Research on Ultrasonic-Based Dynamic Adjustment System of UAV 3D Reconstruction Path Planning

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Abstract

In this paper, we have propose a system which is base on ultrasonic sensors to let Unmanned Aireal Vehiche (UAV) judge the complexity about the next region it will fly over and on-time automatic change its partial flying path and camera shooting strategy.

Our system is mainly divided into three parts. The ultrasonic skensing part, the complex area size judgement and control strategy choosing part and 3D reconstruction model generating part. From section 4 to section 6 we have detailed explained all these parts' principle and how we implemented these parts in experiments.

This research is mainly focus on raising the drone's 3D reconstruction task's efficiency and the drone's power consumption. For verifying, we have done a simulation experiment in a physical engine. We have choose three main parameters in the Structure from Motion (SfM) reconstruction algorithm to help us to compare our proposal's result to other proposal's.

As a experiment result, we have done 5 times simulation experiments on each reconstruction target we choose. We have list all the result from our proposal and others' method's result. The result shows that on all the simulation experiments, our proposal has a better efficiency than other methods. The result means that with the proposal we mentioned in this thesis, the drone's efficiency during the building 3D reconstruction tasks can be raised. Also, at the flight times point of view, our proposal can cut the flight times, which means that can save more drone's power which is very important in drone system. As a conclusion, our proposal can make contribution on both drone's efficiency part and the drone's power saving part during the 3D reconstruction task.

Acknowledgments

I sincerly acknowledge my Professor Shigeru Shimamoto. In this two year, he has teached me a lot of knowledge of communication technology. He also has teached me the japanese way of living and working. Every time when I have some questions or misunderstanding on learning and researching, his door will often open for me to help me solving these problems and make my research better.

Also I will thanks the WASEDA University. As the first good station in my japan tour, this university gave me a lot of good memories. The course in this university is unique and good. It let me know the difference of japanese university's education and chinese universities'. It has bordened my horizen. I feel very satisfied during this two years.

Then I will thank my laboratory's classmates. Within this 2 years, each of them has teached me a class. They has let me know more of person. At technology area, I will specially thank my two friends Mr.Ying and Mr.Shi. Every time I have some bugs in my program, they will always help me. In conclusion, I have spent 2 very good years here. I love here.

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Chapter 1

Introduction

Nowadays, the development of drone technology has been fast impromented. Drone has been used in many industries and there are so much usecase of drone which help people raise there working efficiency. Such as package develivery, 3D mapping, lost people finding, law enforcement and building damage detection etc, drone helps works a lot to make there job done quicker and better.

Within these unmanned aerial vehicle (UAV) technologies, drone 3D reconstruction is very import and integrates many aspects technologies such as wireless communication, remote conrtolling, 3D reconstruction algorithm etc. In this research we want to focus on UAV's path planning while in 3D reconstruction task.

In this paper, we have presentated a system which is base on ultrasonic informat ion to let UAV can automatically on-time adjusting its carried camera's photo shooting strategy and partial on-time changing its flying path. After using this system, the drone can take a better photo set which can genetated into a better 3D reconstruction result within one flight. Our system can not only raise the drone's 3D reconstruction task's efficiency but also can consume less energy than other higher level sensors. We have also presented a simulation experiment result which can show that our proposal can have a better reconstruction efficiency.

1.1 Motivation

In UAV 3D reconstruction field, there have already been many researches. XiaoCui Zheng et al[4] have been proposed a a "S" shape-based path planning method which can fully overlap the target building and take a shortest route. Maria Torres Anaya et al[5] have proposed an algorithm which can calculate best fly path to fully cover the target surface which is also based on "S" shape route planning.

We found that nearly all the researches are focus on how to make drone fully cover the target's surface which is focusing on the cover rate or they are focus on how to make drone has a shortest path to have a most optimized solve. But all the path planning are all base on "S" shape flying path. Drone is not a train, we think its toute could be more flexiable. Even it not flying on the curve line but it can also have some circle partial flying route. So we think we can change the traditional "S" shape path planning method and create a new system which is a modify of "S" shape path planning method.

