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DESIGN OF A QUADCOPTER AUTOPILOT SYSTEM TO TAKE AERIAL PHOTOGRAPHY FOR REMOTE SENSING APPLICATIONS IN AGRICULTURE

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ABSTRACT

This paper presents the design and test of an autopilot control system of quadrotor helicopters for collecting aerial images in agriculture applications. The designed system is built based on the Naza-M Lite flight control system with a GPS module. A Texas Instruments Stellaris EK-LM4F120XL module is employed as the main control unit for managing the autopilot mode and other vital functions. This system also includes a ground station playing a key role to transmit/receive the airplane's GPS coordinates via RF links. Initial experimental results show that the quadcopter can fly along the planned flight routes on the Google Maps. The designed quadcopter is equipped with a 5-Mpixels camera capable of taking aerial photos of rice fields at specified locations. Taken aerial images processed using the Normalised Difference Vegetation Index (NDVI) technique can provide farmers with information about photosynthesis status of plants. Optimizing performance of the control system to improve stability and increase flight times of the quadcopter will be the main topic of our future work. The system is expected to be a suitable solution for taking aerial photography to assess growth and development status of large-scale rice fields and fruit plantations.

Keywords: autopilot, Naza-M Lite, precision agriculture, quadcopter, stellaris.

INTRODUCTION

The rice production area of Mekong Delta region under the large-scale field model has grown rapidly over the past 5 years, to 200,000 hectares in 2015, according to a report from the Ministry of Agriculture and Rural Development of Vietnam [1]. This cultivation model has reported lower production costs, higher yields and better rice quality. Besides, cultivating large paddy fields has also led to difficulties in monitoring and managing crop fields. This means there are not enough manual laborers to inspect massive rice fields without the aid of automated machines. Recently, in some developed countries like United States, and Australia, unmanned aerial vehicles (UAVs) have been applied to support agricultural production [2-4]. Radio-controlled airplanes that carry a spraying system or aerial imaging device can cover hundreds of hectares of crop fields in a short period. Aerial images taken from UAVs can provide farmers with useful information on plant growth and development, pest infestations, soil issues and irrigations.

This paper presents the design and implementation of an autopilot control system of quadrotor helicopters (quadcopter) for collecting aerial images in agricultural applications. The designed quadcopter is equipped with a 5-Mpixels camera for capturing aerial photographs of rice fields and has the ability to fly along planned routes on the Google Maps. Aerial images are processed using the Normalized Difference Vegetation Index (NDVI) technique to extract useful data on plant health and disease status. The system is expected to be an effective and affordable tool for farmers to increase yields and reduce crop damage.

SYSTEM DEVELOPMENT

System overview

The proposed system consists of two main modules: the quadcopter control system and the ground station. Figure-1 depicts the architecture of the designed system. The functional blocks of the system are described as follows:

- CC1101 RF transceiver module [5]: this module is used to send/receive data between the quadcopter and the ground station at the frequency of 433 MHz.
- Stellaris LM4F120 LaunchPad Evaluation board [6] (from Texas Instruments) is used as the brain of the whole system, it communicates with other modules to carry out the autopilot or manual control functionality.
- GPS and Compass Naza module is for sensing the position and direction.
- Quadcopter: a model helicopter that is lifted and propelled by four rotors having main specifications as follows
  - Diameter: 65 cm
  - Length of each propeller: 20cm
  - Load capacity: 500 gram
  - Motor: Brushless DC (BLDC)
- Camera module is a RasPi NoIR camera having a resolution of 5 Mpixels [7]. It is used for taking aerial photographs of the rice fields. The camera module is controlled by a Raspberry Pi kit [8].
- Sensors: the environmental parameters of interest such as temperature, atmospheric humidity, light intensity, etc. can be monitored by integrating a set of sensors onto the quadcopter.
- The quadcopter flight control module: this module is based on Naza M-Lite module that helps enhance the

stability of quadcopter on the fly. This module controls the quadcopter in accordance to the GPS coordinates retrieved from Stellaris module.

The customized software to display the offline map: This software is installed on a laptop at the ground station. It calculates the variation of GPS coordinates, updates current position of the quadcopter in real-time and allows users to locate the checkpoints to capture aerial images.

