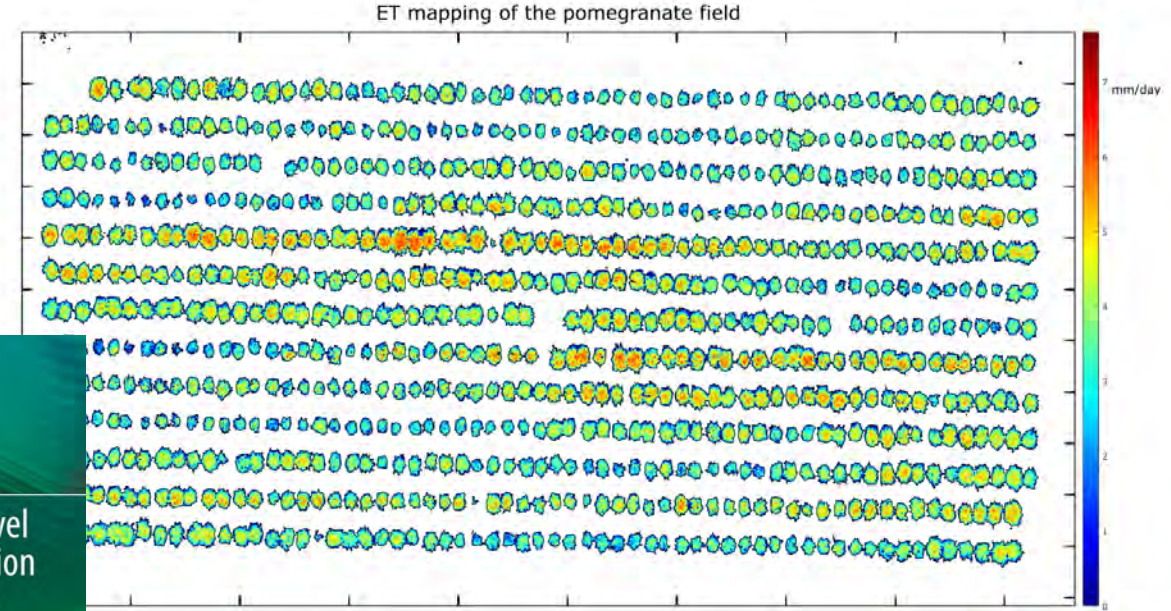
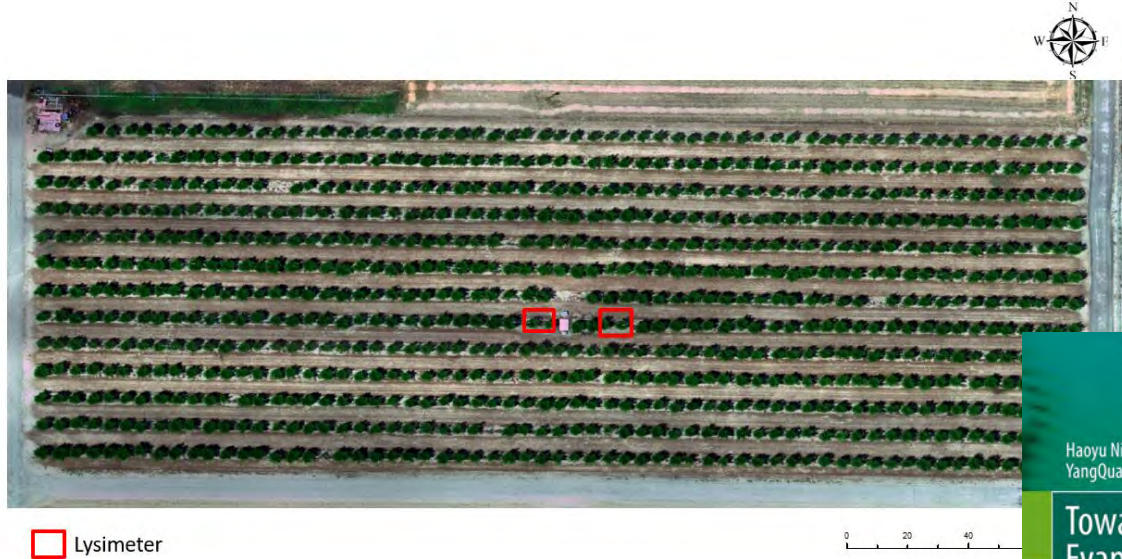