1.2 Problem Statement

There are two main parts in our system:

- How to make our system can on-time adjusting path and photo shooting.
- How to make our system consump less power to achieve this goal.

To solve this problem there are many researchers propose a lot of studies to use many high level sensor or camera to achieve this. For example, . Hu, Y. Niu, et al [6] has propose to use depth camera to make drone detect the complex area first and mark all the complex area then make another flight to make drone take more photo on these complex area. H.Wang, H.Li et al [7] has proposed a method to make a drone can fly a shortest path to reach all the area to take photos for saving drone's energy. But these methods are all have some drawbacks. First, the depth camera cost a lot of power and it is very heavy and expensive which is bad to drone's payload and finanacal cost. Also, these proposal can not make the drone can on-time change its flying path, the drone can only setting path first and then flying on a fixxed path. Then, they can only achieve their proposal at least 2 times of flight. So we think there proposal is not very good. Out problem will be how to make drone finish on-time adjusting and achieve the requirement within one flight.

1.3 System Overview

Since our poposal is using ultrasonic sensor to let UAV knows the situation it will fly over. So we consider this system will need 3 main parts:

- Complex area sensing part.
- UAV Partial controlling part.
- 3D reconstruction result geneerating part.

The first step is area complexity detection. Compare to electronic wave, it has better physical wave characteristics, directionality and reflection ability. By using its good directionality characteristics, it can be used for detection area complexity[8]. When ultrasonic wave hits a smooth surface with a big incident angle, it will reflect away and never back to sensor itself. But if wave hits a denser area with the same incident angle, because of complex surface is construct of different surface angle. These angle provide perfect reflect condition to the wave, and part of wave will reflect the sensor itself. According to this principle, a drone can perceive tether there is a complex surface of objects in front its flight path.

Since the ultra-sonic sensor can return dense area sensing information, according to this principle, a drone can perceive whether there is a complex surface of objects in front of its flight path. Through the time and the average processing of sensor's returned value. By setting the threshold, drone can judge whether it is about to fly over a complex surface. As shown in the figure 1-1 and figure 1-2, when the ultrasonic wave hits the complex area (shown as grey brick) it will gives the drone a effective feedback. And drone will automatically raise its camera photo taking rate (shown as purple dot which means the position camera take a photo) then the drone can automatically take more photo along the complex area. When the complex area is much bigger, only taking more photo alone the path is not enough. Then the drone will automatically calculate a diameter and make a circle flight path during this partial area to make the photo set can get a better reconstruction result.

On 3D reconstruct result generation part, we consider to choose Structure from Motion (SfM) algorithm. This algorithm can identify the order of all the disordered picture sequence and reconstruct a 3D model result base on the reordered picture sequence. Nuimnbili, Penjani et al[9]. has proposed some approaches and application of the SfM algorithm in 3D reconstruction part. SfM algorithm is quite stable and widely used in building 3D reconstruction tasks. We have chosen this algorithm so that the result can shows the difference of the photo set which token in our proposal and others' system. Using this algorithm we can make our test result more representative and have more reference value.

1.4 Paper structure

In this paper we introduce our new proposal in 3D reconstruction path planning algorithm. This thesis has been divided into 11 sections.

