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The Drone Based Hyperspectral Imaging System for Precision Agriculture

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Abstract
Precision agriculture using remote sensing can be traced back to 1980's with various handheld sensors as well as sensors mounted on satellite and airborne platform. Precision agriculture or precision farming is a farming management concept which combines conventional farming method with new technologies such as satellite/radar imaginary and information technology. Unlike conventional farming, precision agriculture integrates a suite of technological tools such as radar images, agriculture monitoring system, and high technology machines into farming practice. The aim is to minimize the crops production costs and maximize the production outputs all in benefiting the farmers. In this project, an experimental study on disease detection and nutrient extraction of plantation such as oil palm n Malaysia will be carried out using a drone based hyperspectral imaging system. In this project, an experimental study on disease detection and nutrient extraction of plantation such as oil palm in Malaysia will be carried out using a drone based hyperspectral imaging system. The major advantages of this hyperspectral sensors are light weight (approximate 250g for sensor) and larger number of band selection (from 600nm to 1000nm) compare to conventional multispectral camera. Therefore, it enables the usage of smaller airborne platform and further reduce the development cost and operation cost. A customised drone has been designed and developed to carry the hyperspectral imaging system. Preliminary testing has been performed in laboratory and oil palm plantation to verify both multirotor drone and hyperspectral imaging system. Initial results show that the hyperspectral data are suitable to be used for differentiation of the healthiness level of the oil palm plantation. In order to achieve the target of disease detection and nutrient extraction, timely ground truth data will be collected together with the field experiment using drone based hyperspectral camera. Data analysis on the obtained ground truth data need to be carried out to study the correlation properties of the hyperspectral images with various oil palm plantation condition. This research is supported by MOSTI International Collaboration Fund, IF0719A1102.
Keywords: Hyperspectral imaging, precision agriculture, multirotor drone, remote sensing

1. Introduction

Remote sensing is an extremely useful tool for agriculture industry to monitor the temporal and spatial changes of morphological and physiological conditions which supports real and practical application [1][2]. Unlike multispectral imaging, hyperspectral imaging is more advanced system that acquires detailed spectral response of target features with higher number of spectrum band. Due to limited accessibility outside the scientific community, hyperspectral images have not been widely used in precision agriculture. However, via the launched of advanced spaceborne hyperspectral sensors (such as PRISMA, DESIS, EnMAP, HyspIRI), hyperspectral imaging is increasingly being used in agricultural applications [3]. Anyway, due to the large volume of data, high data dimensionality, and complex information analysis needed, the acquisition, processing and analysis of hyperspectral images are still a challenging research activity.

The detailed reflectance spectrum acquired by hyperspectral remote sensing enables the researchers to identify and distinguish material and conditions on the ground with very high-resolution imagery. Hyperspectral imaging enables many applications in precision agriculture which may include weed mapping, crop yield mapping, pest detection, disease detection and bare soil imaging for management zone delineation, and pest and disease detection [4]-[8]. It also allows improvement for the analysis of specific compounds, molecular interactions, crop stress, and crop biophysical or biochemical characteristics [9]-[11].

Literature review shows that, research in disease detection using Hyperspectral imaging technology such as detection of Ganoderma disease on oil palm have been conducted in Malaysia for the past decade [12]-[15]. In order to perform the detection of disease using hyperspectral imaging, selection of spectral band which is associated with the disease is essential and critical. The unique signature of the plantation with disease should be able to extract via statistical classification algorithm. From the literature, identification of bruises in apple is applied via 558-1340 nm spectral band [16]-[18]. Whereas for Ganoderma disease detection, suitable hyperspectral band to be used will be 460-500 nm and 720–870 nm [14][15]. Another potential application of hyperspectral imaging is to determine the nutrient condition in a crop field so that the fertilizer could be optimized and directly deployed to the low nutrient areas. For example, in mid-western of America this technique is used to estimate nitrogen and phosphorous concentrations, biomass and yield via the nutrient stresses [19].

Due to advancement in drone technology recently, small unmanned aerial vehicle (UAV) become commonly deployed in precision farming to carry payload of sensor such as optical and hyperspectral camera [20][21]. Anyway, usage of hyperspectral imaging in agriculture industry in Malaysia is still not common due to limited access to the UAV based hyperspectral imaging system and limited data for the deployment of applications such as disease detection and nutrient content extraction for various plantation.