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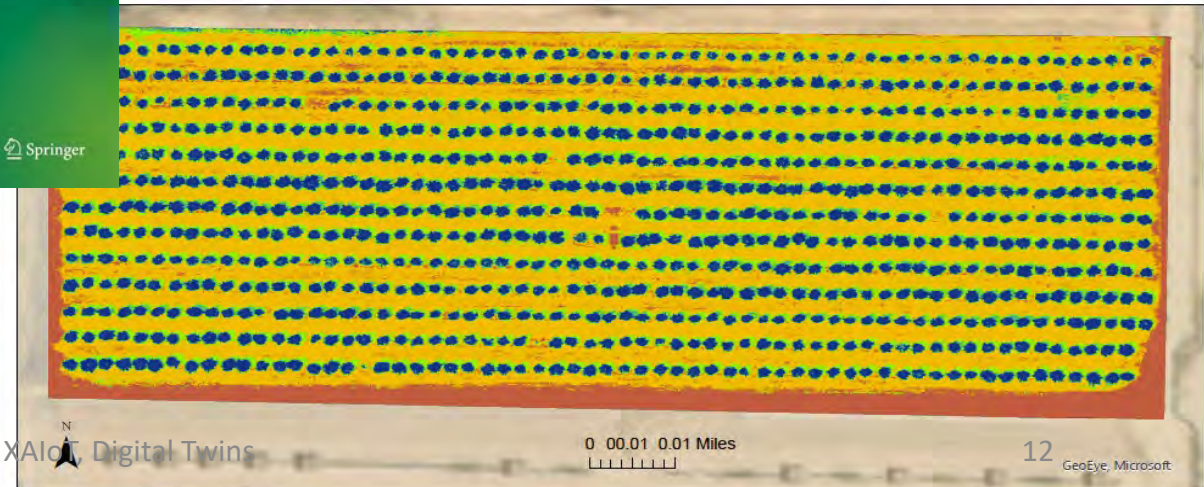
Precision Ag via Drones, XAIoT, Digital Twins



Haoyu Niu
YangQuan Chen

Towards Tree-level
Evapotranspiration
Estimation with
Small UAVs
in Precision
Agriculture

Springer



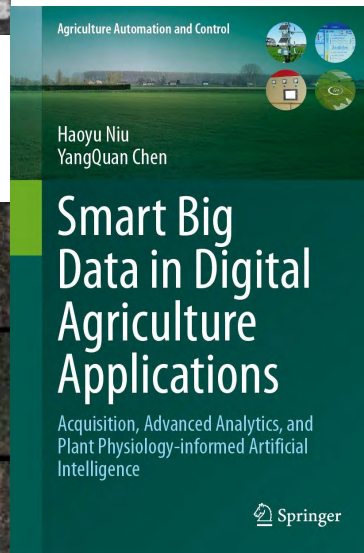
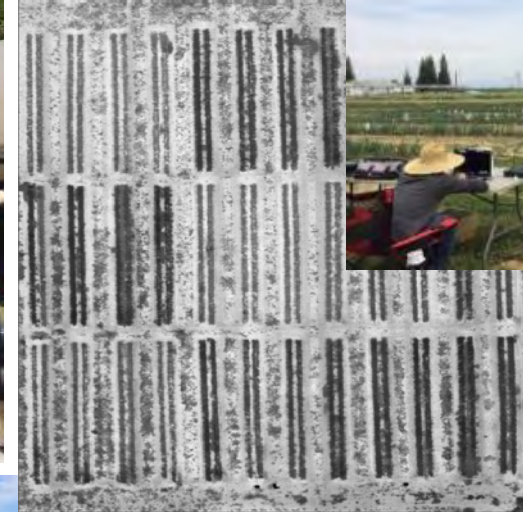
MESA LAB Measurement & Verification (M&V) of Biochar Application in Agriculture

- **EnergyStar** – **WaterStar** – **SoilStar**
- **Drones for**
 1. M&V, incentive/policy design
 2. **mapping/documenting and QUANTIFICATION of before/after applying biochar or other soil amendments in larger region/area**
 3. **Soil variability map for optimal variable rate applications (VRA)**



