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Developing a Ubiquitous Control System for the Protection and Surveillance of Crops from Wild Animals Using a UAV

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Abstract

With a growing population and industrial development, the destruction of ecosystems because of the development of expressways, national highways and tracks increased, and accordingly, the phenomenon of the fragmentation of wildlife habitats increased. Thus, the damages caused by harmful wild animals frequently occur, in South Korea, efforts are made, like saving some damaged farmhouses through monetary compensation. However, the damaged residents cannot sleep at night due to night patrolling or have a lot of inconveniences in their basic life. This study researched and developed a discontinuous system using a UAV (Unmanned Aerial Vehicle) to prevent the access of wild animals in a certain range generating and regenerating ultrasound and ultra-low sound frequencies, based on research on the ecology and habits of wild animals.

***Keywords**: Raspberry Pi, UAV (Unmanned Aerial Vehicle), Infrared camera, Ultrasound, Wild animal*

1. Introduction

With a growing population and industrial development, the phenomenon of the fragmentation of wildlife habitats increased by the development of expressways, national highways and tracks.

Harmful wild animals are wild animals that damage people's life or property, such as wild boars or elks, set by the announced draft proposal of the Ministry of Environment. Recently, these harmful wild animals invade forest zones and nearby farmlands, which do economic damages on crops. The increase of crops damages may harm the crops cultivated in the areas away from the protected areas if there are not enough preys, in addition to the damages set by the Ministry of Environment.

Such damages cause the actual damage to crops and economic problems. As a way to solve these problems, there is a direct patrol to the arable lands of crops. However, this method causes problems, *e.g*. Local residents do not sleep due to night patrolling or they suffer from a lot of inconveniences in their basic life.

Especially, farmers cultivating small farmlands have small crops, overall, so they may get great losses even with a small-scale damage.

Like this, in addition to several systems for the prevention of damages by harmful wild animals, new forms of surveillance system for the normal life of the farmhouses in the damaged areas are needed. This study conducts research and development of a system of loading sensors for the surveillance and prevention of the access of various harmful animals. As important parts in developing a UAV (Unmanned Aerial Vehicle) control system to prevent the access of harmful animals, a control unit for controlling the sensors and attitude control for maintaining the UAV in the air are needed. The attitude control allows a safe flight, which is a technology for night surveillance in place of a man. In addition, the control unit that controls the sensors prevent the access of wild animals in a certain range based on research on the ecology and habits of wild animals, and this study develops a UAV for a discontinuous system that can effectively prevent their access by generating and regenerating ultrasound and ultra-low sound frequencies [1-2].

2. Related Studies

2.1. UAV System

The existing equipment like harmful wild animal repelling devices should be installed in several directions, while a UAV can do the surveillance and patrol by a single unit in a wider range than the existing equipment. The UAV for surveillance and access prevention means a helicopter with four rotors, which is a compound word for quadro rotor type helicopter. There are many names of UAV, and the names most frequently used name is UAV.

A UAV has four rotors and a square form in which two rotors turn clockwise and the other two turn counter-clockwise. Changing the overall speed of the rotors can cause rise and fall of fuselage, and differing the speeds of the front and rear blades causes a pitch moment if the front side direction is x-axis; differing the speeds of the left and right blades causes a roll moment; differing the speeds of the left and right blades and the front and rear blades simultaneously pairwise causes a yaw moment.

In other words, since the principle of the operation of a UAV is much simpler than that of the existing helicopters, it is easy to control it, so it provides a merit of an aircraft. Next, this study conducts mathematical modeling of the UAV. The control formula of the UAV with four rotors (f1, f2, f3 and f4) is illustrated as follows [5].

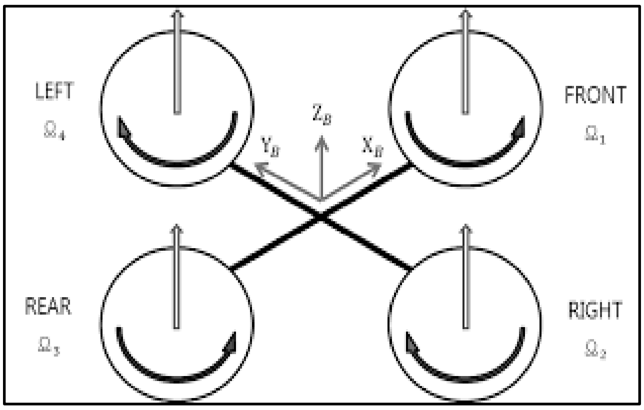

Figure 1. UAV Principle

Potential energy U = mgz
Translational energy $T_{trans} \simeq \frac{1}{2} m\xi^T$ (1)
Rotational energy $T_{rotor} \cong \frac{1}{2} J\dot{\eta}^J \eta$

