The Growth of Agriphotonics

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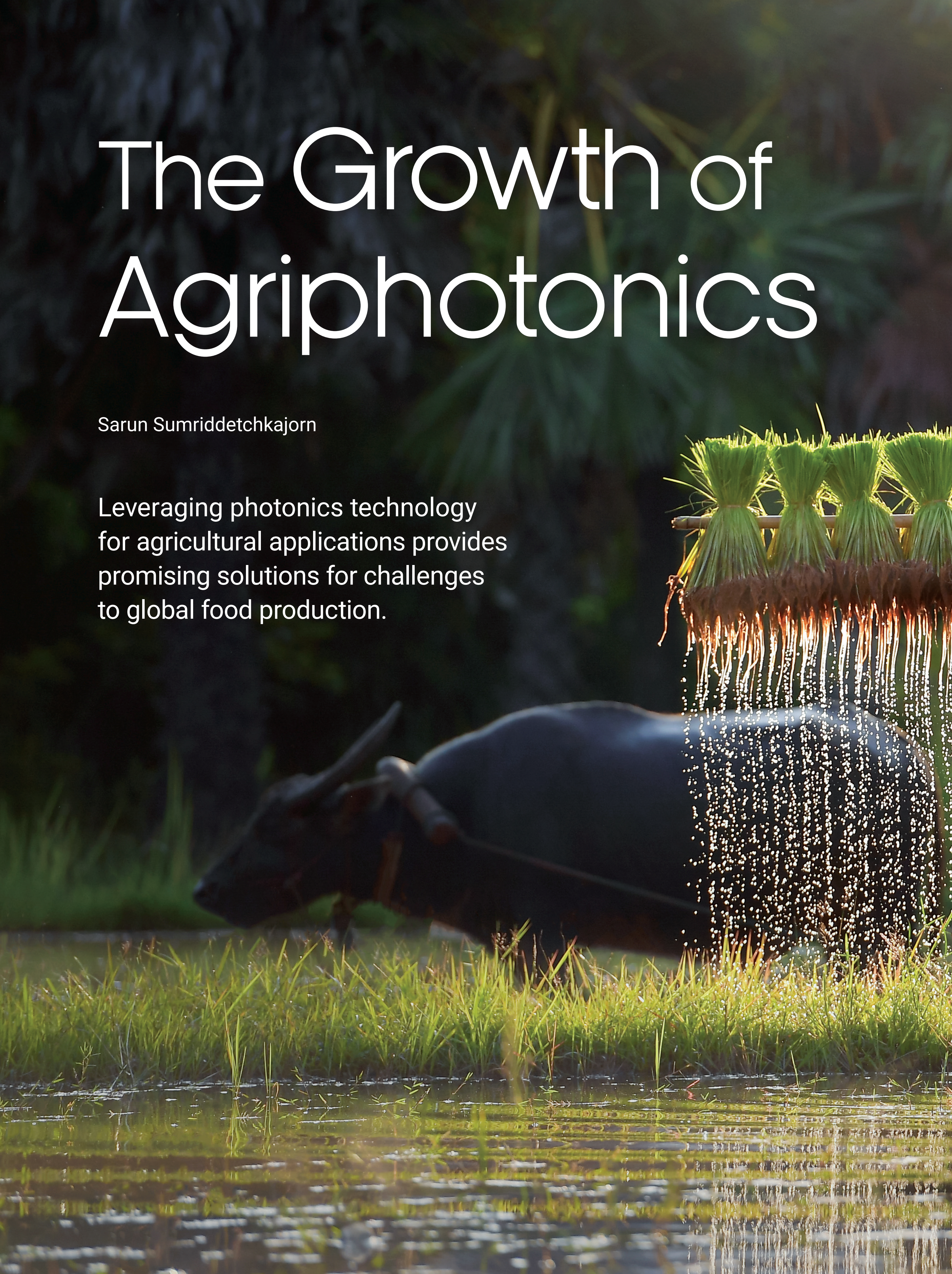
Leveraging photonics technology for agricultural applications provides promising solutions for challenges to global food production.