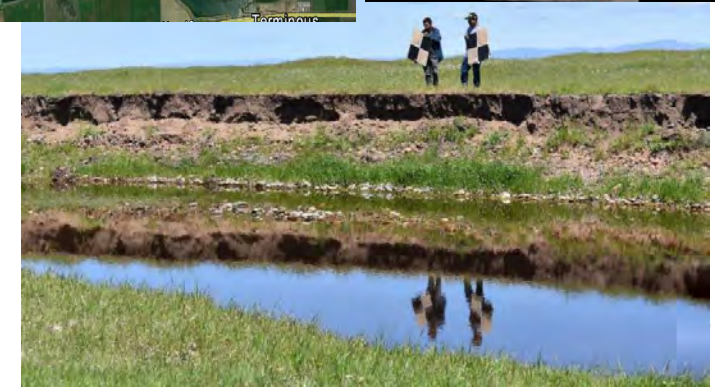
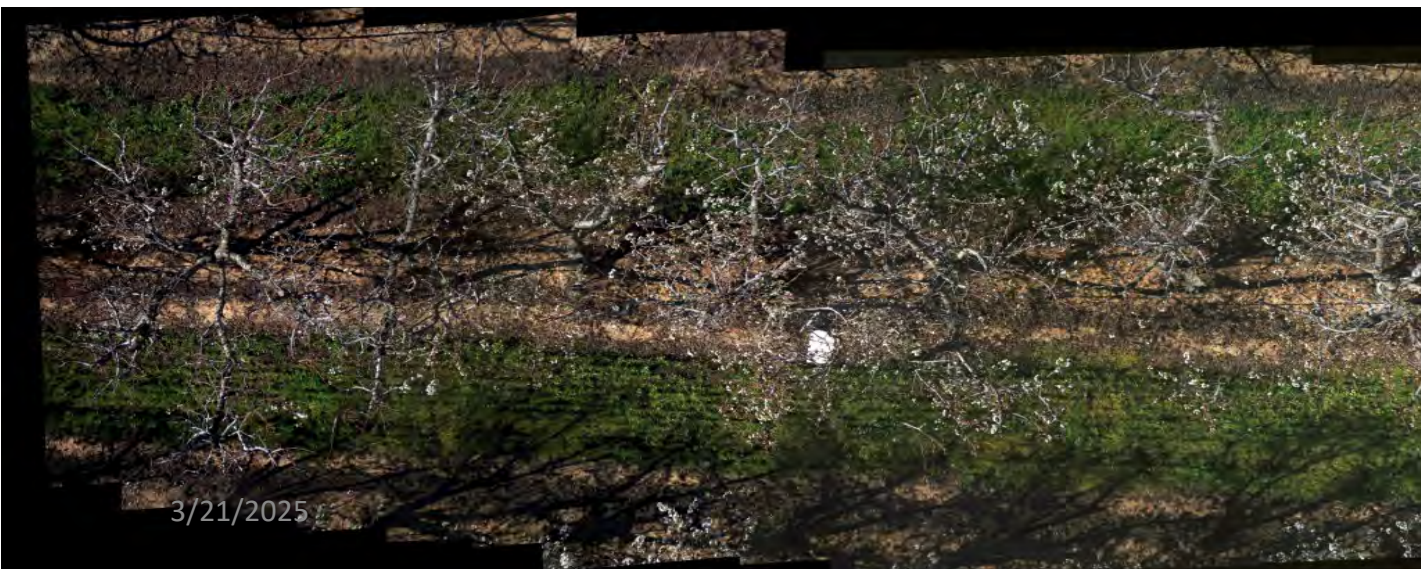
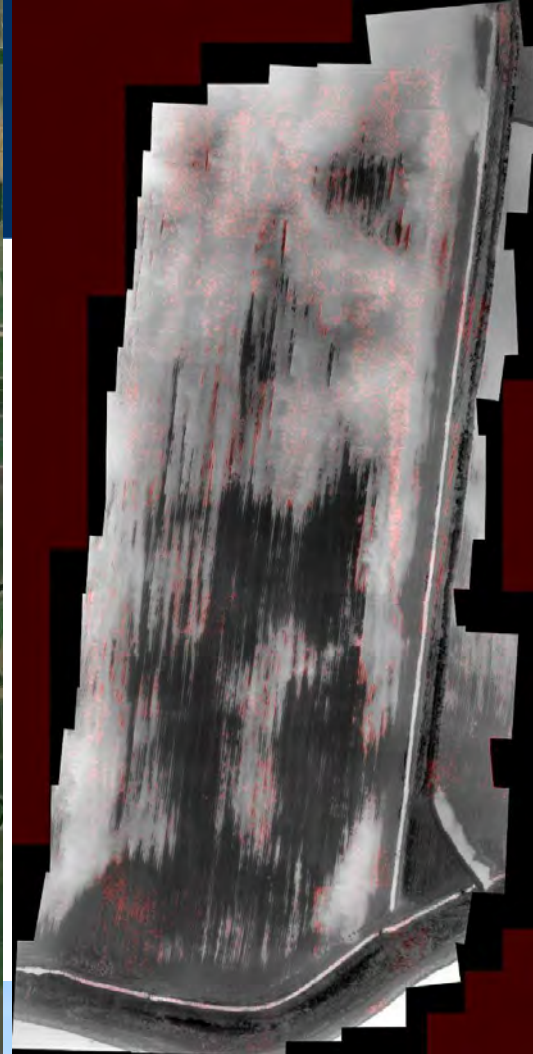
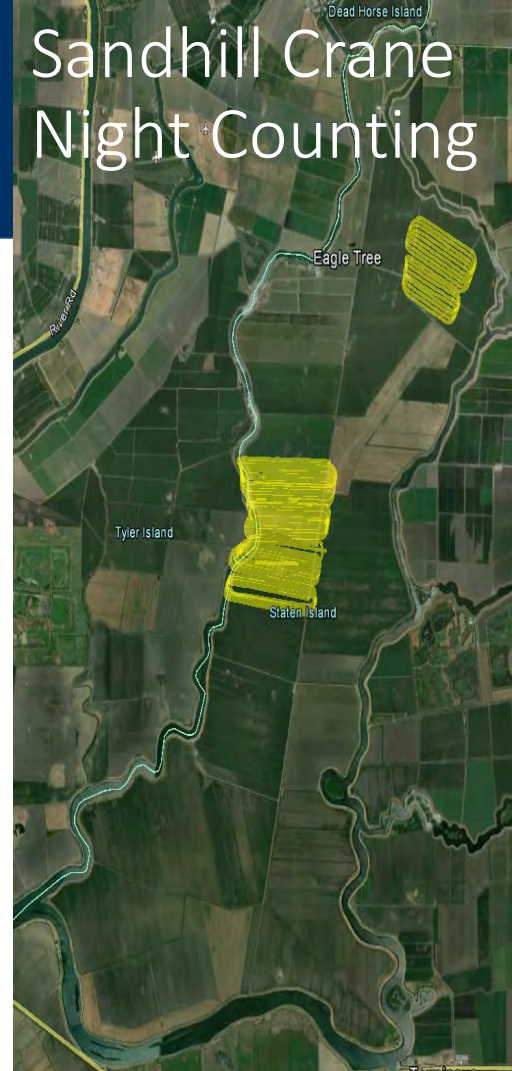
Split-plot design

