Space agriculture: sensing crops in space

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Key words

proximal sensing, food production, machine vision, leafy greens

Take home messages

- Basic metabolic and nutrient requirements of space crew members are required to be met to successfully support deep space missions
- Research is needed into the identification and development of solutions for 'smarter' monitoring of plants to create a sustainable food supply on space missions
- Automated detection of plant stress will enable rapid remediation efforts and provide increased food safety and security.

Background

To successfully support long flight or deep space missions such as those planned through the Artemis series of missions (NASA 2020) the basic metabolic and nutrient requirements of space crew members are required to be met. Currently, astronauts are supported through resupply missions, which have been used on all manned missions to date (Niederwieser 2018). Resupply missions are difficult to support in deep space so manufactured solutions such as mass-produced food bars have been proposed. However, there are no long-term studies on what impacts such a diet would have on astronauts' health. Fresh plant crops, particularly leafy green vegetables provide for both the basic metabolic needs as well as a contributing to a diverse micronutrient balance. Plants rich in antioxidants may also provide some protection from the detrimental but not fully understood effects of deep space radiation. In recent years growing plant crops as a staple component of astronauts' diets has been dismissed for proximal missions. For proximal missions the break-even point favours resupply launches. While adding life support systems for food production increases initial launch mass, it decreases resupply requirements. A break-even calculation for these hybrid systems suggests they would be feasible after a 3-year, 6-crew member mission. This is approximately the duration of the planned Mars missions.

Research is needed into the identification and development of sensing and algorithm solutions for 'smarter' monitoring of plants to create a sustainable food supply on space missions. Currently, NASA has three controlled plant habitats, two vegetable production system (Veggie) units and the larger Advanced Plant Habitat which are currently onboard the International Space Station (ISS). The Veggie units were developed to be simple, low resource systems designed to produce fresh vegetables on board the International Space Station (ISS). The Advanced Plant Habitat provides hundreds of calibrated sensors for monitoring and automating plant growth experiments in microgravity to inform decisions around the development of future space agriculture systems. There is a wall mounted plant growth chamber 'Lada' which has been in use since 2002 in Zvezda, the Russian module of the ISS. The plant habitats are intended to facilitate plant experiments in space however the plant habitats currently do not contain autonomous decision support to assess performance of plants in experiments. Currently, experiments are monitored by experts on the ground for the purpose of reducing additional workload of the astronauts. However, as communication lag increases with increased distance from the Earth, software needs to be developed to accompany existing and new plant sensors to interpret plant stress signals automatically. Automated detection of plant stress will enable rapid remediation efforts and reduce the need for the post-harvest sanitation that is currently used, which will provide increased food safety and security.

A project team at the University of Southern Queensland’s Centre for Agricultural Engineering (CAE) is developing new machine vision-based plant sensing solutions, through a Moon to Mars Feasibility Grant provided by the Australian Space Agency (ASA). The team is developing launch-ready software, associated algorithms and the specification of accompanying machine vision cameras and/or sensors for the early quantification of plant induced stress by examining water, nutrient and plant disease interactions. This paper outlines a brief history of growing plants in space, current plant monitoring approaches for space and Earth, and new approaches for plant monitoring with machine vision.

A brief history of plants in space

The successful growth of plants in space promote not only food production and sustainability, but also oxygen regeneration and water recycling (Stankovic 2018). However, plants in space are exposed to increased levels of electromagnetic and particle radiation and reduced gravity. These extremes affect plant biological responses including the mechanisms necessary for plant growth and development (Morrow 2014; Stankovic 2018). As such, research is needed to understand the impacts of space on plant systems to aid in the development of sustainable plant production onboard spacecraft.