A farmer carrying rice plants through a paddy field in Thailand.
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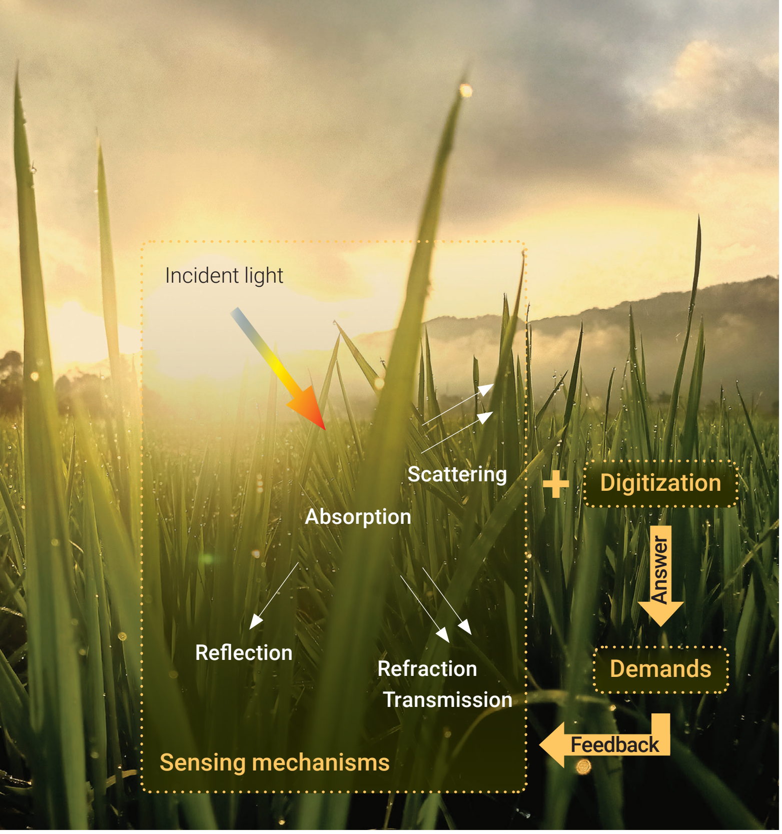

Agriphotonics leverages sensing mechanisms like transmission, absorption and reflection, digitizes them for ease of use, then applies the technologies to answer pressing agricultural questions.

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Agriculture remains the backbone of many economies, providing food security, employment and economic growth. However, challenges such as climate change, soil degradation, an insufficient workforce and the increasing global population demand innovative solutions to improve ineffective processes or tedious work, thus enhancing productivity and sustainability.

Agriphotonics, a field that integrates photonics technology with agricultural applications, is emerging as a powerful tool in addressing these challenges. Governments and societies worldwide are looking for technological interventions to improve food production efficiency while maintaining environmental sustainability. The fusion of photonics and agriculture provides a pathway to smarter, more precise farming methods that align with these needs.

Understanding agriphotonics

Agriphotonics encompasses the use of various optical sensing techniques, including refraction, transmission, absorption, reflection and scattering, to gather desired information—for instance, to analyze plant health, soil properties or environmental conditions. This information, when combined with digital technology and advanced data analysis, provides actionable insights to enhance productivity and ensure sustainability.

The application of photonics in agriculture is not entirely new. Historically, early forms of photonics technology were used in agriculture in a rather rudimentary manner. For instance, farmers have used the heat generated by infrared radiation from incandescent light bulbs to promote egg hatching. Simple visual inspections were used to assess the greenness of rice fields, which provided a rough estimation of the optimal amount of nitrogen fertilizer needed. Since the need to acquire highly and spectrally resolved information from satellite images emerged in the 1970s, advances in cost-effective spectral imaging sensors and systems with artificial intelligence (AI)–driven analysis deployed remotely (airborne or spaceborne) or locally (on the farm) have pushed agriphotonics to the next level.