In this project, a customised design multirotor drone is designed and developed which equipped with hyperspectral camera as the major payload. The main objective of this drone based hyperspectral imaging system is to perform the disease detection and nutrient extraction of oil palm plantation in Malaysia. The performance of this system is verified via various indoor and outdoor testing. The field experiments were conducted with the aim of collection hyperspectral images of the oil palm plantation and ground truth data. The collected data are analysed to study the correlation properties of the hyperspectral images with various oil palm trees conditions with the final aim of develop a classification system for disease detection and nutrient extraction using artificial intelligence.

2. Design Considerations

The primary goal of this research project is to design and develop a customized multirotor drone which capable to carry the hyperspectral camera as main payload. High level design consideration have been carefully considered and presented in this section.

2.1 Multirotor Drone

In this project, a Hexacopter endurance drone is to be designed and developed to carry the proposed hyperspectral camera (main payload) and RGB camera (secondary payload). The minimum requirement of the drone is listed as below:

1) Minimum payload on board - lightweight hyperspectral camera
2) Targeted flight time - 30 to 40 minutes

2.2 Hyperspectral Camera

In order to perform the hyperspectral imaging, a hyperspectral camera is required to mount on the drone system. The basic requirements of the hyperspectral camera that targeted for precision farming are listed as below:

i. Spectral Range: 500-900 nm
ii. Spectral Bands: 500 (minimum)
iii. Minimum Image Rate (frames / s): 100 (10 bit)
iv. Image Resolutions: 1024x1024
v. Exposure time: Adjustable
vi. Memory: 1TB (minimum)
vii. Weight: < 1 KG
viii. Positioning: GPS

3. System Implementation

Figure below shows the functional block diagram for the proposed system. The major modules of the drone based hyperspectral imaging system consists of power management system, payload and drone flight system. The power management system includes the LIPO battery and the power management unit that provides the power supply to the overall drone system (including motor) and the payload. The main payload of this system is hyperspectral camera, and the secondary payload is RGB camera (will not discus in this paper) together with the gimbal. The drone system consists of the flight controller, electronics speed controller, GPS as well as the motor and their corresponding blades.

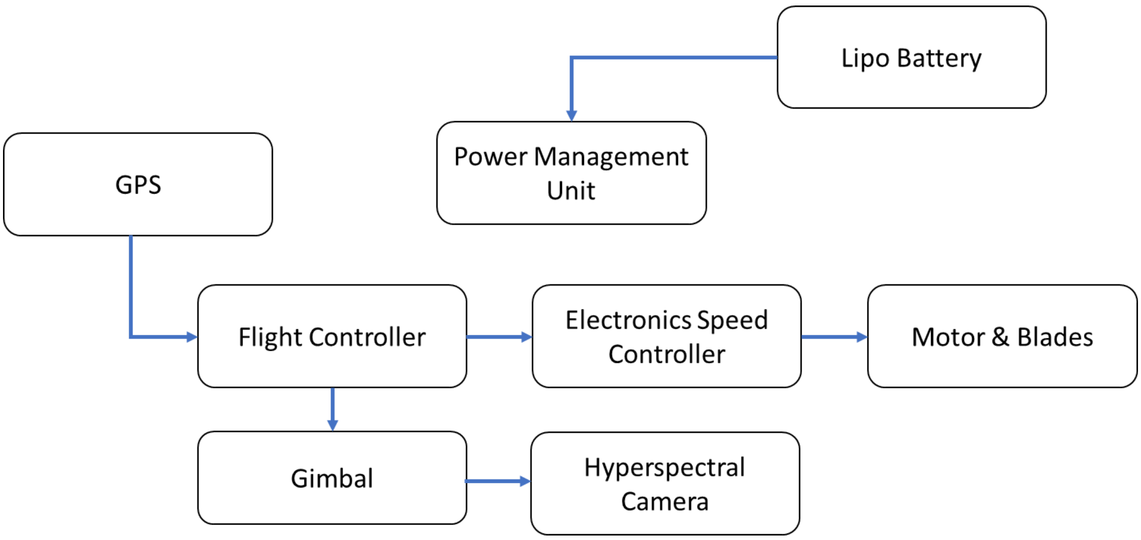

Figure 1: Functional block diagram of Drone Based Hyperspectral Imaging System

3.1 Hyperspectral Camera

Based on the requirements listed, the hyperspectral camera than have been identified is Senop HSC-2 Hyperspectral Camera. The image of the camera and its detail specifications are shown in the figure and table below.