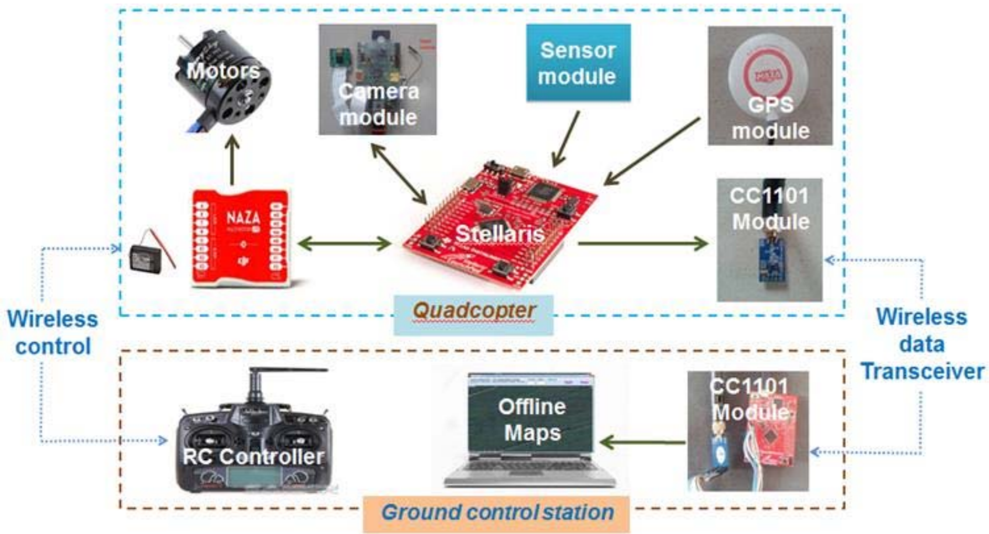

Figure-1. System architectures.

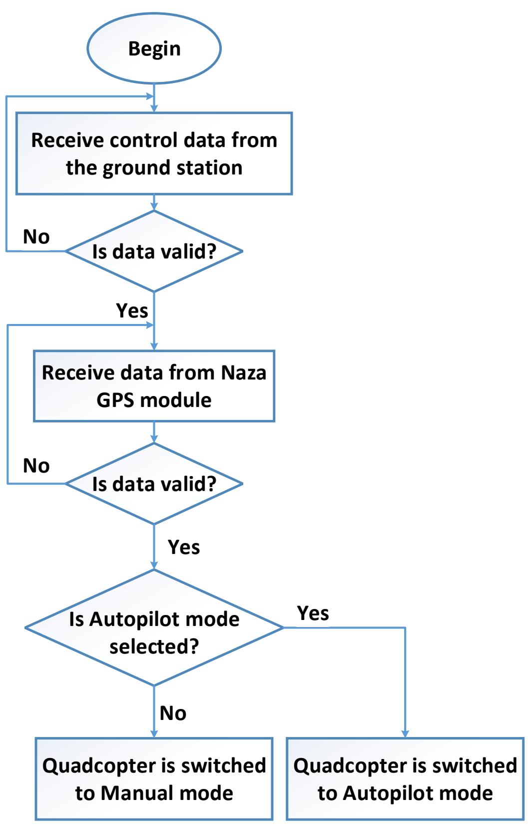

Figure-2. Flowchart describes the operations of the control system installed on the quadcopter.

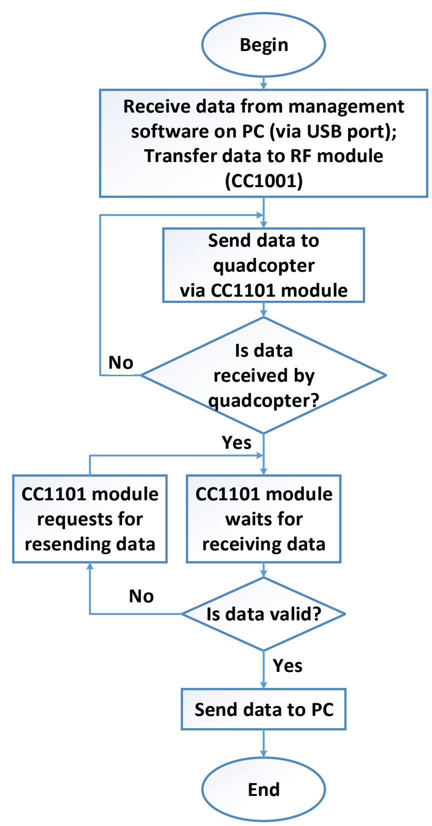

Figure-3. Flowchart for a data transmission session between the ground station and the control system on the quadcopter.