However, those who work in this field must begin with the end in mind. Agriphotonics-based sensors and systems should be practical and easy to use, with simple design and implementation, thus ensuring less difficulty for users and ease of future maintenance. In addition, we should think at the beginning of research and development about component sourcing and device fabrication and manufacturing approaches, so that when the time comes, devices will be scalable and affordable. Otherwise, although the concept may be good and the sensors may work very well, no one will use a system if it is too expensive.

Government policy drivers

Governments around the world recognize the strategic importance of agriculture and are actively working to modernize the sector. In Thailand, where our team is based, agriculture is emphasized in Milestone 1 of the country's current 13th National Economic and Social Development Plan, which also answers the UN Sustainable Development Goals (SDGs). This plan highlights the importance of integrating advanced technologies into agriculture to enhance productivity, sustainability and global competitiveness. Agriphotonics can fall under Milestone 6 (smart electronics), which supports Milestone 1 by providing high-precision monitoring, improving crop quality and enabling sustainable farming practices.

Moreover, with appropriate action plans, agriphotonics can align with other milestones, including strengthening small- and medium-sized agricultural enterprises (SMEs) with cutting-edge technology, enhancing efficiency and increasing competitiveness.

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Governments and societies worldwide are looking for technological interventions to improve food production efficiency while maintaining environmental sustainability.

Researchers from national research institutes can work together with SMEs or startup companies to develop the technology. Agriphotonics can also assist with the goal of a low-carbon society through sustainable agricultural practices, and in mitigating natural disaster and climate change risks by using photonics for plant stress detection and aquaculture water quality control.

The success of agriphotonic technologies hinges on open-minded collaboration across multiple disciplines. Researchers, engineers and agricultural experts must work together to understand the real-world challenges and develop solutions that are both technologically appropriate and practically viable. For our research, our team collaborated with farm workers, farm owners and government officers. After we learned from and understood each other, we started working toward usable prototypes with a technological readiness level above 5 (that is, validated under the relevant environment).

As there are many agricultural products to work with, we focused on those that we had the technology to tackle and that would have a high impact on Thailand's economy. These include durians (2024 export value US$4.4 billion), Thai rice (2024 export value US$6.4 billion), unique Thai silk (2023 export value US$19 million), and shrimp (2024 export value US$1.24 billion). Below, we discuss some of our efforts related to each product.

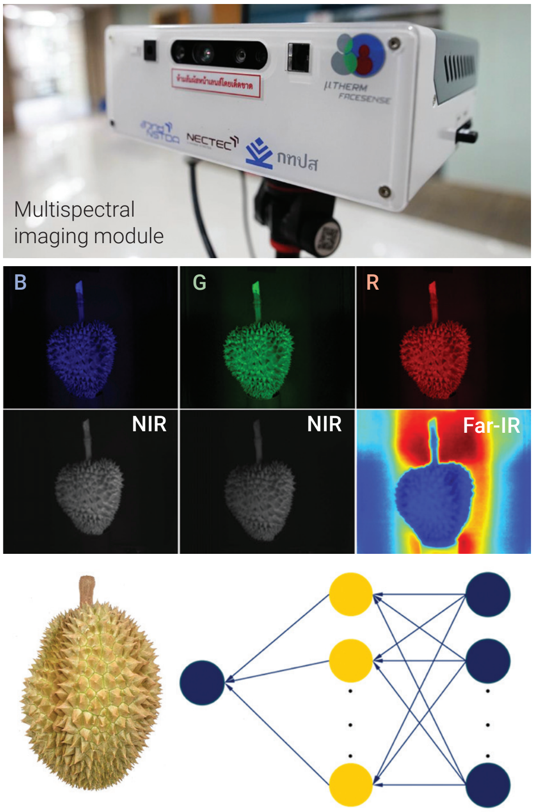
Spectral imaging for durian maturity

Durians, often referred to as the "king of fruits" in Southeast Asia, are known for their distinctive aroma and rich flavor. In Thailand, determining the optimal maturity of durians is critical for maintaining their high export value. Traditionally, durian maturity has been assessed through destructive methods that involve measuring the fruit's dry matter content. This method, while effective, is labor-intensive and susceptible to human error.

