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Master-Slave Coordinated Following of Quad Copters
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Abstract - This study aims to develop an algorithm to make a slave quad copter follows a master quad copter while maintaining a constant distance. The computer helps to process the image captured by the Microsoft Kinect and then determine the position of color ball installed on both master and slave nano quad copters, Crazyflies. The user is able to adjust the X/Y set point of the master meanwhile the set point of the slave will change relative to the master such that a constant distance between the points are maintained. The control loop comprising of three PID regulators that will correct the roll/thrust/pitch is sent wirelessly to the Crazyflies via a radio dongle, Crazyradio. Lastly, the quad copter receives a series of commands consist of roll/thrust/pitch to attain a X/Y/Z set points in the image.

Keywords – Crazyflie; Crazyradio; quad copters; Microsoft Kinect;

1 INTRODUCTION
Applications such as rescue missions, searching, surveillance and data collection are desirable to use more than one quad copter [1]. This is because several workloads can be distributed across multiple quad copters. Without risking human lives, they can be accomplished with the help of master-slave approach such that a slave quad copter follows a master quad copter while maintaining a constant distance.

Previous research has been done on formation flight using micro quadrotors [2]. In the research, the flight performance of a swarm of quadrotors is promising, different types of flying formation are achievable with the help of VICON motion capture system. However, this contrasts with the purpose of nano quad copter that initially target on flying in a tight environment as installing VICON system requires a big setting. Moreover, one of the smallest of the nano quad copters in the world, Crazyflie [3], the flying behavior with the help of Microsoft Kinect has not been tested yet. For the next few sections, the terms “quad copter” and “Crazyflie” are interchangeable. Comparing with its larger counterparts, the formidable advantages of using this smaller size quad copter are due to the factors of manufacturing prices, the ability of operating in a confined space, the flying agility and the stability from crashing.

2 METHOD
The overall implementation of the application is based on the Figure 1. This vision based tracking control system application uses OpenCV as well as libfreenect for developing [4]. Some tunings and modifications need to be accomplished to meet the main objective.

2.1 KINECT SENSOR FOR TRACKING
The Microsoft Kinect sensor equipped with the RGB camera and infrared sensor will help to track the color ball installed on the Crazyflie for position estimation in the space [5]. White background is used so that no other objects of the similar tint will be picked up by the RGB image. This means that when another object of the similar color is kept along with the ball, the position is disrupted. The effective range of the infrared sensor is around 0.8 to 2.1 meters. At the maximum range, the RGB image is around 1.5x1.5 meters which is considered slightly small for flight maneuvering. Therefore, when the colored ball goes beyond the view of the Kinect, the motors of the Crazyflie will come to a stop. The images captured by the Kinect will be sent to the computer and they will undergo some image processing before the position of Crazyflie is identified as X/Y/Z coordinates in the space.

2.2 COMMANDS SENDING
Refer to the Figure 2, the computer calculates the error difference between the actual position and the set point

Figure 1 Vision Based Tracking Control System
Figure 2 Schematic Diagram
and then represents them into a series of flight parameters or commands. Three flight dynamics parameters, namely roll, thrust, pitch are responsible for its position in X/Y/Z coordinates in the space. It is reminded that yaw is not tracked. For instance, when there is a big error between the set point and the actual point in Y coordinate in the image, a larger absolute thrust offset should apply to drive the Crazyflie closer to the set point. Lastly, the control loop comprising of three PID regulators that will correct the roll/thrust/pitch is sent wirelessly to the crazyflie via a radio dongle, Crazyradio.

3 EXPERIMENTAL RESULTS AND DISCUSSION

In this section, the main concept which is image processing will be explained first and followed by testing with the single quad copter. Last but not least, the master and slave quad copter whereby the additional quad copter applies the same concept will be discussed too. However, leader-follower may require some additional work, namely multiple depth detection, adjusting the set point and the communication with both quad copters simultaneously and independently.

3.1 IMAGE PROCESSING

On average, Kinect captures 30 color streams frames per second. The computer will process these images so that the color of interest can be tracked. Consequently, the position of the color ball can be identify and represented in X/Y/Z coordinates in the space.