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Quadcopter control system

On quadcopter, a Texas Instruments Stellaris module is utilized as the central controller to control the autopilot process as well as the operations of the remaining modules such as Naza M-Lite module, camera module, CC1101 transceiver module, GPS module, and sensors (light sensor, temperature sensor, humidity sensor, etc.).

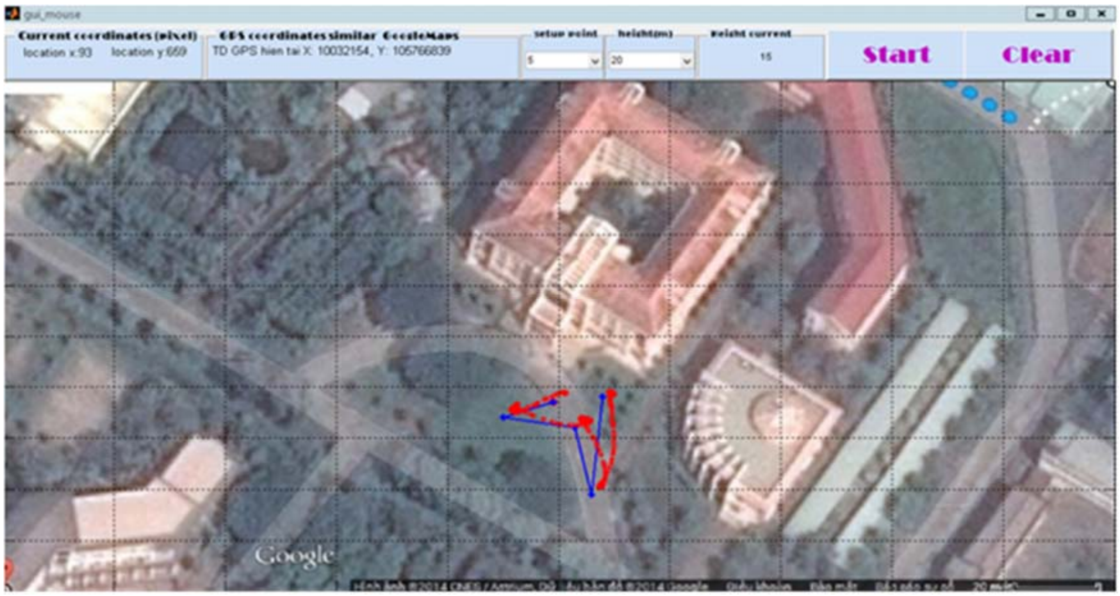

Figure-4. Offline Map: comparison between the planned routes (—, solid line in blue) and the actual routes (- - - , dashed line in red).

The operational principle of the quadcopter control system is described by the flowchart in Figure-2. First of all, the Stellaris module waits to receive GPS coordinates data from the ground station. The data collected will be checked. If the data is valid, the status indicator LED will be lighted up in red; otherwise the LED will be turned to green. Then, the data will be transferred to the Naza M-Lite module and the system waits for the autopilot activation signal. If the autopilot mode is selected, the Stellaris module will process the data received from GPS module and compare them with the values received from the ground station. The GPS coordinates data are the checkpoints that the quadcopter need to be stopped and to capture aerial images. In the manual flight mode, the Naza M-Lite module will receive the instructions directly from the handheld controller.

Ground station

The ground station includes a handheld controller working at the frequency of 2.4 GHz and a laptop with a software pre-installed to manage flight operations. The management software helps to control the autopilot process, receive and display the GPS coordinates data of the quadcopter on the map during its flight. A CC1101 RF transceiver module is employed for communications between the ground station and the quadcopter.

Operations of the ground station are described by the flowchart shown in Figure-3. Firstly, the Stellaris module connected to the laptop through USB port is set in waiting mode to receive the GPS coordinates data sent from the flight path control program. If the data is valid, it will be transferred to the CC1101 RF module to transmit to the flight control system mounted on the quadcopter; at the same time, the communication between the Stellaris module at the ground station and the laptop is halted. A new connection for data communication between the flight control system mounted on the quadcopter and the Stellaris module at the ground station is established. The GPS coordinates data is transmitted from the ground station to the quadcopter and the values of environmental parameters collected from sensors are transmitted to the ground station as well for displaying on the graphical user interface in real time.