Multispectral imaging under white light and UVA illumination has previously offered a noninvasive method that promised to spatially pinpoint the maturity levels of green fruits (for instance, bananas) as immature, ripe or overripe. Our current use extends this method for durian maturity analysis under white-light, near-infrared and far-infrared illumination. And importantly, we

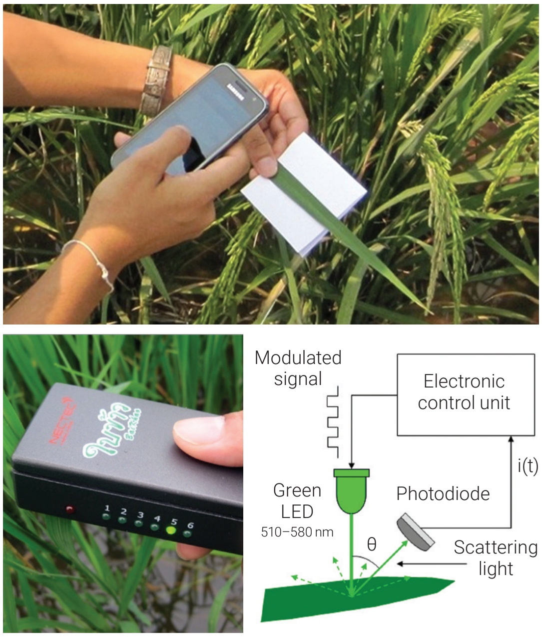
Assessing fruit maturity

Multispectral imaging + image processing + AI
= Durian fruit ✓ mature or ✓ immature



Nondestructive method to measure the maturity of durian fruit under broad visible to far-infrared spectral imaging.
S. Sumriddetchkajorn

Enhancing rice cultivation



The Bai-khao app (top) and Bai-khao box (bottom left) are used for estimating the greenness level of the rice leaf and showing the suitable amount of nitrogen fertilizer recommended by Thailand's Department of Rice.

S. Sumriddetchkajorn

The physical characteristic measurement of rice seeds or grains, a difficult and time-consuming manual process, is automated by modifying an optical scanner used for document scanning.

S. Sumriddetchkajorn / Earth100;

designed and implemented our multispectral imaging system using low-cost and off-the-shelf components.

The method's current accuracy of greater than 90% is achieved with AI assistance. As our multispectral imaging system is inherently embedded with two near-infrared imaging cameras to help create 3D objects, rather than determining only the maturity level of the whole durian, this method has the potential in future to simultaneously analyze the weight of durians using 3D analysis and pinpoint the maturity levels spatially. The integration of such technologies can enhance the quality and marketability of Thai durians, ensuring higher export value and increasing economic returns.

Enhancing rice cultivation with sensing

Rice is a staple crop in many countries. Traditional methods for determining the optimal level of nitrogen fertilizer to use in rice cultivation often rely on visual inspection of the greenness of fields or the use of color charts. These methods, however, are prone to human error and inconsistencies. To eliminate these issues while ensuring optimal fertilization, improving yield quality and reducing input costs, our team developed a low-cost, compact device known as the Bai-khao (named after the Thai word for "rice leaf") box. This device illuminates a rice leaf with an LED, then measures the intensity of the green light that is reflected. The result is displayed through an LED indicator that correlates with the appropriate amount of nitrogen fertilizer recommended by Thailand's Department of Rice.

Recognizing the need for scalability with free delivery, we further integrated this concept into a mobile application known as the Bai-khao app. Farmers simply take a snapshot of a rice leaf within a reference frame displayed on the app, and a small white piece of paper is used for calibration. The app then provides a straightforward, four-level greenness assessment.