The energy relation of the potential, translational and rotation motions that act overall can be illustrated as follows:

$$\xi = [xyz]^T, \eta = [\psi\theta\phi]^T, q = [xyz\psi\theta\phi] \quad (2)$$

Where, ξ is the state of translational motion; η, the state of rotational motion; and q, the combination. It is induced with the below Euler-Lagrange method:

To put each energy in the above formula, it is developed as follows:
Euler-Lagrange equation $\frac{d}{dt}\frac{\vartheta L}{\vartheta \dot{q}} - \frac{\vartheta L}{\vartheta q} = F$

$$\mathrm{L}(\mathrm{q},\dot{q}) = T_{trans} + T_{rotor} - U \quad (3)$$

$$\mathrm{F} = [F_{\xi}\tau]^{T} \quad (4)$$

$$\mathrm{L}(\mathrm{q},\dot{q}) = \frac{1}{2}\mathrm{m}\dot{\xi}^{T}\xi + \frac{1}{2}\dot{J}\eta^{T}\xi - \dot{m}gz \quad (5)$$

$$\mathrm{m}\ddot{\xi} + \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} = F_{\xi}, \ddot{J}_{\eta} = \tau \quad (6)$$

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & -sin\phi \\ 0 & sin\phi & cos\phi \end{bmatrix} R_y = \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix} R_z = \begin{bmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (7)$$

$$R_{xyz} = R_x \times R_y \times R_z \quad (8)$$

Where, if a 3-axis (x-y-z) rotation matrix is applied as rotation matrix centered on each axis, the control input can be summarized as follows:

$$R_{xyz}^{T} = \begin{bmatrix} Cos_{\theta}Cos\psi & Cos_{\theta}Sin\psi & -Sin_{\phi} \\ Sin_{\phi}Sin_{\theta}Sin_{\psi} - Cos_{\phi}Sin_{\psi} & Sin_{\phi}Sin_{\theta}Sin_{\psi} + Cos_{\phi}Cos_{\psi} & Sin_{\phi}Cos_{\theta} \\ Cos_{\phi}Sin_{\theta}Cos_{\psi} + Sin_{\phi}Sin_{\psi} & Cos_{\phi}Sin_{\theta}Sin_{\psi} - Sin_{\phi}Cos_{\psi} & Cos_{\phi}Cos_{\theta} \end{bmatrix} \quad (9)$$

$$\mathrm{m}\ddot{\xi} + \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} = F_{\xi}, \ddot{J}_{\eta} = \tau, F_{\xi} = R^{T_{xyz}}[0 \quad 0 \quad u] \quad (10)$$

$$\mathrm{u} = f_1 + f_2 + f_3 + f_4, F_t = \begin{bmatrix} -usin\theta \\ ucos\theta sin\phi \\ ucos\theta cos\phi \end{bmatrix} \quad (11)$$

$$\tau \cong \begin{bmatrix} \tau_{\phi} \\ \tau_{\theta} \\ \tau_{\psi} \end{bmatrix}, \tau_{\theta} = (f_2 - f_4)l, \tau_{\phi} = (f_3 - f_1)l, \tau_{\psi} = M_1 + M_2 + M_3 + M_4 \quad (12)$$

$$M_i = Morotroque$$

After the arrangement, the Eulerian angles of the inertial coordinate system have an interaction formula with the angular velocity of fuselage. Also, the formula of the impact of the force generated by the rotation of the four rotors installed in the fuselage is as follows:

$$\begin{bmatrix} \ddot{z}_v \\ \tau \end{bmatrix} = \begin{bmatrix} \ddot{z}_v \\ \tau_x \\ \tau_y \\ \tau_z \end{bmatrix} = \begin{bmatrix} \frac{1}{m} & \frac{1}{m} & \frac{1}{m} & \frac{1}{m} \\ 0 & l & 0 & -l \\ -l & 0 & l & 0 \\ r & -r & r & -r \end{bmatrix} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix} \quad (13)$$

Where, m means the fuselage mass; l, the distance between the two rotors facing each other; and r, the correlation coefficient between power and moment.