Offline map

In this study, the authors have developed a management program in MATLAB language to display the offline map. This program helps to calculate coordinates, location, and to set up the autopilot flight paths. In addition, the program also allows users to update and display current position of quadcopter. The position and coordinates of the checkpoints (where the user wants to take images) are sent to the quadcopter from the ground station by a pair of CC1101 RF transceiver modules.

The tracking method on the position of the cursor (tracking mouse location) is chosen to build the offline map. This method is used to calculate and convert the data received from the mouse click operations on the map to the corresponding GPS coordinates [9]. Figure-4 shows the graphical user interface of the offline map with the blue and the red lines represent the planned routes and the actual routes, respectively. The system will calculate the

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difference between the assigned GPS coordinates of the checkpoints on the routes and the actual coordinates received from the quadcopter during the flight. The differences will be saved into the program (installed on the laptop) to facilitate the examination and evaluation.

Design of the GPS-guided autopilot system

The design of the quadcopter autopilot operation is based on the GPS signals retrieved from the GPS Naza module (shown in Figure-6). The GPS coordinates are sent from the GPS Naza module to the flight control system through serial communication at a speed of 115,200 baud. Their formats are described in [10], [11].

55 AA XX YY <payload> ZZ ZZ
55AA is the two-byte message header that all messages will be started with.
XX is a byte indicating the length of the message.
YY is an identification (ID) byte, used to define the message type.
Payload is the coordinate information for quadcopter. This information is XOR encoded and changed by time.
ZZZZ is the two-bytes used for checksum.
The GPS Naza module could send three message types with different ID as follows:
YY=10: the message contains GPS data.
YY=20: the message contains compass data.
YY=30: the message contains version numbers of GPS module.

Figure-5 is the flowchart describing a cycle of a flight for taking aerial photos from the quadcopter. The quadcopter, after taking off and flying to the predetermined hanging point, will receive coordinates data of checkpoints from the ground control station. The validity of this data will be checked by the quadcopter's control system. If the data is valid, then the system will continue to check whether the route is finished or not. In case the route is completed, the system will automatically control quadcopter fly to the pre-determined hanging point (or keep hanging at the current position) for manual landing. In case of the route has not been completed, the system will control quadcopter continue moving to the next checkpoint. After that, the system will send the current GPS coordinates to the ground station for tracking services of the route on the digital map. Besides, the current GPS coordinates is also compared with the required values. If there are deviations, the quadcopter will continue to fly to the appropriate coordinates. While the quadcopter is at the right position, sensing data from sensors mounted on quadcopter is also sent to the ground station. At the same time, taking pictures at checkpoints and saving the photos to the memory card are performed. After sending data to the ground stations and taking photos are completed, the system checks whether the route was finished or not in order to continue functioning until the planned mission is fulfilled.

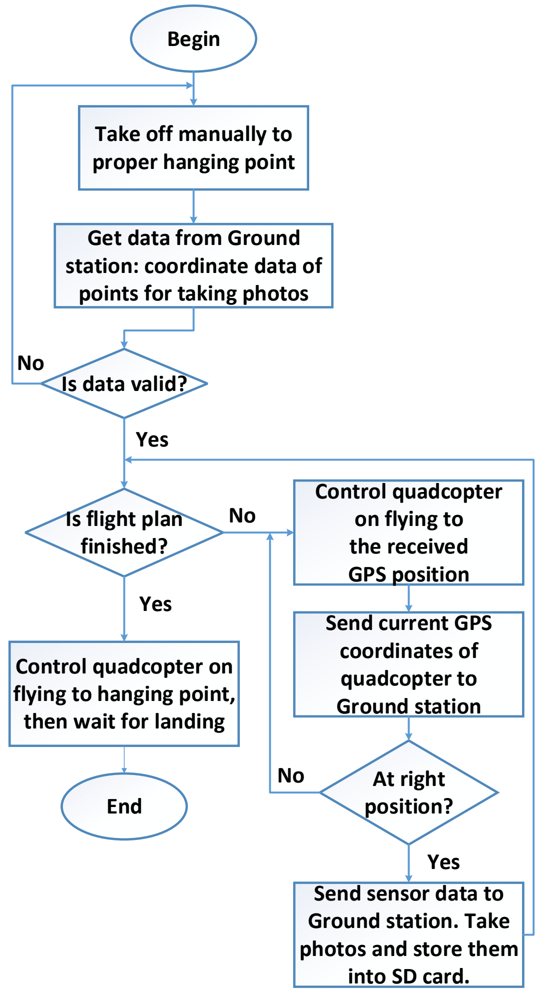

Figure-5. Flowchart for controlling quadcopter to fly according to the preset GPS coordinates.