The first part is the introduction. In this section, we have give a bref description of why we want to do a research on thsi topic, the main problem we are facing to. Then we briefly introduced our system structure, which is how this system constructed of and how this system works. In the second part we have introduced some related researches which are focusing on UAV 3D reconstruction technologies area to show that our research is very new, has a better point than others' proposals and has reference values. At third section, we gived a brify system structure flow introduction to let you know how every part in out system in section 1 has linked together and base on which principle they word together. From seciton 4 to section 6, we gived a very

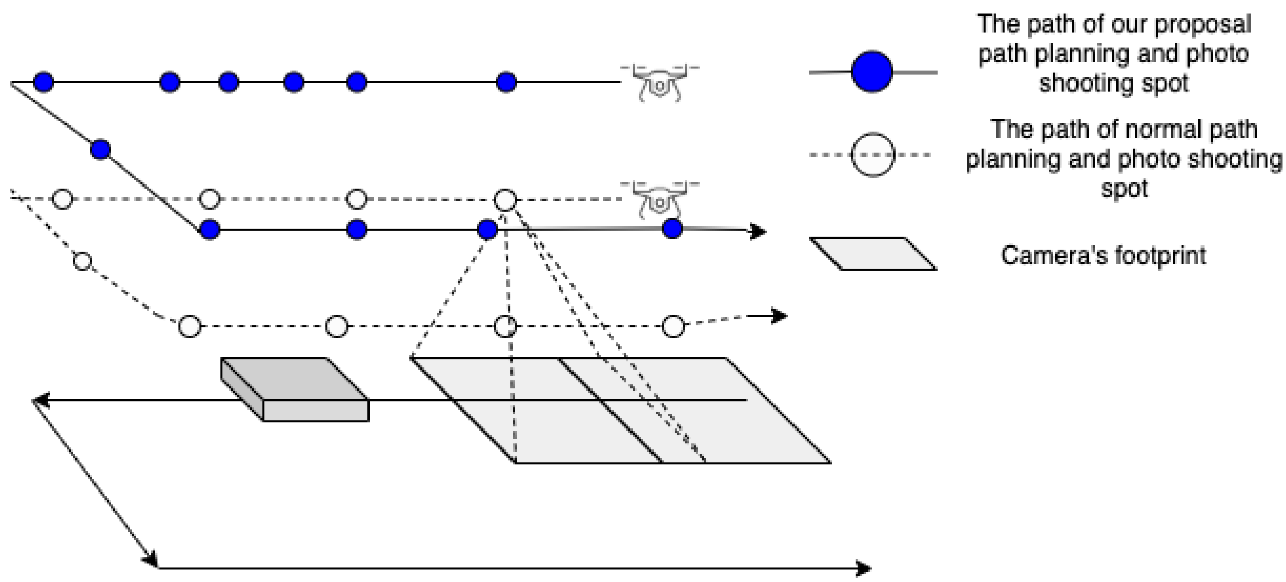

Figure 1-1: The strategy when the drone facing a normal size complex area.

