John Chang
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FÖ0435 Product Development and Innovation Systems in Horticulture

Exercise 4: Innovative Plant Protection in Horticulture

1. Project title:

Multimodal Imaging with Unmodified Smartphones for Plant Disease Detection

2. Name of project leader:

John Chang

3. Abstract (ca. 200 words)

A system is proposed that leverages the capabilities of smartphone hardware to detect plant disease in a novel and cost-effective manner. Rather than using only two-dimensional (2D) red-green-blue (RGB) images of plants, a much richer set of image data is acquired and processed using multiple methods:

1. RGB (using the front RGB camera for standard color digital photography),
2. Depth Map (using the front infrared camera in conjunction with the front infrared light projector to capture point distances).
3. Pseudo-HSI (mathematical reconstruction of hyperspectral images from RGB images), and
4. RGB-LEDMSI (using the front RGB camera to capture monochrome images in conjunction with a sequence of illumination colors from the front LED display).

The latter have been employed in medical imaging, geological imaging, etc., but their application in horticulture is uncommon. Using these methods in an ensemble machine learning (ML) approach is particularly novel.

The rich image data can be used directly with image classification techniques to detect not only signs and symptoms of plant disease but also pests and nutritional deficiencies and toxicities.

Importantly, this system can be implemented on unmodified consumer smartphones, possibly obviating the need for expensive, specialized imaging systems in commercial applications.

4. Purpose and Aims of the Project (ca. 150 words)

The purpose of the project is threefold:

1. To investigate the research question “Can Pseudo-HSI and RGB-LEDMSI be more effective than standard RGB imaging for plant disease detection using unmodified smartphones?” Pseudo-HSI involves the mathematical reconstruction of hyperspectral images from RGB images; LED-illumination based multispectral imaging (LEDMSI) uses the front RGB camera of a smartphone in conjunction with colors produced by the front LED display to capture a sequence of *n* monochrome images, resulting in an *n*-band multispectral image.
2. To investigate the research question “Can an ensemble machine learning approach, combining image data acquired via multiple methods, be more effective than image classification using only RGB image data?”
3. To serve as an open data collection platform for rich image data of plants, both healthy and unhealthy, via multiple imaging methods. The dataset can be used directly with machine learning image classification techniques as well as made accessible for future research efforts.

5. Background (ca. 150 words)

In order to eat food every day, the world's humans and domesticated animals depend on a global machinery of agricultural and horticultural production. Protection of plants against pests and disease as well as management of nutritional deficiencies and toxicities are key challenges for reliable and sustainable crop production. Throughout much of history, expert diagnosis was mostly performed via direct inspection with naked eyes. Modern imaging techniques are available, but such techniques require specialized equipment which is costly and rare (Singh et al., 2020).

Since the introduction of the Apple iPhone in 2007, manufacturers have packed increasingly sophisticated hardware displays, sensors, etc. in consumer smartphones. High-resolution red-green-blue (RGB) cameras are widespread, while near-infrared (NIR) cameras and wide color gamut (WGC) light-emitting diode (LED) displays are becoming common. Such capabilities can be employed to perform multispectral and hyperspectral imaging without additional equipment (Fraunhofer, 2018; Akhtar, 2020; He, 2020).

6. Innovation and Capability Development (ca. 150 words)

The concept of using unmodified smartphones to perform multispectral and hyperspectral imaging was demonstrated only in recent years (Fraunhofer, 2018; Akhtar, 2020; He, 2020). These methods have been employed in medical imaging, geological imaging, etc., but their application in horticulture is uncommon. Using these methods together in an ensemble machine learning approach is particularly novel. Here, a successful implementation could obviate the need for costly, specialized imaging systems in many research and production applications, with implications for horticulture worldwide.

Additionally, this project promises to generate a vast repository of image data of plants in various conditions, both healthy and unhealthy, via multiple imaging methods. This rich dataset can be used directly with machine learning image classification techniques as well as made accessible to present and future research and commercial efforts.