Table 1: Detail Specifications of Senop HSC-2 Hyperspectral Camera

Parameter	Specifications
Spectral Range	500-900 nm
Spectral Step	0.1 nm
Spectral Bands	up to 1000
Horizontal FOV	36.8°
Vertical FOV	36.8°
Image Sensor	CMOS
Dynamic Range	10/12 bits
Max Image Rate (frames / s)	74 (12 bit), 149 (10 bit)
Image Resolutions	1024x1024
Exposure time	Adjustable
Memory	1TB
Connections	GigE RJ-45 Mini-Displayport v1.2 IO port with UART and 4GPIO pins MMCX for external GPS antenna (if needed) USB-C for irradiance sensor
Weight	990 g
Dimensions (l x w x h)	199 mm x 131 mm x 97 mm
Positioning	GPS and BeiDou
Voltage supply	7-17 VDC
Inertial Measurement Unit	Gyroscope and 3 axis accelerometer
Adjustable optics	Focus distance: 30 cm - ∞
Data export	Standard ENVI

Figure 2: Photo of Senop HSC-2 Hyperspectral Camera

3.2 Customize Drone

The drone body frame was implemented by the readymade body frame for agriculture spraying drone, which is originally capable of holding 16L volume of liquid tank with 6-axis motor configuration. However, some modification will be performed to fit all the required module into the drone. The original mounting and payload of the drone is removed and replaced with custom made holder. Besides, the landing gear will be replaced with the longer dimension to carry the gimbal and proposed payload. The 3D assembly of the drone is illustrated in Figure 3.

Figure 3: 3D drawing of drone assembly

3.3 Motor Selection

The selection of the motor will be based on efficiency type motors as the drone is targeted for endurance. The target is to run on 12s battery configuration instead of 6s (Rated 12s = 44.4V, 6s=22.2V). Since power is equal to the voltage multiply with current, for the same amount of power, higher voltage resulting in less current drawn and vice versa. For our design, we will avoid high current to be used in our system as it will cause more heat generated. With the 12s battery configuration and 28-inch propeller, the selection of motor is justified as below. The comparisons between the two motor T-motor U8 II KV100 and T-motor U10 II KV100 are listed as below.

Table 2: Comparison of T-motor U8 II KV100 and T-motor U10 II KV100

Specifications	**T-motor U8 II KV100**	**T-motor U10 II KV100**
Weight include cables	272g	415g
Operating temperature @ max continuous current	95°C @ 80% throttle running for 10minutes	51.8°C
Max thrust @ 100% throttle	8716g	8629g
Price	USD 309.9	USD 339.9

It can be noticed that U8 II KV100 motor weight is lighter than U10 II KV100, thus it will be benefited in terms of the total endurance as the endurance is depended partly on the total weight of the drone. Both motors have almost the same maximum thrust at 100% throttle.

However, the U8 II KV100 motor has higher operating temperature due to the design structure. (Smaller size of coil windings and metal casings). With almost similar performance, the reduced weight using U8 II KV100 motor can be utilized for more room for payload also cheaper in price.

For a multicopter drone, the ideal thrust to weight ratio is 2:1, which is 50% throttle for each motor. We can also attach extra payload up to 60 or 70% of the throttle with shorter flying time (requires more current drawn to achieve higher thrust). Generally, the motors cannot be fully loaded due to the copter behaviour and compensation during flying (Strong wind, higher air viscosity on thin air etc). There are also variations of U8 BLDC motors such as U8, U8 Lite and U8 Pro. U8 and U8 Lite does has different mechanical structure which has the coil windings exposed, while U8 Pro is the older version of U8II where U8II has slight increase in efficiency.

3.4 Weight Analysis & Flight Time Estimation

Based on the selection of the Hyperspectral Camera, Senop HSC-2 Hyperspectral camera. Some of the key components are selected. DJI Ronin MX gimbal is chosen for HSC-2 Hyperspectral camera as suggested by manufacturer. Two 6s 30000 mAh Lipo battery will be paralleled to achieve 12s configuration.