Like this, the UAV can do hovering, unlike fixed-wing aircraft, hovering, so it can observe nearby places with small moves at a certain point. To that extent, it can efficiently perform its mission at the certain areas. In addition, the UAV has a general purpose, which can support many fields such as agriculture and life-saving cartography. Even if it is made for the use of wild animal access prevention, it can be utilized in other sectors.

2.2. Sensor for Surveillance and Access Prevention

With the sensor for surveillance and wild animal access prevention, the method of using the workforce can check even the object unseen in human eyes, appropriately for night surveillance in place of a man, and even in a dark environment, it can exactly figure out where the object is. The frequency part, which is the center of several sensors, can prevent wild animal access in a certain range by generating and regenerating the sound waves wild animals hate (ultrasound (10~30 kHz) and ultra-low sound frequencies (under 18 Hz). It is designed so that even if an object comes from a blind spot, the speaker alarm sounds by the passive Infrared sensor and it makes an additional response [3][4].

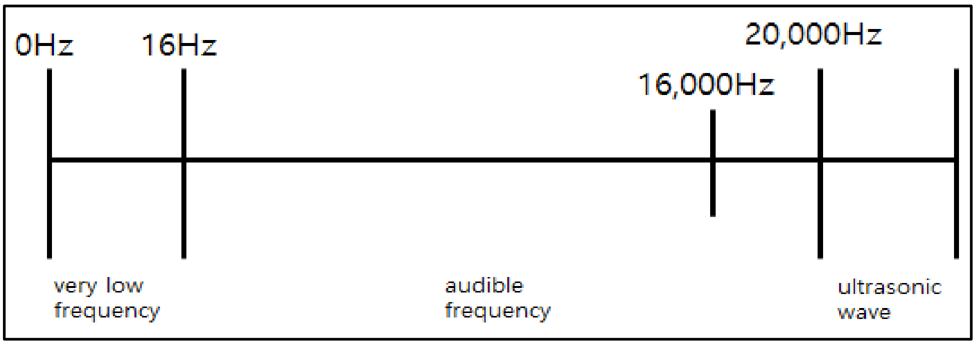

Figure 2. Frequency Range

Through autonomous flying aiming at the UAV, an infrared camera, PIR (Passive Infrared sensor), ultrasound generation can be used to prevent wild animal access in a certain range by generating and regenerating ultrasound and ultra-low sound frequencies based on research on wild animals, appropriately for night surveillance in place of a man based on the ecology and habits of research on wild animals. First, the method of generating the sound waves wild animals hate (ultrasound (10~30 kHz) and ultra-low sound frequencies (under 18 Hz)) prevents wild animal access by generating ultrasound with a buzzer using Raspberry Pi. In addition, in order to prevent them from being familiar with that, the sound is randomly output. For the range wild animals hate, ultrasound range is used, which is not audible to human ears, instead of audible frequency. Figure 2 shows the frequency range.

The second infrared camera uses an infrared camera for Raspberry Pi. It is a camera module removing the infrared filter, which is suitable for taking infrared photographs or taking pictures in a situation with low illumination. The infrared camera is used to record images well even in a dark environment in order to find out access direction and moving path at night when a wild animal enters crops. The following Figure 3 is an infrared camera module for Raspberry Pi.