Another crucial process in rice cultivation is the grading of rice seeds and grains, which traditionally involves manually measuring the physical dimensions of randomly selected samples. Typically carried out using a micrometer, this task is both time-consuming and labor-intensive.

To address this issue, our team repurposed an optical scanner, commonly used for document scanning, to measure the length, width and thickness of rice seeds. By flipping the scanner upside down and incorporating a specially designed tray with individual slots, each rice seed can be imaged from both the top and the side. The tray features a reflective surface angled at 45°, which

We discovered an easier way to identify the gender of a silkworm pupa after shining a laser pointer on our fingertips and seeing light pass through.

allows the scanner to capture both top and side views of each seed. This dual-view approach enables the simultaneous measurement of all of the seed's dimensions during a single scanning session. This simple, modified piece of office equipment can also analyze qualitative features, such as the yellowness and chalkiness levels of rice grains.

In addition, during the preparation of non-glutinous rice seeds—rice varieties that are less sticky—some batches might not grow well enough and instead become unwanted sticky rice or red-shell rice, which is difficult to distinguish using the naked eye or a typical imaging system. As these rice characteristics have different transmission and reflection properties, we implemented an optical imaging system where we can take transmitted and reflected optical images under orthogonal polarized light to enhance the image contrast. With appropriate image threshold-setting, these rice characteristics can be easily identified.

During rice seed development, rice specialists also need to know the size of the embryo and endosperm of the seed, as they relate to healthiness and nutrition. In this case, the above optical imaging principle can be used to enhance these two small areas of the rice grains, thus enabling the specialists to better assess them. This tool can be used on a tablet, so the researcher can carry it to check the quality of rice grains while visiting farmers.

Innovations in silk production

In sericulture, or the cultivation of silkworms to produce silk, separating male and female pupae is critical for preserving valuable silkworm breeder stock and maintaining high-quality breeders that lead to high-quality silk products. The sericulture industry has long relied on manual sorting methods that use a weight and shape analysis or visual inspection of the abdomen segment of the silkworm pupa to complete this task, which can be difficult to do accurately.

We discovered an easier way to identify the gender of a silkworm pupa after shining a laser pointer on our fingertips and seeing light pass through. Our soft fingertips are similar to the body of the silkworm pupa, so shining light through the bottom of a female

Optimizing silk production

Operating system for using optical penetration to identity the gender of silkworm pupae.

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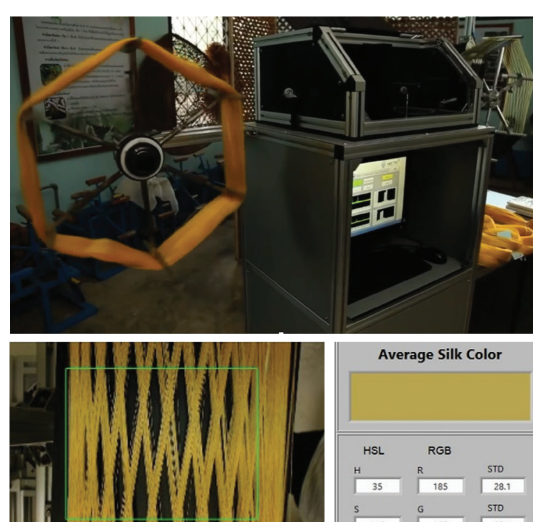

"Silk check" is an optical process that grades the quality of silk based on variation of silk diameter and also assesses the average color shade of the yarn.