Table 3: Actual weight measurement breakdown

No.	Item	Qty	Actual weight per unit (g)	Total weight (g)
1	Drone body frame w/ components + wires + BLDC motors w/ QAD adapter + DJI Ronin MX gimbal holder adapter	1	10486	10486
2	6s 30000mAh 25C Lipo battery	2	3436	6872
3	T-motor 28 inch propeller w/ QAD adapter	6	102	612
4	DJI Ronin MX gimbal w/o holder	1	2254	2254
5	DJI Ronin MX camera adapter plate + screw	1	88	88
6	Senop HSC-2	1	990	990
7	Irradiance sensor w/ Type-C cable & mountings + screws	1	118	118
			Sum total weight (g)	21420

Referring to Table 1 and T-motor U8II KV100 manufacturer data sheet, the calculation of required power rating such as the current needed can be performed. With the selected battery type, the estimated flight time can be calculated. With this we can set the safety margin of 80% from the calculated theoretical flight time. The main considerations and calculations are listed as below.

Table 4: Flight Time Estimation

Thrust required per motor	3570 g
Current drawn at thrust required per motor	7.09 A
Total current of 6 motors drawn	42.72 A
12s Lipo battery capacity	30000 mAh
Theoretical estimated flight time	42.29 minutes
Safety estimated flight time @ 80%	33.83 minutes

3.5 Flight System and Overall Wiring Diagram

In a drone system, the flight controller functions as the "brain" to control settings such as Proportional-Integral-Derivative (PID) tuning, maintaining level flight, perform routing of drone etc. There are many flight controllers available in the market such as Pixhawk, DJI Naza etc. In this custom-built drone, DJI N3 is used as the flight controller as it is more user friendly and easier to settings. Figure 4 shows the connection diagram for DJI N3. Overall connections between flight controller and other components are also shown in Figure 5.