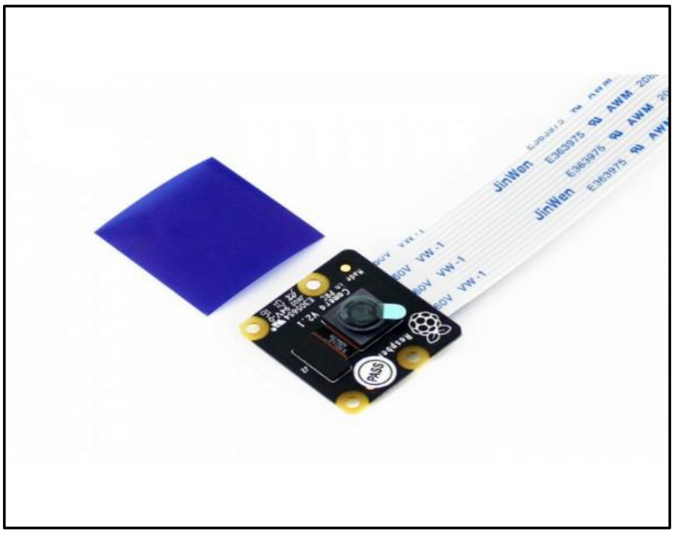

Figure 3. Infrared Camera

The third passive infrared sensor, PIR (Passive Infra-Red) sensor is an infrared operating sensor, which has two slots made of a special material sensitive to infrared. If an object passes, first, one of the two slots detects this change. The opposite phenomenon takes place, also, when it is off the measuring area of the sensor. This PIR sensor is used as a sensor to deliver the situation in which a wild animal has come in and gone out of crops. Figure 4 shows the principle of the operation of the PIR sensor [8].

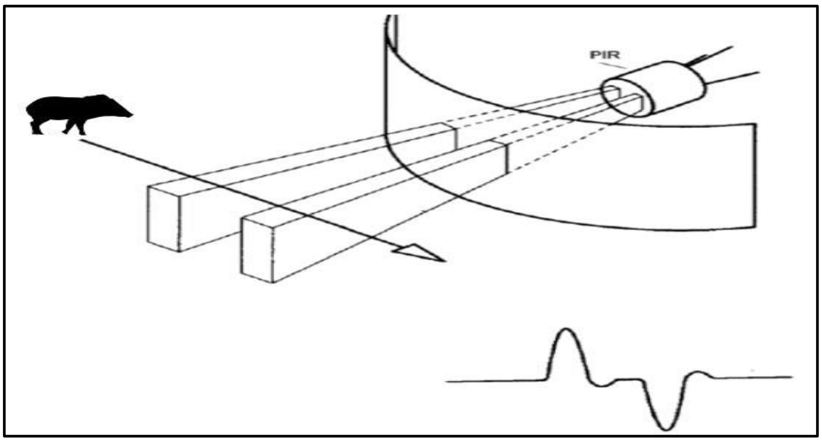

Figure 4. PIR Sensor Operating Principle

Table 1. PIR Sensor Performance

Model Name	HW-8002
Operating voltage	DC 4V~12V
Resistance	<50 μA;
Distance	0.5 ~ 27m
Range	10~140
Working temperature	-20 ~ +70
Size	7*20*32mm

Finally, the system is made to prevent the access of a harmful wild animal that would come in by the output of the frequency through the buzzer from the harmful wild animal that would come in before the detection through the PIR sensor. A piezo buzzer is inexpensive and simple, which can generate ultrasound at a frequency over 20,000 Hz, so it is used in various products utilizing ultrasound. Figure 5 shows a buzzer used for the output of the frequency that prevents a wild animal that entered in the range from access.

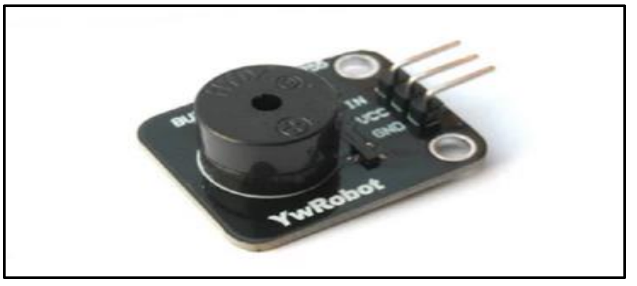

Figure 5. Buzzer

3. System Composition

3.1. UAV System Development

Mainboard, Raspberry Pi receives information on each sensor, transmits the information in real time information and makes the output of ultrasound in the buzzer. If the information sent from the camera module is transmitted to Raspberry Pi, it is printed on the screen in real time, using wireless communications.

In the PIR (Passive Infra-Red) sensor, when a wild animal is detected, alarm sounds in the speaker, instead of ultrasound, and images begin to be saved and recorded until there is no response. The recorded images are saved in the memory in Raspberry Pi for checking. Ultrasound is unspecific ally output through Raspberry Pi [7].