4 biochar trts: check, Bio, BC, BCS @ 12 dry tons/ac (or 60 cy/ac); 3 irrigation levels; 3 replications



MESA LAB And Even More!

- Water quality sampling
- Soil sampling (salinity, soil carbon)
- Air quality sampling
- Natural Gas (NG) pipeline leak sniffing
- Methane emission quantification
- ...



al Twins

SPRINGER BRIEFS IN ELECTRICAL AND
COMPUTER ENGINEERING • SIGNAL PROCESSING

Guoxiang Zhang
YangQuan Chen

Towards Optimal Point Cloud Processing for 3D Reconstruction

 Springer

3/21/2025

Haoyu Niu
YangQuan Chen

Towards Tree-level Evapotranspiration Estimation with Small UAVs in Precision Agriculture

 Springer

Agriculture Automation and Control



Haoyu Niu
YangQuan Chen

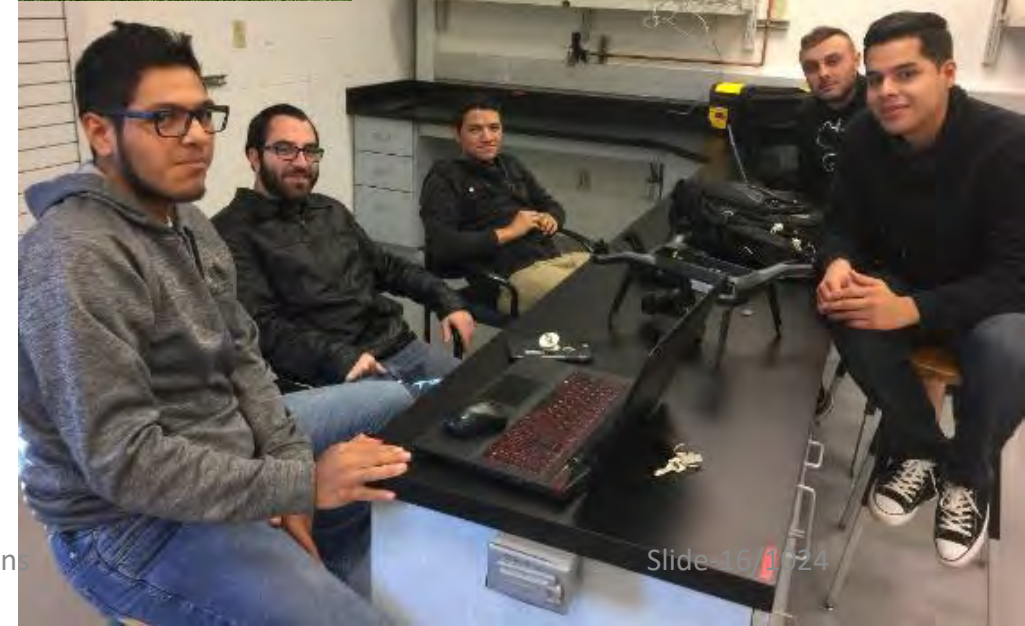
Smart Big Data in Digital Agriculture Applications