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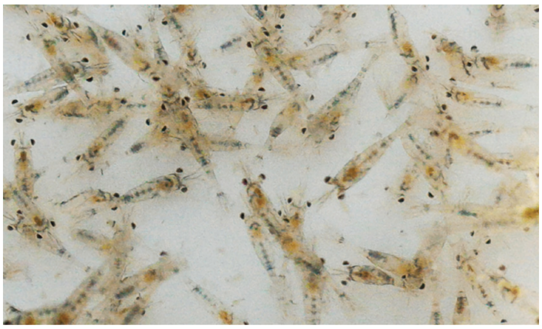
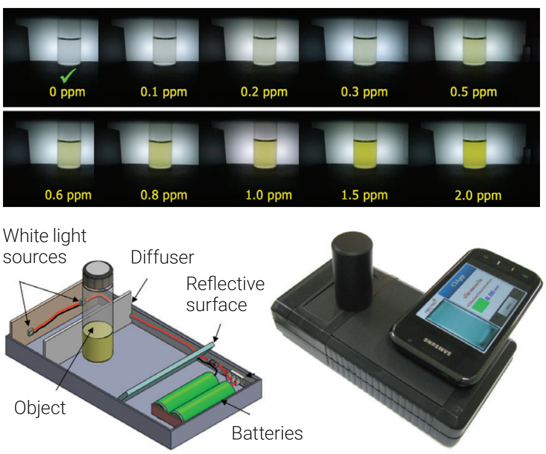
silkworm pupa also allows light through and reveals a shadow of an organ. This shadow does not appear in a male. This non-destructive optical method, which uses low-power LEDs, a web camera, a laptop and other simple components, can assist in identifying the gender of silkworm pupae with an accuracy as high as 95%.

In contrast to mass-produced silk thread, hand-reeled silk is produced with a traditional method in which silk filaments form several cocoons in boiling water, and are reeled together on a wooden spindle into a uniform strand of raw silk. In Thailand, the quality of hand-reeled silk is evaluated through a naked-eye inspection of a random sample length to assess the color uniformity and number of defects. This process does not effectively serve farmers, and incorrect grading of the silk yarn due to human error can seriously affect the price of the silk yarn, which has significant economic impacts.

If silk thread is instead placed between an optical beam and a photodetector, any change in diameter of the silk thread can be detected as the optical power of the beam is decreased. Therefore, we can determine the location, number and size of defects as the silk thread from a silk yarn moves across the optical beam. We created a system leveraging this concept, called "Silk Check," that can grade silk based on the measured coefficient of variation (that is, a ratio of standard deviation and the mean) of the silk diameter. In addition, once the whole silk yarn has been reeled from the input to output reeling wheels, we can analyze the denier and the average color shade of the yarn. These important parameters can be quickly and precisely evaluated—within 1.5 to 2 hours for an average length of 1,200 to 2,000 meters under the finest sampling interval of 1 cm and a maximum speed of 75 cm/s.

Improving shrimp farming





Measuring chlorine concentration: (Top) Shading of water under different chlorine concentrations. (Bottom) "Cl App" on a mobile phone for Cl analysis.

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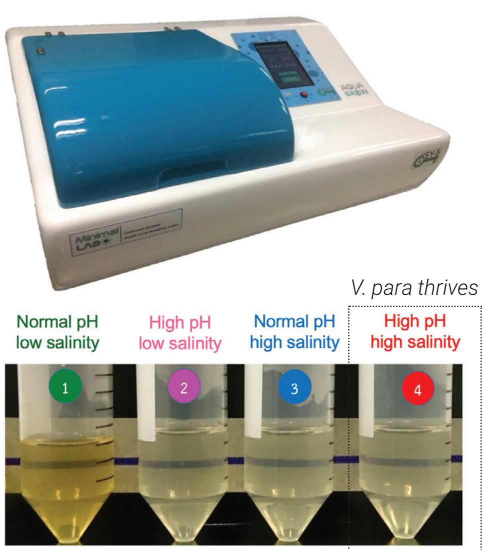

Monitoring bacteria: The presence of *V. parahaemolyticus* bacteria is detected by monitoring the optical transmittance of light passing through water samples.