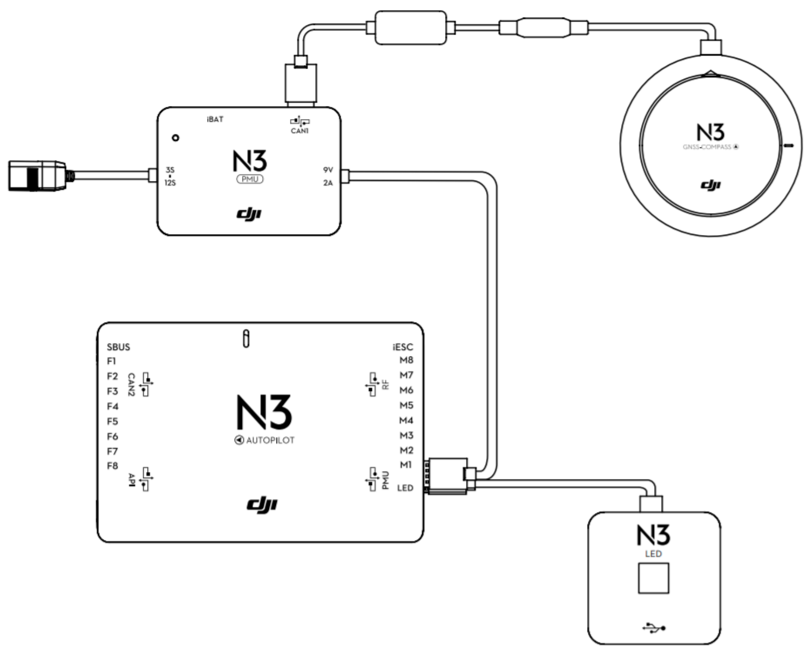

Figure 4: DJI N3 flight controller connection diagram

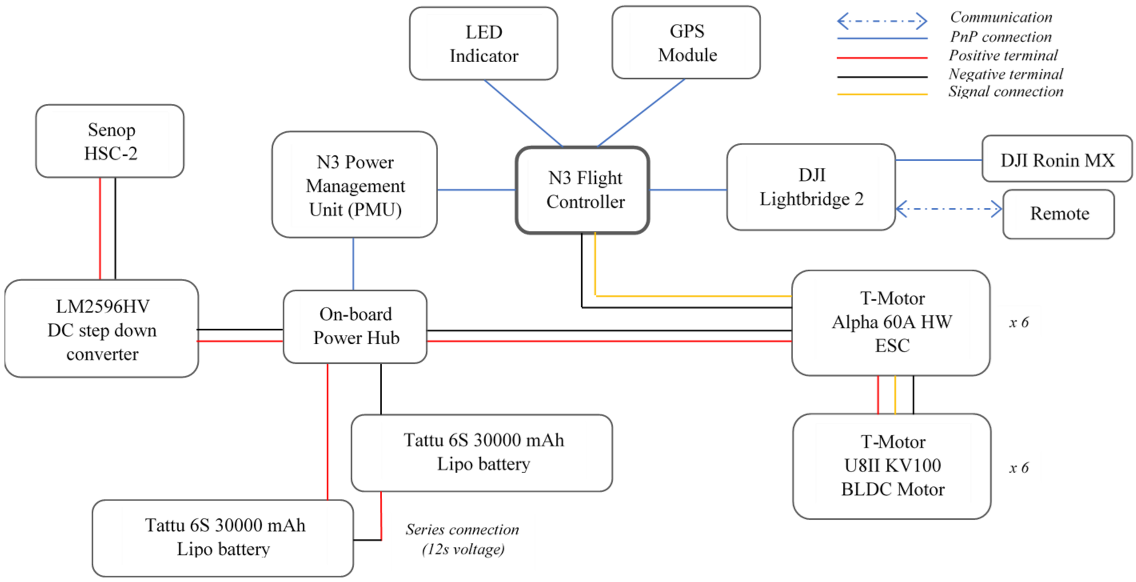

Figure 5: Overall drone based hyperspectral imaging system block diagram

3.6 System Installation

The payloads of the drone are two Tattu 6S 30000mAh Lipo batteries, DJI Ronin MX gimbal and Senop HSC-2. A 3mm thickness twill weave carbon fiber plate is used to create a tray to mount the Lipo batteries and fit with DJI Ronin MX drone on board adapter mount. The measurements of the battery size and gimbal on board adapter mount are measured and digitized into CAD drawing for reference. With the digitized drawing, the exact dimension of the tray can be illustrated and eliminate excess material for optimum weight. Figure 6 shows the complete assembly of the payload tray with digitized reference model.

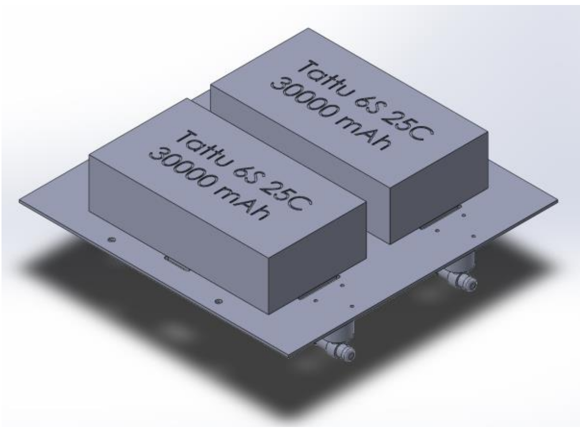

Figure 6: Assembly of digitized reference model

An overall area size of 330*330 mm^2 plate is needed for the payload holder. The plate is measured and cut from a stock of 500*400 mm^2 area size, 3mm thickness twill weave plate. Due to the limited machining size of the CNC machine available, the plate is fabricated manually using power tools. Figure 7 shows the illustration of battery holder plate.

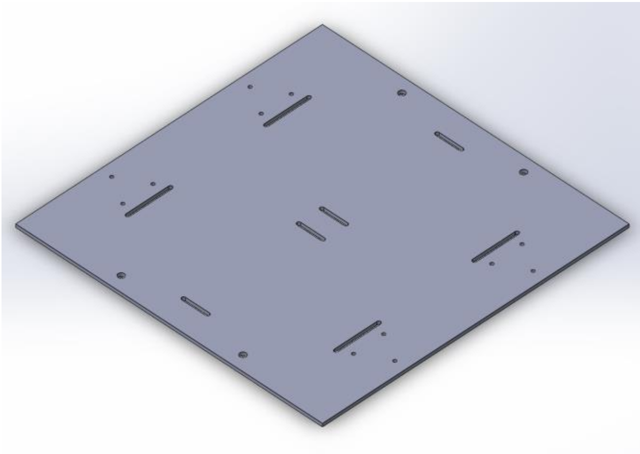

Figure 7: Battery holder plate

With the battery holder plate fabricated, it is fitted on the existing mounting originally meant for the liquid tank. The batteries are strapped on the plate using velcro strap and the gimbal adapter mount is mounted using M2.5 screws and nuts. However, the remaining space below for DJI Ronin MX gimbal is not high enough to get clearance.