Figure-6. Naza GPS module mounted on the quadcopter.

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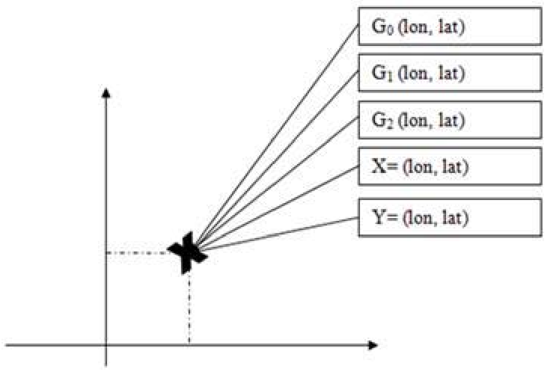

Figure-7. Initial coordinates of quadcopter before receiving control signals from the Stellaris module.

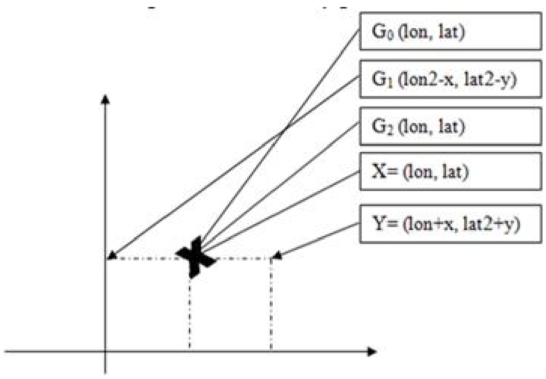

Figure-8. Coordinate data at the beginning of autopilot process.

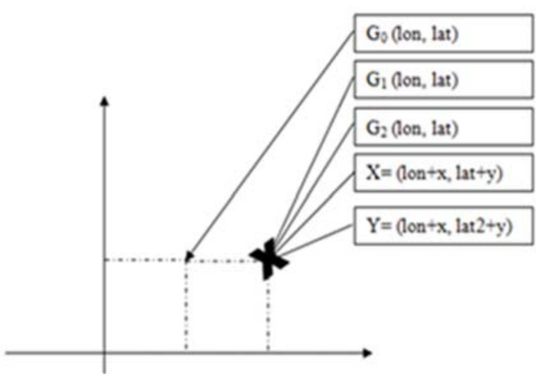

Figure-9. Coordinate data after being adjusted by the Stellaris module.

Figures-7, 8 and 9 illustrate the autopilot process for steering the quadcopter to a pre-determined point with the parameters in the figures as follows:

- YY=30 represents information about the version of the GPS module.
- G0 (lon, lat): the actual GPS coordinate values.
- G1 (lon, lat): the GPS coordinate values that the quadcopter received
- G2 (lon, lat): the GPS coordinate values at the checkpoints.
- X: the actual position of the quadcopter.
- Y: the destination position for the quadcopter.

The quadcopter is able to operate in self-navigation mode; it will stop only when $G_1 = G_2$.

Figure-10. A picture of the autopilot control system.

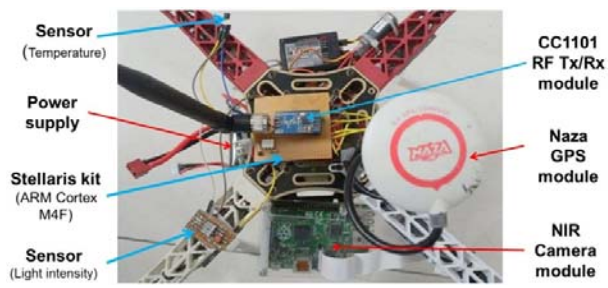

Figure-11. Positions of on-board modules installed on the quadcopter.