Acquisition, Advanced Analytics, and
Plant Physiology-informed Artificial
Intelligence

 Springer

MESA LAB Multi-tier #UAS4STEM ecosystem at UCM

- Tier-0: (K-12 outreach) Sample effort: [TEAM-E Summer Institute](#)
- Tier-1: (student clubs) UAS related Student Clubs ([AIAA UCM DBF](#), [Drone Racing Club](#))
- Tier-2: (service learning) [Engineering Service Learning UAV Team](#) (since Spring 2014)
- Tier-3: (extension) [CITRIS Aviation](#) / [UCM Extension UAS training courses](#)
- Tier-4: (for credit courses)
 - Undergraduate Technical Elective course: ME143 "Unmanned Aerial Systems" (4 credits, lab intensive) ([Summer17](#))
 - Undergraduate Independent Research courses related to drones (ENGR195, ME195, CSE195) (1-4 credits)
 - Capstone projects for seniors related to beneficial use of drones (sample project: 2013 [Team GLASS](#) leading to www.SeekOps.com)
- Tier-5: (graduate research) Graduate education: [UAS Research](#); our [UAS papers](#).



Where do our alumni end up?

- Google
- Collins Aerospace
- Inspired Flight Technologies
- Textron Systems
- Boeing
- Lockheed Martin
- Northrup Grumman
- Naval Sea Systems Command (NAVSEA)
- Bowles Farming
- Monterey Bay Aquarium Research Institute
- Trimble
- Code Rev Kids, Educational Robotics
- ...
- At least two startups (SeekOps, Alpha Aerospace Inc.)





Top 10 bragging rights of our drone research and education in 10 years at UC Merced (2012-2022)