7. Methods (ca. 150 words)

The project consists of four phases, each lasting about three months:

1. A mobile app will be designed and developed to provide separate proof-of-concept implementations of the imaging methods. A cloud backend will be developed to provide a data collection platform and machine learning pipeline. A small set of plants and health conditions will be chosen, and baseline models and metrics will be established for performance evaluation.
2. The system will be further developed to improve performance, reliability, and usability. Focus will be on developing ensemble learning and increasing automation.
3. The system will be opened to beta testing with a limited set of field partners in academia and industry. Feedback will be used to guide development.
4. The system will be released for general availability. The system will continue to be developed, and a larger number of plants and health conditions will be supported.

8. Expected Outcomes (ca. 150 words)

The expected outcome of the project includes the design and implementation of a digital service (in the form of a mobile app and cloud backend with data collection and machine learning functions), a database of rich image data, and functional machine learning models for image classification of not only signs and symptoms of plant disease but also pests and nutritional deficiencies and toxicities. The entire system should be usable for a fixed number of plant types and be of sufficient performance and reliability to allow for semi-public usage.

Additionally, at the end of the 12 months, the maturity of the project should be sufficient to consider pursuing further funding and/or commercialization.

9. References

- Fraunhofer Institute for Factory Operation and Automation IFF, Magdeburg. "HawkSpex® Mobile: Smartphone Spectroscopy," *technical brochure*, 2018. Accessed at https://www.iff.fraunhofer.de/content/dam/iff/en/documents/publications/hawkspex-mobile-smartphone-spectroscopy-fraunhofer-iff.pdf
- He Li, Gang Li, Yaping Ye, Ling Lin, "A high-efficiency acquisition method of LED-multispectral images based on frequency-division modulation and RGB camera," *Optics Communications*, Volume 480, 2021, 126492, ISSN 0030-4018, https://doi.org/10.1016/j.optcom.2020.126492
- Naveed Akhtar and Ajmal Mian, "Hyperspectral Recovery from RGB Images using Gaussian Processes," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Volume 42, Number 1, Pages 100–113, 2020, doi: 10.1109/TPAMI.2018.2873729.
- Qinghua He and Ruikang Wang, "Hyperspectral imaging enabled by an unmodified smartphone for analyzing skin morphological features and monitoring hemodynamics," *Biomedical Optics Express,* Volume 11, Pages 895–910, 2020.
- Vijai Singh, Namita Sharma, Shikha Singh, "A review of imaging techniques for plant disease detection," *Artificial Intelligence in Agriculture*, Volume 4, Pages 229–242, 2020, ISSN 2589-7217, https://doi.org/10.1016/j.aiia.2020.10.002.

10. Short budget (ca. 150 words)

The total amount requested is 984 000 SEK. This is composed of the following costs for personnel and IT equipment/services:

Headcount	Role	Wage (per hour)	Cost (per hour)	Cost (per year)
1 × 20%	Project coordinator	350 SEK/hour	437,50 SEK/hour	182 000 SEK
1 × 25%	Developer (mid-level)	425 SEK/hour	531,25 SEK/hour	276 250 SEK
1 × 20%	Data scientist / Machine learning engineer	500 SEK/hour	625,00 SEK/hour	260 000 SEK
1 × 10%	Horticulturalist	350 SEK/hour	437,50 SEK/hour	91 000 SEK
1 × 5%	UX Designer (mid-level)	400 SEK/hour	500 SEK/hour	52 000 SEK
				861 250 SEK

Personnel wages were multiplied by an additional 25% to account for indirect costs.

Amount	Description	Cost (per unit)	Cost (per year)
10 devices	Smartphones (e.g. iPhone XR)	6 275 SEK/device	62 750 SEK
15 days	Hyperspectral camera (rental)	2 000 SEK/day	30 000 SEK
12 months	Cloud services	2 500 SEK/month	30 000 SEK
			122 750 SEK