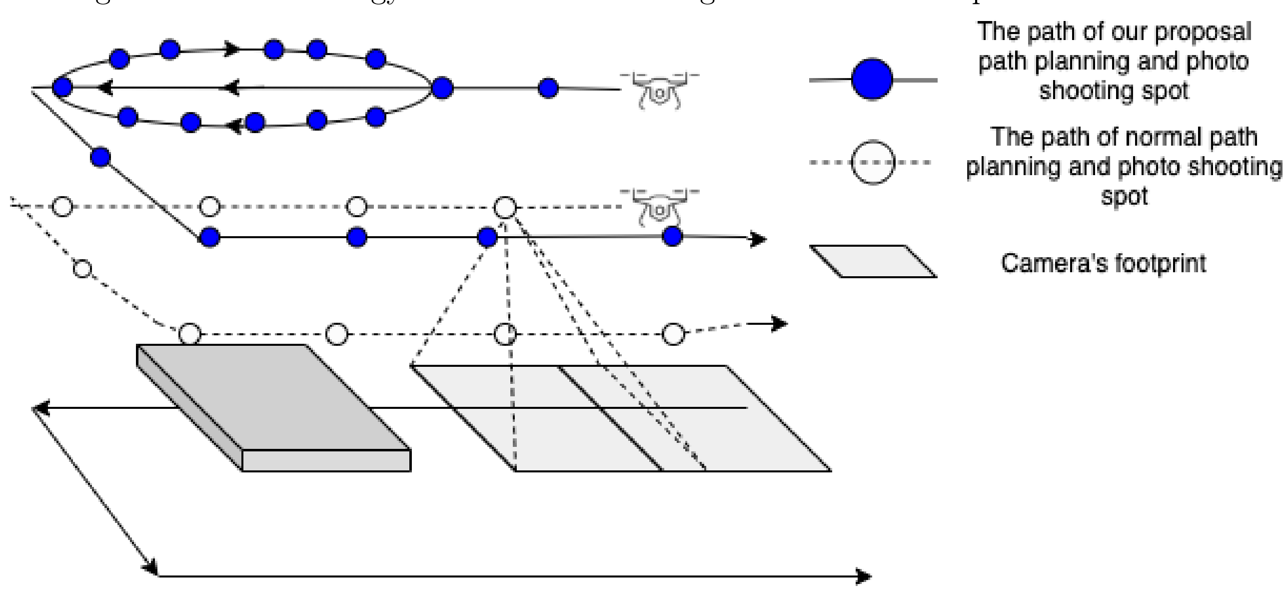

Figure 1-2: The strategy when the drone facing a large complex area.

detailed of our proposal system model and how we achieved every part in technology visual. We introduced the principle we design each part and how we use technology to achieve very part's function. At section 7 we gived a simulation experiment result to prof that our proposal has a higher efficiency. Section 8 we explain all the results and at section 9 we make a brief conclusion and gived some possible future improvment work. On chapter 10 is our references.

1.5 Conclusion of this sector

In this section, we have give a briefly introduction of our proposal. We have demonstrate our motivation about why we want to do this research. Also, we explain the main problem we a facing to. We give the easy explaination of our system to let the reader know what our system is mainly about. We also give a brifly structure of this paper.

Chapter 2

Related Research

2.1 Releated research on path planning

In UAV 3D recosntruction area, there has been already many researches. These researches can be mainly divided into these different catigories:

- Research on 3D reconstruction image processing algorithm.
- Research on using high-end sensors to achieve 3D reconstruction.
- Research on UAV path planning algorithm.

First, the most popular research focus point is 3D reconstruction algorithm. Because the 3D reconstruction in UAV system is not completely same to normal photo based 3D reconstruction system. So many researchers have made some optimization on this area. Yong-Bo.Chen et al. has proposal a method of UAV path planning based on optimization of control.[10]

Second, on how to make UAV smarter in 3D reconstruction task, many studies are focusing on how to use high-end technnologies such as depth camera, 3 domains Lidar, mili-wave sensor, etc. These high-end technnologies are main stream of how tech development. By using these sensors, the drone can know more information than before, also how to fusion these sensors, how to processing these different style of information is also a problem. Myungseok ki et al has proposed a algorithm to use sensor fusion to make drone to do the obstacle avoid sysetm[11]. But we consider that these high-end technnologies on the drone have a big drawback point, they consump power too much and power is very precious in drone system. So a lower power consumption solution is also worth considerable.

Third, there are some studies are focus on how to optimize a UAV path planning algotirhm to make drone can have a better efficiency. There have been some researchers have some proposals on this focus point. ZeFeng He et al, has made a compare of many drone path planning algorithm based on geometry search[12].

We have considered and review many researches on UAV path planning part and we have found some problems:

- None of them let the drone on-time adjust its partial path.
- None of them have used some sensor or other thing to help the drone.
- The camera shooting strategy are not been considered in the system.

By the influence of three problems mentioned above, we think it can generate many problems. First, the drone's path is fixed at the first time. They has proposed many algorithms to make the drone fully cover the target building or safely fly around the building to avoid the obstacles. Or they make the drone fly at least 2 times, first time to let the drone using its captured visual information to judge all the complex area distribution. Then they start calculate the best flying path based on the complex area mapping. After all, all the research around this topic are all about how to fully cover the target surface in nearly all the conditions.

