Digital Twins for Plant Growth Resilience in Space Agriculture

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As humanity embarks on long-term space exploration, astronauts will need a stable supply of fresh food from space farms. Three studies on “Plants for Space” (P4S) will be presented (www.plants4space.com).

The first study identifies crop combinations providing a balanced diet while growing sustainably in space. We follow the NASA recommendation for optimal food of astronauts, and considered 36 nutrients and 102 crops, evaluating 10 "space dish" scenarios, including 4 vegetarian and 6 omnivorous options, for full daily nutrition. Each scenario was analyzed for plant growth, required planting area, water usage, waste generation, recyclability, and overall mass processed. The optimal space dish was prepared as a salad, comprising soybeans, poppy seeds, barley, kale, peanuts, sweet potato and sunflower seeds. Its palatability was assessed through a small psychological test of four test persons.

Knowing which space food to choose, we then studied plant growth under extreme conditions, as to be expected in space, with a bespoke digital twin approach. We used the interaction between a "physical twin-sender" ("space") and "physical twin-receiver" ("Earth") with the aid of machine learning (ML) models. Lettuce was grown on a mountain in Spain under extreme weather conditions which were exactly repeated in a growth chamber. Our ML model comprised historical data of lettuce growth from arid zones In Spain and USA. Main result was that adding our own lettuce plant growth data and historical lettuce growth data increases the effectiveness of the model. The quality of the model's trend predictions has improved, as has its quantitative forecasting capabilities. The best fit-% is 0.998.

As second digital twin study, we compared lettuce growth under different stresses in six climate zones on Earth, including tropical and arctic regions) We transferred the corresponding actual weather data as reported via the IoT to our "physical twin-receiver; meaning we set temperature and other weather parameters in the growth chamber according to the actual weather in six cities. The lettuce was grown “as being each week

in a different climate environment". Our study informs plant growth under extreme environments, from another vantage point as the first study, which includes the forecasted global warming effects of the 'weather 2050'. The main result was that the lettuce did grow surprisingly well under those unusual conditions, which no terrestrial plant so far experienced. A final biomass of 34.4 g was achieved, and ML modelling was well predicting the biomass of some samples, e.g. those being watered properly.

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