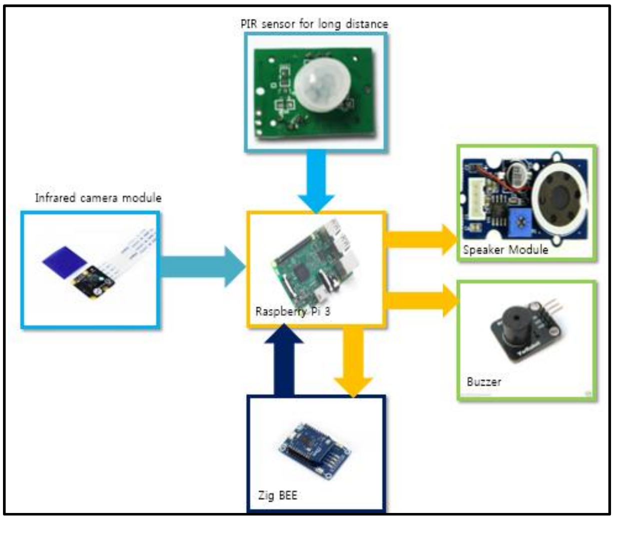

Figure 6. An Overall Configuration Diagram

3.2. Flow Chart

3.2.1. Mainboard

Raspberry Pi is a single-board computer developed by U.K. Raspberry Pi Foundation in order to promote the basic computer science education at school. Raspberry Pi 3 to be used in this study is equipped with 1.2GHz 64bit quad-core ARM cortex-A53. It basically supports low-power Bluetooth and wireless LAN. The mainboard receives all information from the sensors and images and changes the operations according to the value of the sensors by delivering commands again, and the ultrasound part prints ultrasound in the speaker randomly with a command entered to Raspberry Pi. All sensors are given values 8 seconds later, and they operate again according to the values [6].

Figure 7. Raspberry Pi3

3.2.2. Infrared Camera

In ordinary times, it prints the screen through Zigbee in real time, but if the PIR sensor detects a motion, recording begins for a certain time and images are saved in Raspberry Pi.

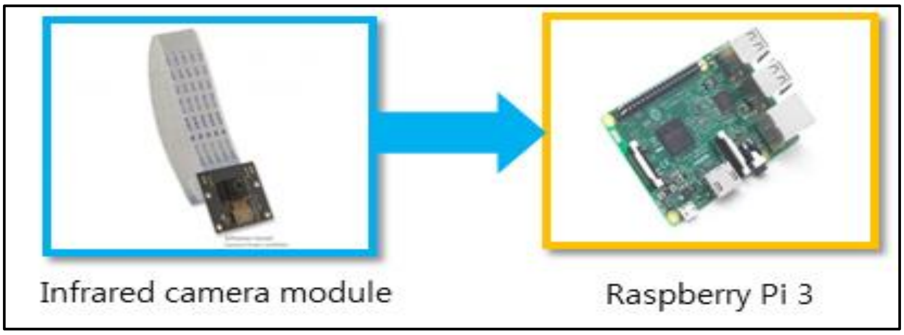

Figure 8. Infrared Camera Part

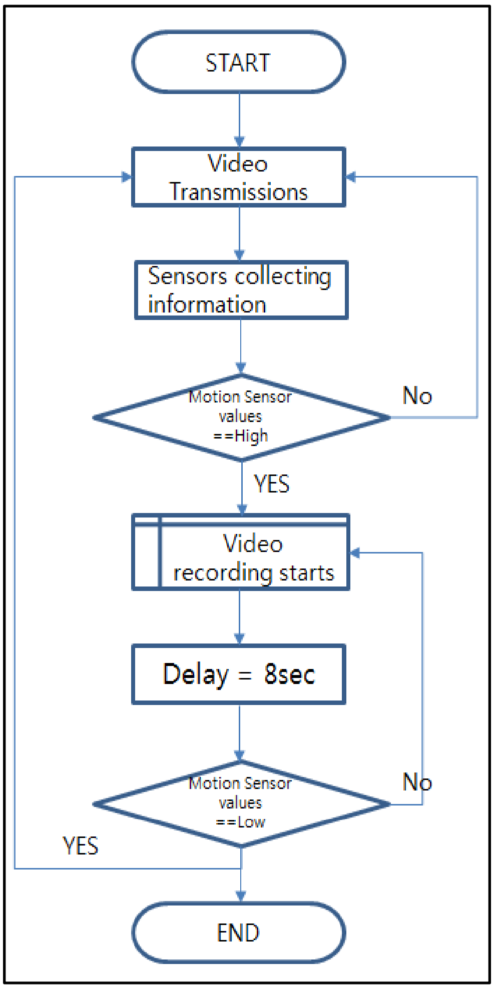

Figure 9. Algorithms of Infrared Camera and Mainboard

3.2.3. PIR (Passive Infrared Sensor)

Passive Infrared sensor part plays an important role. It detects a wild animal around that, and if one is detected, the sensor value appears to be high or low. It delivers the value to the mainboard, which gives commands to each module according to the value.