The first plant experiments to be successfully deployed into orbit were onboard the Biosatellite II which flew in orbit for three days before returning to Earth in 1967 (Morrow 2014). The first plant grown through a full life cycle in space was *Arabidopsis thaliana*, flown on the Soviet Salyut-7 low orbit space station. Some viable seed resulted, but most was unviable. Differences were observed between space and Earth grown plants (Stankovic 2018). The first successful seed-to-seed plant growth experiment (*Arabidopsis thaliana*) in space was completed in 2001 (Stankovic 2018). Recent plant experiments have focused on better understanding the biological mechanisms which may allow plant adaptation to space (Morrow 2014; Stankovic 2018).

Plant growth habitats that have been developed for use in space include the Astroculture system, the Advanced Astroculture system, the Biomass Production System, the Plant Generic Bioprocessing Apparatus, the Advanced Biological Research System, the Lada Greenhouse and the European Modular Cultivation System. However, these systems are limited in their growing area, limiting their potential to supplement space crew diets, as they were developed primarily for small-scale experiments (Morrow 2014). The habitats currently in use for food production and experiments on-board the ISS are the Veggie units and the Advanced Plant Habitat, developed by Orbitec, now Sierra Nevada Corporation.

Space agriculture research and its subsequent developments has both contributed to and benefitted from terrestrial agriculture, particularly through controlled agriculture systems (Wolff et al., 2014; Stankovic 2018). The resulting novel technologies developed initially for space agriculture include the use of LED lighting systems for crop production, hydroponic system development, significant increases in crop yields and innovating waste recycling approaches (Stankovic 2018).

Automated plant monitoring in space and on earth

Currently, real-time crop monitoring in space uses automated camera image capture with relatively low pixel and temporal resolution intended for remote communications, as captured images are used for visual review by experts on the ground who can communicate recommended next steps to the space crew. The newest advancements in machine vision systems for space agriculture come from the EDEN II research facility in Antarctica. This facility is a container-sized greenhouse test facility which was built to demonstrate and validate technologies for safe food production in space (Zabel *et al.,* 2016). Single image NDVI capable cameras were incorporated for monitoring of tomatoes in the EDEN ISS Future Exploration Greenhouse for a year. The NDVI cameras consisted of GoPro Hero4 cameras modified with dual-bandpass filters. NDVI calculated from these cameras were used to develop an aggregate NDVI for monitoring tomato health (Tucker *et al.,* 2020).

Current research on machine vision systems for terrestrial agriculture on Earth offer potential advancements in addition to NDVI for monitoring of plants in space. Machine vision incorporates colour, texture, shape and spatial image information using machine learning and traditional hand-crafted algorithms, and on Earth is commonly applied to precision agriculture tasks including plant detection, grading, counting and yield estimation (Mavridou *et al.,* 2019).

New approaches for plant monitoring with machine vision

NDVI-based approaches are currently reported as being developed and tested for use on the ISS (Zeidler *et al.,* 2019). The new USQ/ASA project is enabling development of novel automated plant stress algorithms for space, based on knowledge from precision agriculture and machine vision systems. Currently, early discrimination between water and nutrient stress of lettuce and cabbage with machine vision are being developed, with further experiments focusing on pathogens. Plant stress algorithms are being designed in parallel with the refinement of a ground-based laboratory and sensor test rig(s) (Figure 1) which are translatable to both microgravity and planetary surface facilities for potential further research and development of automation and commercial deep space technology.

Figure 1. Experimental setup in ground-based laboratory – a) experimental rig, b) top view image from visible colour camera, c) basic image processing to segment plant leaves from the background

Discussion and conclusions

The development of sustainable food production systems in space is critical to the success of future deep space missions. A project led by USQ is supporting food production for space missions by developing automated machine vision techniques for detecting plant stress for use in space, allowing real-time and precise monitoring of plant health. The development of launch-ready software for the identification of plant stressors in space will allow plant habitats to respond to detected stresses automatically, decreasing the reliance on experts on the ground and freeing space crew time for other tasks. Potential future priorities for the continued development of space agriculture systems are automated remediation for identified plant stressors, increased volume of current plant habitats, and increased water and nutrient resource recycling and recovery.

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Acknowledgements

This project received grant funding from the Australian Government’s Moon to Mars Initiative.

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