2.2 Conclusion of this sector

In this chapter we have give a introduction of others' proposals on UAV 3D reconstruction path planning method. we explain the focus points of their proposals. By compare others' proposal researches to our proposal method. We can demonstrate the better point of our proposal method, which gives out our proposal's main contribution: The efficiency raising on drone's single flight. And the power consumption reduce due to the reduce of number of flights.

Chapter 3

Proposal and System model

3.1 System Structure

In this section we will explain our proposal's system structure in detail. As mention above, In order to make drone can automatically on-time adjust its flying path and adjusting camera photo shooting stategy, we consider our system has three main parts which is "Complex area sensing", "Partial strategy on-time sdjusting" and "Reconstruction result generating". About how these three main part work we will give a detailed demonstration.

3.2 Complex area sensing

As we all know, the target building's surface can not be fully smooth, there are serval things no matter it is decoration or functional. For example, a lamp, a window or a pipe. In normal way of 3D reconstruction task, the drone are using a fix photo shooting rate to take picture. That will cause a phenomenon that within a unit length of area, no matter it is a very surface area or a very complex area, the number of photo around these area in the final photo set are the same. But in 3D reconstruction algorithm, there is no need to have so much photo around a not very complex area and there is also need very much image information around a complex area. But if the UAV keeps using a fixed flying path and fixed photo shooting rate. In the very

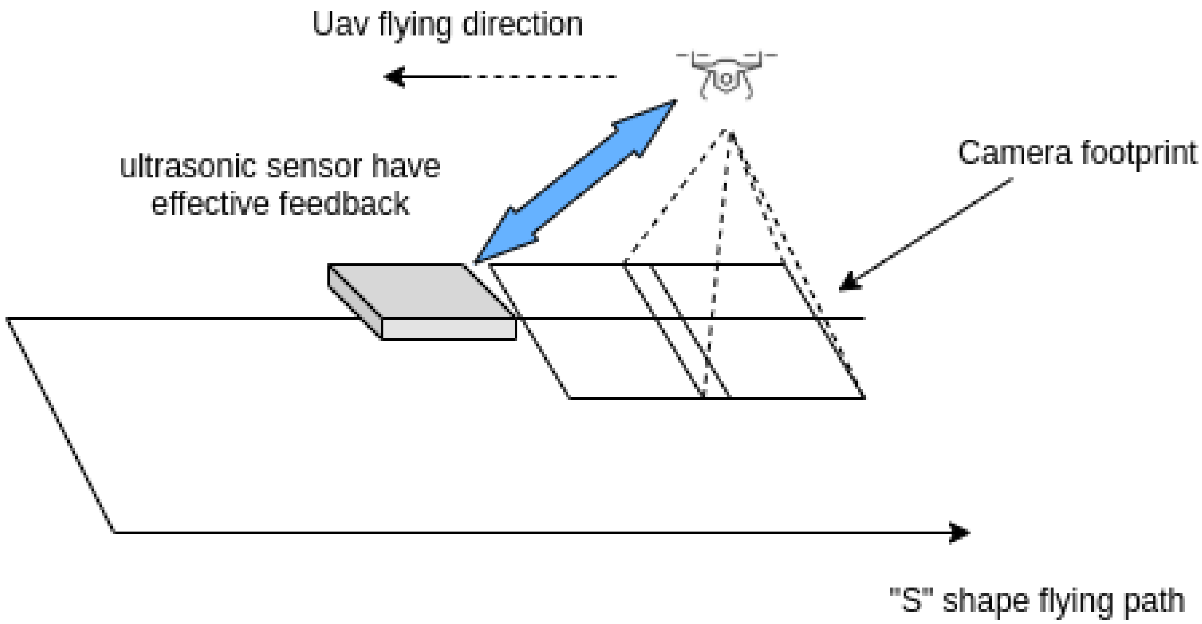

Figure 3-1: The implementation of ultrasonic sensor. (Blue arrow shows how we want to use ultrasonic to sense the complex area.)

smooth area, there will be a waste of photo shooting and calculate resource and in the very complex area there will maybe not enough image information and it will cause a damage to final reconstruction result[13]. So that will shows that how important a flexable partial path planning and a flexable photo shooting rate adjustment system are.