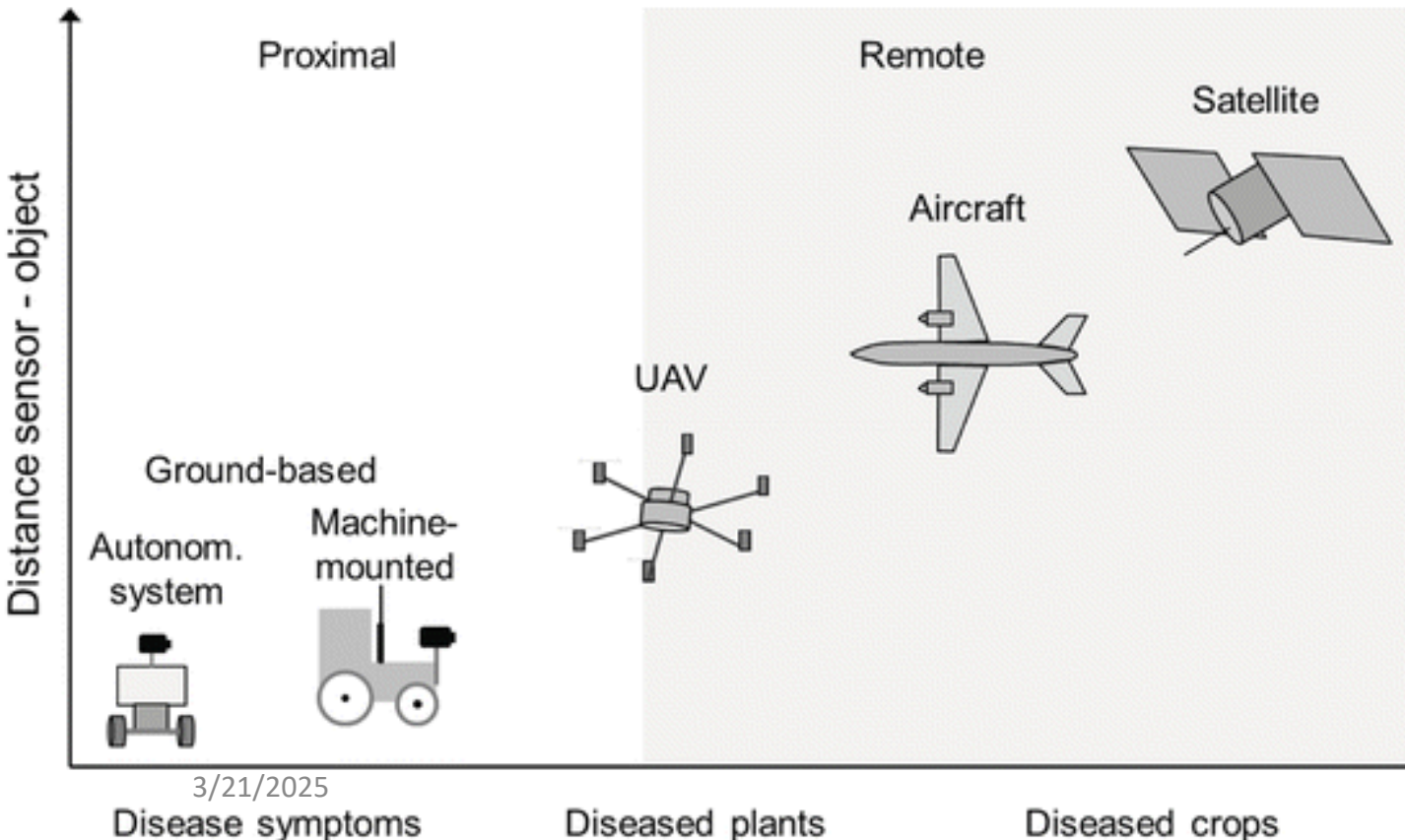
- 1.6 Ph.D.s finished in 12 years on drones. (total 10 in UCM [2012-2022], 9 in USU [2002-2012])
2. Published over 150 papers in UAS related fields and one research monograph. (3 books 1 pending)
3. Serve General co-chair of Int. Conf. on Unmanned Aircraft Systems, 2017, 2019, 2023;
4. Drone safety center for the whole UC system established by former lab manager/member Dr. Brandon Stark. UC Merced "Senate Distinguished Scholarly Public Service award" 2018
5. Offered series preconference workshops at ICUAS with broader impacts. (AgDroneTech, Drones as Edge Devices 2010-)
6. First flew SWIR payload on fixed wing UAV and the best paper award (1 per year!) for ICUAS 2015.
7. Formal 4 credits drone course offered since 2016 (ME143 Unmanned Aerial Systems (UAS), Summer and Spring)
8. TC Co-Chair for IEEE RAS TC-ARUAV from 2012-2018 and "Drones" Editor-in-Chief for Ag and Forestry since 2022.
9. Diverse innovative applications of drones in crops, water, air, soil, methane, caves, sandhill crane counting night flights etc.
10. First to propose smart big data in precision ag and digital twins (DT) framework for environmental sensing and plant-physiology-informed machine learning.



- Drones
- XAIoT
- Digital Twins

- Di An (Spring 2020) XAIoT soil carbon sensing (defended 3/20/2024)
Ph.D. dissertation entitled "**XAIOT ENABLED SMART SENSING OF SOIL CARBON CONTENT FOR SMART APPLICATION OF BIOCHAR**" [news]

<https://escholarship.org/uc/item/0m61z4qs>





- **Drones**
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MESA LAB Smart Precision Ag via Digital Twins

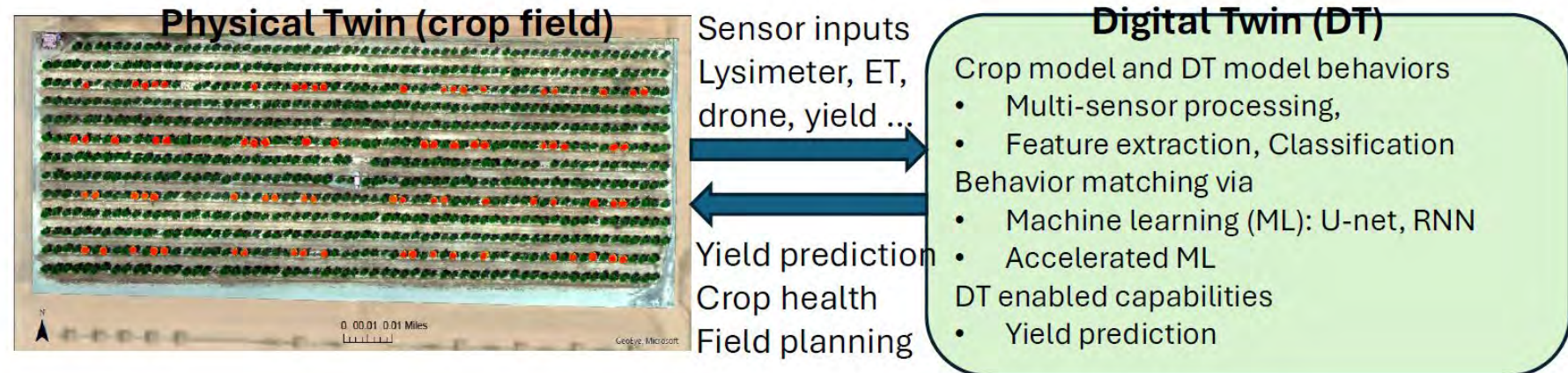
Synthesis Lectures on
Engineering, Science, and Technology