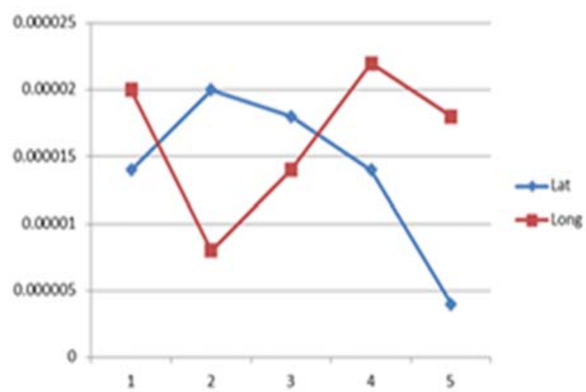

Figure-12. Absolute error graph of GPS coordinates calculated from Table-1.

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Figure-13. A near-infrared image of a paddy field taken by the Raspberry Pi NoIR camera module.

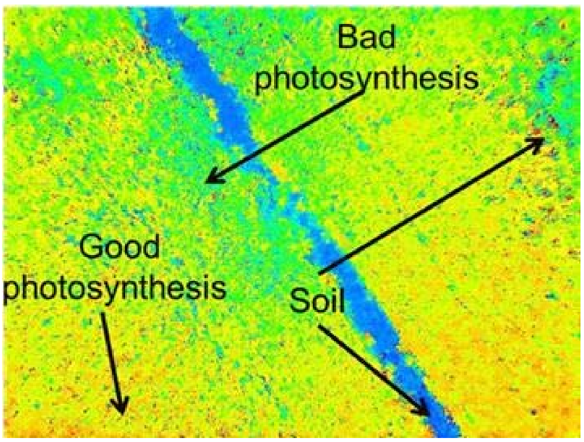

Figure-14. NDVI analysis of the near-infrared image in Figure-13.

Table-1. Comparison of the GPS coordinates between the pre-programmed values and the actual values.

Planned flight path (Latitude; Longitude)	**Actual flight path** (Latitude; Longitude)
10,032169; 105,766710	10,032183; 105,766730
10,032113; 105,766588	10,032133; 105,766596
10,032089; 105,766744	10,032107; 105,766758
10,031929; 105,766780	10,031933; 105,766778
10,032171; 105,766812	10,032175; 105,766830

RESULTS AND DISCUSSIONS

After being designed, the autopilot flight control system for quadcopter has been fabricated and tested to verify its functionality. Figure-10 shows a photo of the whole system, while the positions of on-board modules installed on the quadcopter are presented in Figure-11.

Table-1 shows the comparison between the GPS coordinate values of the pre-programmed flight path and its actual values collected from a typical test flight.

The absolute error of the GPS coordinates calculated from the data in Table-1 is shown in Figure-12. Experimental results have shown that average error between the planned flight path and the actual one is of about 0.5 m. A video clip recorded during a typical test flight can be accessed at the following link: http://goo.gl/iNs07q.

In the field of aerial photography and remote sensing, Normalized Difference Vegetation Index (NDVI), which is calculated as the reflection difference in the near-infrared and red spectrum divided by its total, has been used to quantify the density of green leaf vegetation on lands [12]. By analyzing the differential reflectance of visible and near-infrared lights from plant leaves, farmers and agronomists can assess the growth and development of plants in precision agriculture [13].

In this work, a Raspberry Pi 5-Mpixel NoIR camera module mounted on the quadcopter was employed to take aerial photographs of rice fields. These images were then processed using the NDVI technique. The near-infrared image of a paddy field taken from the quadcopter and its NDVI version are shown in Figure-13 and Figure-14, respectively. It can be seen from Figure-14 that the NDVI image can provide information on the photosynthesis status of rice leaves. Therefore this technique can be a useful tool to evaluate plant stress and health. In future work, we plan to look into developing an NDVI image processing software that aims to extract information for assessing pest infestations and estimate crop yields. Besides, optimizing performance of the control system to improve stability and increase flight times of the quadcopter is also a topic of concern.

CONCLUSIONS

This work has presented the design of an auto-piloted quadcopter that can fly on a planned path and acquire aerial images of rice fields at pre-determined locations. The designed system is built based on the Naza-M Lite flight controller with a GPS module. Aerial images processed with the NDVI technique can provide useful information on plant health and crop status. This system has the potential to be a suitable platform for real-world applications, but needs further development to overcome the accuracy and stability issues. This low-cost system is expected to be a feasible solution for taking aerial photography to assess growth and development status of large-scale rice fields and fruit plantations.

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