To achieve this target, we consider to add some sensor on the drone to achieve this target base on sensor's feedback information. But we do not want to choose a very high-end sensor. First reason is there already sombody has done some research of implement these high-end sensor on the drone. Second, a more important reason is we think that these high-end sensor's power consumption is too high it will affect the drone flying so this is not very good to adding on a drone. Also, the dron carry computer can not has too much power cosumption so the computer calculate ability is also not very propable for a high-end sensor. Then is high-end sensor's feedback information such as depth camera is too big. It will take too much communication bandwidth. By the way these kind of sensor such as Lidar are too heavy so it is not very good we think.

We consider to use a ultrasonic sensor. We choose this kind of sensor because the ultrasonic wave has a very good derectionality and reflection ability. In a big incidence angle situation, when the ultrasonic wave encounter a smooth surface, it will bounce to another direction and the ultrasonic sensor will have a not effective feedback data. But if a ultrasonic wave encounter a very complex area, it will bounce back to the ultrasonic sensor, and the ultrasonic sensor will get a effective feedback data[14]. So we think we can use ultrasonic sensor with a big incidence angle implement system to achieve our goal like in the figure 3-1 which the blue arrow shows how we want to use ultrasonic sensor to sensing the complex area.

3.3 Partial strategy on-time adjusting

Since in last section we have demonstrated that by using the effectiveness of ultrasonic sensor's feedback data. But only let the drone know it will fly over a complex area or not is not enough. Because between complex areas are not always the same. For example, the situation of drone flying over a lamp and the situation of drone flying over a window have a lot difference. The image information demandation between this two situation is also not the same. So we think to different situation, we need to let drone have different ways to deal with it.

Now, we have setting two difference ways to deal with different situations. We have divided the different situation into two main catgories, very simple in big and small by area's othogonal length. When the drone flying over a small complex area, because compare to normal photo shooting way and flying path, the drone only needs to shoot more photo to raise the amount of image information when the final photo set goes into the 3D reconstruction algorithm. So we think in this situation, the drone only needs to raise its photo shooting rate to make sure that it will get more image information data while flying over this area and no need to fly back.

To the second situation, when the drone flying over a larger complex area. We consider compare to the situation of flying over a small area, the drone simply increase its photo shooting rate is not enough. Because icreasing the photo shooting rate can only increase the amount of image data on a linear region. But maybe a linear region of a large complex area is not enough, it can not contain all the complex region. So we consider that let the drone fly a partial circle flying path when detects a large complex area by measureing its orthogonal length. We think it is enough to let the drone have two different method while it flying over a complex region during a 3D reconstruction task.

3.4 Reconstruction result generating

Since in the section 1 and secton 2 in this chapter, we have already demonstrate that we can use a ultrasonic sensor to detect a complex area and also we can have two different method to deal with different complex area size situation. So in the third section we will talk about the 3D reconstruction we use after the drone acquire enough photos.

During the 3D reconstruction result generating part, we choose a very classic algorithm, the "Structure from Motion" aka "SfM" algorithm [15]. The reason why we choose this algorithm is because this algorithm is widely use in 3D reconstruction area[16]. It is very stable, very representative and has lot of reference information. We consider that using this algorithm, when we compare our result with others' it will be more reliable. Because everybody's reconstruction algorithm are all slitely different, so we choose a most representive one to make our research have more representative. Also there are many research have made some modify on the SfM algorithm, but because they did not submit the original code so we can not re-implement it. But we think we use the normal SfM algorithm is already enough to show our system is better.