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Applications in shrimp farming

Thailand's shrimp industry faces a number of challenges, including the necessity to ensure that water is of sufficiently high quality for raising baby shrimp. In particular, chlorine concentration should ideally be 0 ppm, as chlorine affects the health of the crustaceans. It is typically and quickly monitored by introducing a few drops of a chemical solution into a water sample, then visually inspecting the sample for a color change that would indicate the presence of chlorine.

To improve this process, we adapted the concept we used in Bai-khao for rice leaves into another prototype called "Cl App." A small box holds a bottle of sample water, and a thin white plastic sheet is placed behind

As governments and industries continue to prioritize sustainability and efficiency, agriphotonics will play an increasingly vital role in shaping food security and economic growth.

the bottle as a reference background. To make the device user friendly, we divided the calibration curve into three zones, green, yellow and red, like traffic lights, to allow workers to make quick and easy decisions simply by looking at the display, without needing background knowledge about the technical measurements. If it shows green, indicating sufficiently low chlorine, they can pour baby shrimp into the pond. If the signal is yellow or red, they'll need to wait to let the sun evaporate the chlorine before putting shrimp in the water.

Another issue in shrimp farming involves monitoring for *Vibrio parahaemolyticus* (*V. parahaemolyticus*), a bacteria believed to be responsible for early mortality syndrome in shrimp. After discussions between members of our research team and a group of experts in the shrimp industry, we discovered that we could detect the presence of *V. parahaemolyticus* by monitoring the optical transmittance of light passing through water samples. We prepared samples to test four water conditions—normal pH–low salinity, high pH–low salinity, normal pH–high salinity, and high pH–high salinity—in a shrimp pond. Our setup allowed us to monitor optical transmittance from several bottles at once, and the bottles must also be shaken at appropriate intervals under both room and high temperatures.

We discovered that if the optical transmittance of a sample was low, that indicated that the water condition was conducive to the growth of bacteria. Our results showed that *V. parahaemolyticus* particularly thrives in a high pH–high salinity environment. Once farmers are aware of this result, they can then apply biotreatments as necessary to improve the water conditions before introducing the shrimp to the pond. This simple optical transmittance measurement done with a minimal lab setup can therefore help mitigate risks related to water contamination and disease outbreaks.

Integrating advanced technologies

As agriphotonics continues to evolve, there is considerable potential for integrating even more advanced technologies into agricultural practices. Techniques such as optical coherence tomography (OCT), terahertz (THz) spectroscopy, Raman spectroscopy, and robotics-enhanced artificial intelligence are on the horizon. These technologies, once refined and made cost-effective, could further improve the precision of agriphotonic systems, making them indispensable tools in modern agriculture.

For example, OCT has the potential to provide high-resolution cross-sectional images of plant tissues, enabling researchers to monitor the internal health of crops. Similarly, THz spectroscopy could be used to assess moisture content in soil, leaves and roots with unprecedented accuracy. As these technologies become more affordable and scalable, their integration with existing agriphotonic systems will lead to even more comprehensive solutions for precision farming.

Agriphotonics stands at the intersection of technology and agriculture, offering innovative solutions to some of the most pressing challenges in agricultural production. The above case studies in agriculture, sericulture and fisheries not only highlight the technological aspects involved but also demonstrate how these innovations are designed with scalability, affordability and practical usability in mind. Agriphotonics is forging the path to a future where agriculture is smarter, more efficient and more sustainable. As governments and industries continue to prioritize sustainability and efficiency, agriphotonics will play an increasingly vital role in shaping food security and economic growth, in line with strategic development goals. OPN

I would like to express my sincere gratitude to all the research teams and collaborators who have contributed to the development of agriphotonic technologies. Special thanks go to the National Electronics and Computer Technology Center, the Department of Agriculture, the Department of Rice, the Department of Sericulture, and the Thai Eastern Shrimp Association in Thailand. Their unwavering support, insights and commitment have been invaluable in advancing this exciting and fun work.

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For references and resources, go online: **optica-opn.org/link/0625-agriphotonics**.

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