3.1.1 Depth Image

The Microsoft Kinect that equipped with the infrared sensor is capable of capturing the depth image of the specific color object. Therefore, even there exists another object with different color in the view of Kinect, the calculation of the mean depth is still working. The purpose of this depth stream is to detect the approximation of the distance between the Crazyflie and Kinect.

3.1.2 Threshold Values

The images will be converted to HSV color space as the intensity or value is able to distinguish the object from the background [5]. After setting the upper and lower bound of tint values of interest, a gray image is obtained. These values are tweaked so that RGB image is able to pick up the red and blue color ball installed on the master and slave Crazyflies in the HSV space [6]. To enhance the prominent objects, opening morphological transformation is applied and performed by eroding of an image followed by dilation [7]. The figure below summarizes the threshold image processing.

3.1.3 Contour Extraction

The threshold image comprised of the intensity pixels is processed to extract the circle shape of the color ball. Firstly, the rectangle shapes are retrieved using the height and the width of the boundary points. Next, the circle contour is constructed after the center point of the rectangle is calculated. Therefore, if the color of interest is detected, an adjustable circle shape will be created.

3.1.4 X/Y/Z Coordinates

Depth image and the normal RGB image captured with the Kinect help to track the position of Crazyflie object in X/Y/Z coordinates in the image. The usage of depth image is to detect the distance between Kinect and the Crazyflie or Z position, whereas the usage of RGB image is to obtain the X/Y position.
3.2 SINGLE QUAD COPTER

The results are promising. During the taking off as shown in Figure 5, the thrust offset is adjustable so that it enables the regulations to drive the color ball installed on Crazyflie to meet the green center set point. As shown in Figure 6, the Crazyflie pilots swiftly to reach the green set point whenever there is a sudden change of it.

Figure 5

As explained in the previous section, the Crazyflie pilots towards the X axis by increasing the magnitude of the blue plot corresponded to its roll and the magnitude of the pink plot corresponded to its thrust of motor as shown in Figure 7.

Figure 7 Stabilizer of Pitch, Roll, Thrust

3.3 LEADER FOLLOWER QUAD COPTERS

As shown in Figure 8 and 9, the results are considerably successful. Refer to the legend in the Figure, the positions of the master and slave are identified with the help of the depth and the X/Y coordinates. The key concepts will be explained as follows.

Figure 8 Master-Slave Tracking Points 1

3.3.1 Multiple Depths Detection

As there are multiple Crazyflie objects, morphological filter and masking are applied for detecting multiple depths of the objects. Firstly, the dilation image is obtained as explained in section 3.1.2. This dilation is masked with the depth image so that the depth of the red colored ball installed on Crazyflie is revealed as explained in section 3.1.1. The figure below shows the process of obtaining the depth of the red color ball only.

Figure 9 Master-Slave Tracking Points 2

Figure 10 Multiple Depths Image Processing

3.3.2 Multiple Communication

When using one radio dongle, Crazyradio for multiple Crazyflies, the bandwidth will be shared among the connections. Furthermore, the current implementation of Crazyradio requires 1 to 2 milliseconds for switching between the channels. Therefore, there is a need to use
2 Crazyradios for establishing the connection with master and slave independently and simultaneously. For instance, this is accomplished by setting up the both Crazyflies with different channels with the radio link as //0/channel0/bitrate and //1/channel1/bitrate respectively.

3.3.3 Multiple Set Points
Additional set point of the Crazyfly (slave) is configured such that it maintains the constant distance with the master set point. Dragging of the set points function is also taken care of. Therefore, when the master set point is being dragged, the slave will maintain a constant distance with respect to the master so that the collision can be avoided.

4 CONCLUSION
The autonomous pilot of the master-slave nano quad copters with the Kinect is fairly successful and stable. Kinect sensor acts as an outstanding tool for developing the quad copter as it is capable of capturing the depth image. The wireless centralized commands via the radio dongle, Crazyflie is an impressive communication and yet cheap wireless module that is applicable to other project as well.

In the future work, the regulation and image processing should be improved to be more robust. Moreover, camera module together with OpenCV tracking could be implemented on quadcopter to get a wider exploration space than using Kinect.

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