SYNTHESIS
COLLECTION OF TECHNOLOGY

Jairo Viola · YangQuan Chen

Digital-Twin-Enabled Smart Control Engineering

A Framework and Case Studies



2022

3/21/2025

Springer

Precision Ag via Drones, XAIoT, Digital Twins

23



DT (Digital Twins) related credentials @ MESA Lab

<https://mechatronics.ucmerced.edu/digital-twin>

- 2012. “**Cognitive Process Control**” for Lam Research. ([PPT](#)) ([PDF](#))
- 2019. A DT website we developed: <http://www.TheEdgeAI.com/>
- 2021. A DT education paper: <https://doi.org/10.1115/DETC2021-70708> + another one <https://doi.org/10.1109/DTP152967.2021.9540196>
- 2022. A tutorial on DT at IFAC Mechatronics at UCLA. <https://mechatronics.ucmerced.edu/spm>
- 2022. A DT research monograph: <https://link.springer.com/book/10.1007/978-3-031-22140-8>
- 2022. Ph.D. dissertation finished “**Self-Optimizing Smart Control Engineering Enabled by Digital Twins**” (Dr. Jairo Viola)
- 2022. Ph.D. dissertation finished “**Digital Twin Enabled Collective Sensing and Steering for Source Determination Problems**” (Dr. Derek Hollenbeck)
- 2022. Ph.D. finished “**Smart Big Data in Precision Agricultural Applications: Acquisition, Advanced Analytics, and Plant Physiology-informed Machine Learning**” (Dr. Haoyu Niu)
- 2023. Ph.D. dissertation finished “**Smart Predictive Maintenance Enabled by Digital Twins and Physics Informed Smart Big Data**” (Dr. Furkan Guc)
- 2023. The Best Paper Award in the flagship DT conference (only one award, paper title: “**FPGA-Based Digital Twin Implementation for Power Converter System Monitoring**”) <https://2023.ieee-dtpi.org/>
- 2024. A chapter in DT handbook (chapter 34 is from us): <https://www.routledge.com/Handbook-of-Digital-Twins/Lyu/p/book/9781032546070>
- 2024. Ph.D. dissertation finished “**XAIOT Enabled Smart Sensing of Soil Carbon Content for Smart Application of Biochar**” (Dr. Di An)
- 2024. A DT undergraduate 4 cr. lab intensive course (Fall 2024) (ME190/ME152) [[course flyer PDF](#)]

Synopsis (**why bother and who cares?**):

In the era of **digital transformation** driven by **internet of things, big data, edge/cloud computing, artificial intelligence/machine learning, cyber-physical human systems** etc., digital twins are becoming a core technology that a modern engineer should have. *A digital twin (DT) is a digital representation of the physical asset or process with its behavior matched to and information exchanged with its physical counterpart.* Digital twin enables awareness of performance and health of the physical twin so that the physical system can **become smarter than before**. This course will prepare engineering undergraduates with digital twin basic concepts, digital twin fundamentals (modeling and system identification, optimization, machine learning, behavior matching), digital twin construction framework and deployment methods, digital twins enabled capabilities (performance and health monitoring). *This course is lab-intensive. 150 min. lectures per week (two 75 min. lectures) and 3 hours lab session per week. 6 extra hours for self-study (book reading, homeworks, literature review, report writing etc.)*

Prerequisites by Topic:

ME140: Vibration and Control, Unit 4; or, ME141: Introduction to Control Systems, Unit 3 or, EE 145: Signal Processing and Linear Systems, Units: 4; or by Instructor Approval

Catalog Description:

ME152: Digital Twins [4cr]. Introduction to digital twin that is a digital representation of the physical asset or process with its behavior matched to and information exchanged with its physical counterpart. This course covers digital twin basic concepts, digital twin fundamentals (modeling and system identification, optimization, machine learning, behavior matching), digital twin construction framework and deployment methods, digital twins enabled capabilities (performance and health monitoring).

