How can air-coupled non-contact ultrasound technology and AI be used to survey plant health?

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Introduction:

For the past 17 years California has endured on and off droughts due to low levels of precipitation and heightened temperatures. As climate change continues to worsen, California will continue to experience record breaking temperature levels and as a result, continued drought. Some have suggested tackling this problem head on by reducing climate change, but it is important to have measures in place in the event that the effects of climate change become too much for our current systems to handle. The government has already started acting upon drought conditions. To increase the amount of water available, the government has suggested rationing water by only using what is necessary. One industry notorious for its water consumption is agriculture; with 40% of water in California going to this industry in 2019[1]. In this line of thinking, this paper wishes to put forward technology meant to reduce water usage in agriculture.

Applications of air-coupled non-contact ultrasound technology:

The technology in question is the theoretical combination of air-coupled non-contact ultrasound technology with machine learning to determine how drought ridden a plant is and precisely how much water the plant will need to exit this stage. Although ultrasonic technology is conventionally used in the medical field, its ability to breach through different layers of tissue can prove useful when examining plants.

In a research paper, scientists were able to use ultrasonic techniques to determine the change in water content in evergreen and deciduous leaves[2]. This was done by using a portable transducer to emit ultrasonic pulses between 0.2 to 2 mHz, causing the leaves to vibrate, then subsequently using a second transducer to detect the waves. Depending on the frequency, the wave will be able to pass through different layers of tissue until it hits a layer which is too dense to pass through, at which point the wave is reflected back and detected by the second transducer. Through this method, they were able to determine the insertion loss (the amount of energy a signal loses as it travels) and phase shifts (the change in position of a wave at two different locations that occur at the same time) which allowed them to calculate for a transmission coefficient (the ratio of transmitted fluxes to incident energy flux), velocity of the ultrasonic waves in the leaf, thickness of the leaf, and the attenuation coefficient (a measure of how much the wave has been reduced when passing through the leaf). Velocity and attenuation, specifically, were then used to calculate water content. However, issues like surface condition and the softness of the matter being tested can create errors in data collection.

Another paper aimed to tackle this by using a similar air-coupled non-contacting dynamic elastic modulus elastography method on cactuses and were able to use the data collected to create elastographic images, showing the dynamic elastic modulus throughout the leaf (the stiffness of the leaf)[3]. This paper used the dynamic elastic modulus to determine the water loss in a plant based on the fact that lower water content leads to increased biomass which then leads to an increased effective elastic modulus. Both papers used similar data collection techniques; however, one paper focused on the effective elastic modulus to determine water content while the other used velocity and the attenuation coefficient to do so.

To deal with applying this technology to real fields, researchers found that emitting an ultrasonic pulse of 20-60kHz from 30-50 cm above a canopy surface allowed them to successfully capture crop canopy info like the vertical distribution of leaves and specific plant parts (stems, dry leaves, pods, etc.)[4]. Smaller frequencies reached lower levels while high frequencies reached the upper levels of the canopy. In the past, contact was needed to observe these structures, resulting in the damage of plants that were being studied. This new method will maintain crop yield while still allowing crops to be studied. Also, this is useful for practical application as plants will have different canopy and growth structures based on a number of external factors.

All papers show that by altering the frequency emitted by an air-coupled non-contact transducer, certain information can be collected and then used to study water content.

Applications of AI/ML:

Artificial Intelligence (AI) can play a role in improving the clarity of data and predict the necessary amount of water needed for a plant to exit its drought stage. In regards to improving data, a 2022 paper, researchers discussed the use of AI techniques to increase the resolution of waves, which were derived from using air-coupled non-contacting dynamic elastic modulus elastography, to the subwavelength scale[3]. This would improve the specificity of the data and allow for more accurate monitoring of plant water levels. As for prediction software, most ultrasonic data comes in the term of numerical and visual data (e.g. graphs). Firstly, original water content and species needs to be recorded. Afterwards, water needs to be given to the plant with the water given being recorded along with how much the overall water content of the plant changes over time. By changing the amount of water given and maintaining the same species, there will be enough data to input into a supervised learning algorithm. Specifically, a deep learning algorithm may be beneficial due to the quantity of the data. Ideally this algorithm will determine a pattern that will predict the lowest amount of water needed for a plant to exit its drought stage. From there, more experiments need to take place to determine the practical accuracy of the algorithm's prediction. Manual adjustments to things like the learning rate can take place to better tweak the algorithm.

Potential issues and areas to further research:

This technology can prove to be useful but some issues may arise when implementing this technology out of the lab. As a result, continued research needs to be done to explore the issues listed below.

Because different species may have different ultrasonic properties, one prediction algorithm may not work for another species and thus, different algorithms need to be made per species[2]. This will lead to more time and resources being invested due to the data collection and testing required per algorithm.

External factors such as pollutants may affect the data outputted by a transducer, resulting in a prediction with a large error value. AI can be used to reduce this issue by improving the resolution of images and improving the overall quality of data collection;however, there will always be a bit of error. Another way to fix this issue is to keep produce in as much of a controlled environment as possible, but this limits the technologies use to highly controlled environments and thus is not advisable.

In terms of practically applying this technology to large and small scale farming operations, things like cost and ease of use need to be taken into account. There might be a large learning gap depending on how user friendly the algorithm is. Also, the technology and all its required data collecting equipment may be too high of a cost for small farms to take on.

Lastly, if produce is not in a controlled setting, things like environmental data (temperature, humidity, soil moisture, light intensity, and time of year) need to be taken into account for accurate prediction.

As populations continue rising along with sea levels and temperatures, researchers need to look into adaptive solutions. Water, being necessary for life, will continue to become a strained resource. This technology has the power to reduce water usage in the agricultural sector, allowing more water to be reallocated for personal use. Although this proposed technology has a long way to actualization, its potential is promising.

Bibliography:

1. Mount, Jeffrey F., and Ellen Hanak. *Water use in California*. Public Policy Institute of California, 2019.
2. Gómez Álvarez-Arenas, T. E., et al. "Noncontact and noninvasive study of plant leaves using air-coupled ultrasounds." *Applied Physics Letters* 95.19 (2009).
3. Yang, Teng, et al. "Non-Contacting Plant Health Monitoring via Ultrasound in Ambient Air." *Biophysica* 2.4 (2022): 315-323.
4. Shibayama, Michio, Tsuyoshi Akiyama, and Ken Munakata. "A portable field ultrasonic sensor for crop canopy characterization." *Remote sensing of environment* 18.3 (1985): 269-279.