The landing gear uses four 20 x 17mm carbon fiber tube with 400mm length. After measuring the clearance needed for DJI Ronin MX gimbal, the tube length needs at least 750mm length. The tubes are then replaced with 20*16mm carbon fiber tube with 750mm length, which is thicker than the original for better sturdiness and any heavier payload usage in the future. Figure 8 shows fully integrated customized drone with the payload tray of batteries and gimbal mounted.

Figure 8: Payload tray mounted with batteries and gimbal

3.7 System Performance

The multirotor drone based hyperspectral imaging system have been successfully constructed. The hyperspectral camera and the customized drone have been successfully integrated and tested. The following table listed the final achieved specifications.

Table 5: Actual drone specifications

Specifications	Description
Total weight w/o payload	18kg
Max payload	Up to 19.2kg (Total weight of 80% max thrust)
Total weight with current payload (HSC camera & gimbal)	21.42kg
Max flight time with current payload	33.8 minutes (with battery tapped to HSC camera)
Flying height	Max 500m (DJI flight controller limitation)

4. Drone Based Hyperspectral Imaging System Preliminary Results

A preliminary field experiment was conducted at early of April 2021 at Palong Timur Test Site, Johor. The purpose of this experiment was to verify the functionality of hyperspectral camera as well as the multirotor drone in the actual field measurement such as oil palm plantation. A RGB camera on-board small drone was used to map the test site and to generate a high-resolution geo-referenced map for the study area and the customised designed drone based hyperspectral imaging system was used to collect samples of oil palm trees for preliminary test and evaluation. Figure 9 shows the drone based hyperspectral imaging system in action. Figure 10 shows a sample of RGB raw image captured at Palong Timur Test Site. Figure 11 shows a sample of hyperspectral image.

Figure 9: Drone Based Hyperspectral Imaging System Operated in Oil Palm Plantation

Figure 10: Sample of RGB raw image

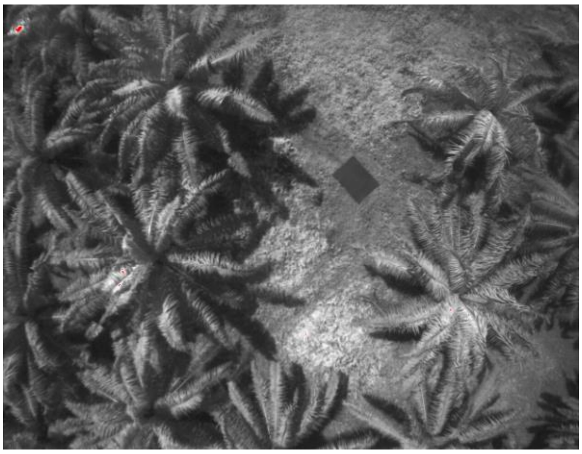

Figure 11: Sample of Hyperspectral Raw Image (at 730 nm) captured

6. Conclusions

A drone based hyperspectral imaging system has been successfully designed and developed at the Multimedia University, Malaysia. A series of indoor testing and field measurement have been conducted to verify the performance of the system. The captured raw data has been successfully processed into hyperspectral images and preliminary analysis of the images has been performed. The preliminary results show that the developed customized drone based hyperspectral imaging system is able to meet the operational requirement and generate the desired hyperspectral images. This drone based hyperspectral imaging system will be used as the testbed for future development of algorithm to perform disease detection as well as for nutrient content estimation of the oil palm plantation.

Acknowledgement

This research is supported by Ministry of Science, Technology and Innovation (MOSTI), Malaysia, International Collaboration Fund (IF0719A1102). Special thanks to FGV R&D Sdn. Bhd. for providing the ground-truth information and test site to conduct the field experiment.

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