Course outline:

Part 1: DT concepts (What is and is not a DT, DT components/applications/industrial examples) (weeks 1-2)

Part 2: Math foundations for DT (LA/DE, SVD/PCA, optimization/machine learning/dynamic fitting) (Weeks 3-6)

Part 3: Dynamic systems modeling and analysis, simulation and system identification (weeks 7-10)

Part 4: DT constructions from edge to cloud (weeks 11-13)

Part 5: DT enabled capabilities and smart systems (weeks 14-16)

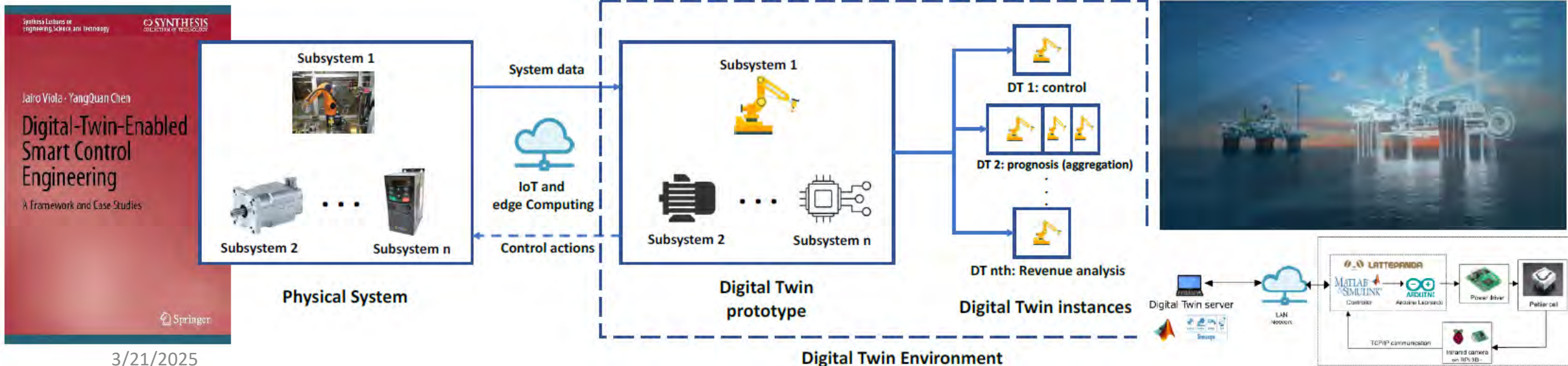
Instructor:

YangQuan Chen, Director of MESA LAB <http://mechatronics.ucmerced.edu/> (E):

ychen53@ucmerced.edu (O): SRE-327; Ph. (209)228-4672.

Textbook: none; Reference texts: Two, both free to all:

<https://doi.org/10.1007/978-3-031-22140-8> and <https://doi.org/10.1137/1.9781611976977>



- Q/A
- Information items

YangQuan Chen, Ph.D., Director,
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E: yqchen@ieee.org; *or*, yangquan.chen@ucmerced.edu
T: (209)228-4672; O: SRE-327; Lab: CAS Eng 820 (T: 228-4398)

- 2023. General Co-Chair, Int. Conf. Unmanned Aircraft Systems (Poland)
- 2021. Editor in Chief in Ag and Forestry, Drones
- 2012-2018. TC Co-Chair, IEEE RAS (Robotics and Automation Society)
TC-ARUAV

UC Merced's drone research has global visibility and respect

Our drone papers are widely cited



LEAPFROG – long video

- 50 min detailed introduction of UC CITRIS First Aviation Prize winner LEAPFROG project
- https://youtu.be/Jyr_GztE-QY?si=16FiO8wZPMaum8-i

- Advisory Committee member, UCOP EHS UAS Safety Center (HQ at UC Merced, inaugural founding director Dr. Brandon Stark)
- Faculty Advisory Committee member, Merced Vernal Pool and Grassland Reserve (MVPGR)
- Faculty Advisory Committee member, UROC – undergraduate research opportunities council.
- AIAA Student Branch founding Faculty mentor (DBF design-build-fly, ~60/300 ranking worldwide)

MESA LAB 2018 UCM Senate Award

"Senate Distinguished Scholarly Public Service award" recognizes a faculty member who has energetically and creatively applied his or her professional expertise and scholarship to benefit the *local, regional, national or international* community.

<https://mechatronics.ucmerced.edu/news/2018/prof-chen-won-academic-senate-award-2017-2018-ucm>