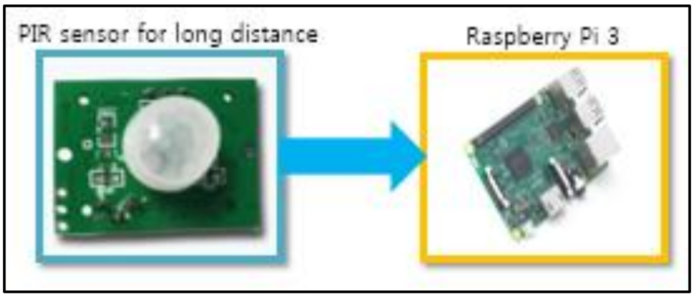

Figure 10. PIR Sensor Part

3.2.4. Ultrasound and Alarm Occurrence

The ultrasound randomly sent from the mainboard according to the given time is output with the buzzer. Unless the PIR sensor's value changes, it is output continuously, and if it is detected in the PIR sensor, ultrasound output stops, and alarm sounds in the speaker. The alarm outputs ultrasound through the buzzer again after a fixed time.

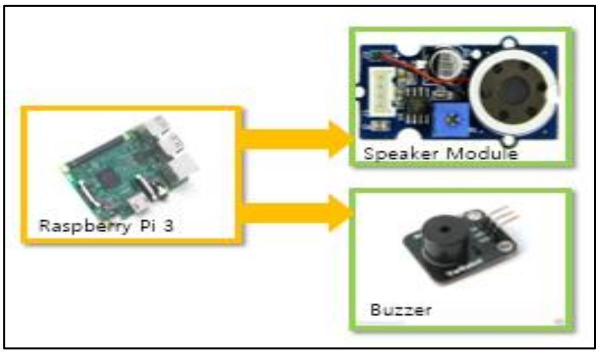

Figure 11. Ultrasound and Buzzer Output Part

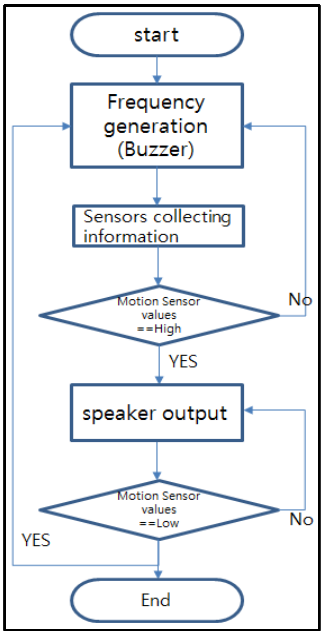

Figure 12. Ultrasound and Buzzer Output Algorithm

3.3. Surveillance and Access Prevention UAV

In order to develop a surveillance and access prevention UAV, attitude control is important. Since the attitude control allows safe UAV flight, this study conducted an experiment on the attitude control. Next, for a UAV for access prevention, Raspberry Pi was used. After installing various sensors in Raspberry Pi, ultrasound is output by putting a buzzer for access prevention.

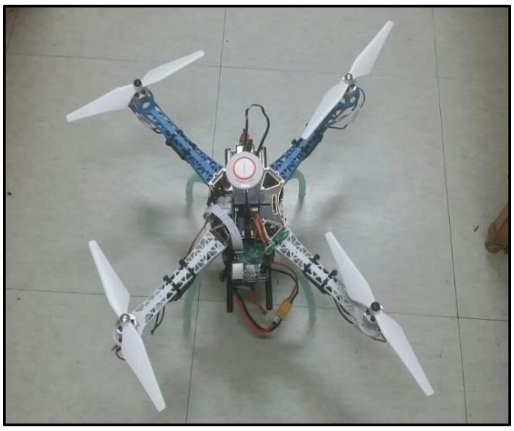

Figure 13. UAV System

Table 1. RCX S500

RCX S500 (PCB) UAV Combo			
Wheelbase	500mm	Battery	3S~4S 2200mAh
Height	170mm	Controller	TAROT ZXY-M
Weight	425g	Motor	2212 KV980

