論 文 の 内 容 の 要 旨

論文題目　System Design of Cost-Effective Soil Monitoring Networks for Agriculture
（コスト効率のよい農業用土壌モニタリングネットワークのシステム設計）

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In this thesis, system design of cost-effective soil monitoring networks is presented. The soil monitoring networks capture soil parameters such as soil moisture and soil temperature then collect measured data through wireless communication. Precision farming has large potential for enhancing farming productivity since it enables efficient natural resource management. The collection of environmental and crop data by using various sensors is a crucial part of precision farming; therefore, an agricultural wireless sensor network is considered as one of the most attractive Internet of Things (IoT) applications. As soil parameters significantly affect to plant growth, soil sensors play quite important role in agricultural sensing systems. While there are several commercialized agricultural sensing systems, their cost tends to be forbidding to large-scale implementation. As a result, IoT technologies have not much contributed to solve issues related with food and agriculture. To guarantee water resource sustainability and food supply through precision farming, huge scale deployments of agricultural sensors on developing country are required. Thus, reducing cost of agricultural sensors is the key challenge to enhance its potential.

The cost of an agricultural sensing system can be broken down to initial and operational cost. Currently available sensors and data loggers are mainly designed and

used for research purposes; therefore, they can provide very precise measurements, in various environments, but at increased cost. Thus, cost-effective soil moisture sensor leveraging printed electronics technologies is developed. The sensor can measure soil parameters in multiple depth and its sensor probe is detachable to select a target parameter. The sensed data is both stored locally and remotely so the real-time data is presented on Web app and the other clients.

Its usability and durability were tested in iterations of experimental deployments all over the world. Several hundreds of the sensors were fabricated and tested in various fields from 2015 to 2017. Combining the irrigation control system and the soil monitoring network, more precisely automated irrigation system can be developed. Once it achieved, both farming productivity and labor efficiency should be significantly improved. As Japan is facing gradual population decreasing of farmers, automation will be a key to remain farming production.

Such data driven irrigation should play important role on agriculture in India as well. As India is under monsoon climate, irrigation optimization is fundamental for farming in dry season and overuse of groundwater is considered as a social problem. If soil moisture is monitored in real time and farmers just supply appropriate amount of water based on the data, water consumption can be drastically reduced. Considering the background, the developed sensors were deployed and tested in India. The soil moisture sensors successfully captured soil moisture data which indicates relationship between irrigation control and soil moisture levels. As the next step, cooperation with efficient crop management strategy and remote sensing is expected.

Other than the sensors for professional farmers, a simple version of soil moisture sensor for hobby use was developed. In this package, sensor film for soil moisture sensing can be customized using ink-jet printer with silver ink. Since the artwork for sensor film can be drawn on PowerPoint, the rapid prototyping is suitable for soil sensor design workshops. Through the workshop, interesting ideas on sensor film design have been collected. The outcome would be reflected in the next version of the sensor.

While initial cost is reduced by using printed electronics, operational cost is still significant and remaining problem because our sensor nodes are currently powered by batteries, which require additional labor expense for their replacement. Since the number of sensors is limited, battery replacement is not a serious matter; however, if a farmer introduced several hundred sensors in their farm field, and each sensor required battery replacement every year, the project would become unsustainable. With consideration to scalability issues, battery-less sensors are preferable to battery-driven sensor networks. Therefore, Unmanned Aerial Vehicle (UAV) assisted wireless power transmission (WPT) system and thermoelectrical energy harvesting are proposed as battery-less solution for agricultural sensing networks.

Combining low-cost fabrication technics and battery-less solutions, cost-effectiveness is improved in both initial and operation cost. While sensing accuracy of the soil moisture sensor is not equivalent to the other precise soil sensors, according to the feedbacks from experimental deployments, the sensed data is useful enough to quantifying soil management knowledge and expand productivity eventually. Battery related troubles were matter on the experimental deployments, but they will be resolved by introducing the battery-less solutions and long-term usability will be significantly improved.