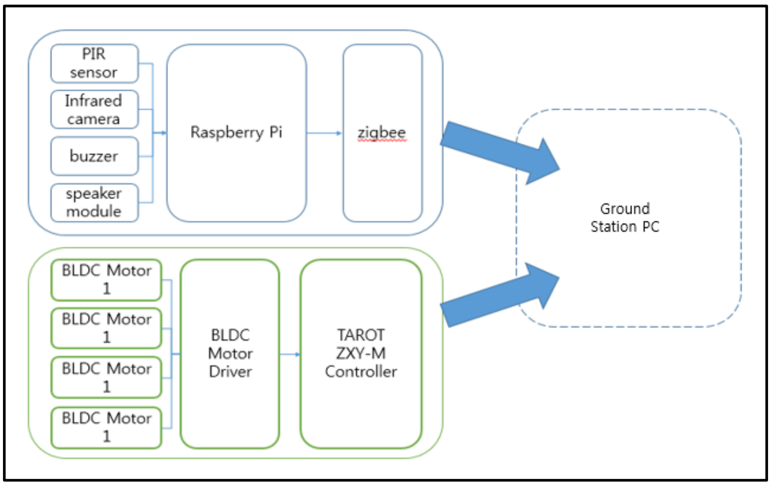

Figure 14. UAV System Diagram

3.4. UAV Attitude Control Test

For safe surveillance with a UAV, most of all, it should be able to be hovering for a long time. For safe hovering, Axes x, y and z should be freely controlled. Chapter 3 shows the values of position, translation, rotational energy for the UAV control in a formula, and using this, modeling of a controller design was conducted with MATLAB. When values are entered for positions x, y and z (5, 10, 15) and 1 rad is entered for a yaw angle, x, y and z are controlled like Figure 15. For fuselage angle, like Figure 16, it is noted that the direction seen from the fuselage converges towards the target direction, 1 rad in 0.5 seconds.

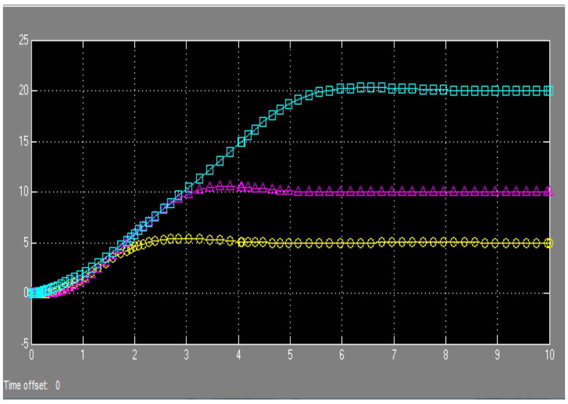

Figure 15. Simulator Value for the UAV Position

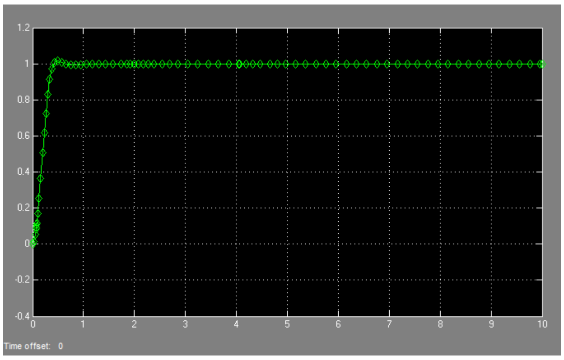

Figure 16. Simulator Value for the UAV Position

4. Conclusion

For surveillance and access prevention, this study effectively completed a controller for the angle and position of the fuselage for autonomous flying of a UAV using MATLAB, and based on a mathematical calculation formula, this study conducted an experiment so that the UAV could freely make a flight by giving proper signals to four individual motors and designing the controller. This study developed a UAV for a system that could prevent wild animal access to a certain range, generating and regenerating the ultrasound and ultra-low sound frequencies wild animals hate and prevent it effectively by sounding alarm with a buzzer if a wild animal access is detected, using an infrared camera in a certain range.

Acknowledgement

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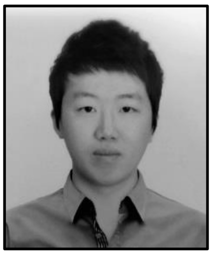

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