3.5 Conslusion of this sector

In this sector we have brifly explain the three-part model of our proposal system. To make the reader get a more clearer we also give some figures to demonstrate the system. First we have briefly introduced the system's stucture. Then, we introduce the complex area sensing, partial strategy on-time adjusting, reconstruction result generating. Every part looks like not very complicated, but they are all very important in this system. But in this chapter we did not give how we implement every part and the detail we want to make these part. In next chapter, we will detailed introduce how we have made every part and the how these part and the how these part works in detailed.

Chapter 4

Stage I: Ultrasonic Complex Area Sensing

In this chapter, we will detailed introduce our Ultrasonic-Complex-Area-Sensing part. We will start from the principle and the specific information about how we realize all the things.

4.1 Principle

In this little section, we will introduce our principle based of ultrasonic area sensing part. We will introduce our physics base about why we choose the Ultrasonic to be the main sensing part in our system.

4.1.1 Introduce of ultrasonic wave

Ultrasonic wave is a kind of wave which transmitt by the vibration of air. Its frequency is much higher than human possible hearing range. Human hearable vibration range is between 20 - 20000 Hz and ultrasonic's vibration rate is over 20000 Hz. With a very good derectivity and reflection ability, it is very easy to concentrate the energy. It can transmit more far in solid than transmit in air. It has been widely used in many aspect such as range sensing, speed sensing, cleaning etc [17]. It has been named by its lower freq is higher than human highest hearing rate.

Since ultrasonic wave have a good reflect ability, so we consider we can use it to achieve our cdomplex area detection work.

4.2 Specific implementation

In this section, we will introduce how we implementation the ultrasonic sensing which mentioned above into reality. We will introduce our chosen ultrasonic sensor model. Also we will produce our method to use this sensor to get the complexity result and how we gonna use this result. Although this ultrasonic sensor is not a very complex one, its low power consumption, very light weight and very easy usage are really what we need. For us, this is a perfect ultrasonic sensor[18][19].

4.2.1 About HC-SR04 ultrasonic sensor

HC-SR04 is a ultrasonic sensor which working frequence is 40 Hz and main function is range sensing. Its possible sensing ranging is from 0.02 to 4 meters. Its power input is 5 V DC. Its measuring angle is around 15 degree, trigger input signal is 10 uS TTL pulse signal and echo output signal is Input TTL lever signal and the range in proportion just like the infromation shows in figure 4-1.

HC-SR04 ultrasonic sensor is using a TTL pause signal to sensing the range which principle is shown in figure 4-6.

This sensor is also not very big, its dimension is around 45 * 20 * 15 mm. Like the sensor in figure 4-2.

4.2.2 About arduino NANO

Arduino Nano is one of products of a very famous development board serials. It is very easy to be implemented to the develop system. It use ATmega328 as its center processor[2]. Compare to the normal version of Arduino, it has nearly the same function. It also use a 5V DC power input and it works with a Mini-B USB cable.

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Figure 4-1: The main datasheet of HC-SR04 ultrasonic sensor.[1]

Figure 4-2: The main datasheet of HC-SR04 ultrasonic sensor.[1]

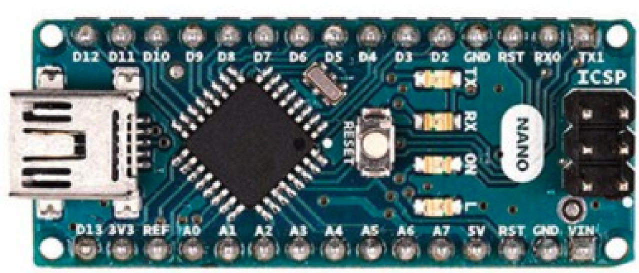

Figure 4-3: The outlook of arduino NANO board.[2]

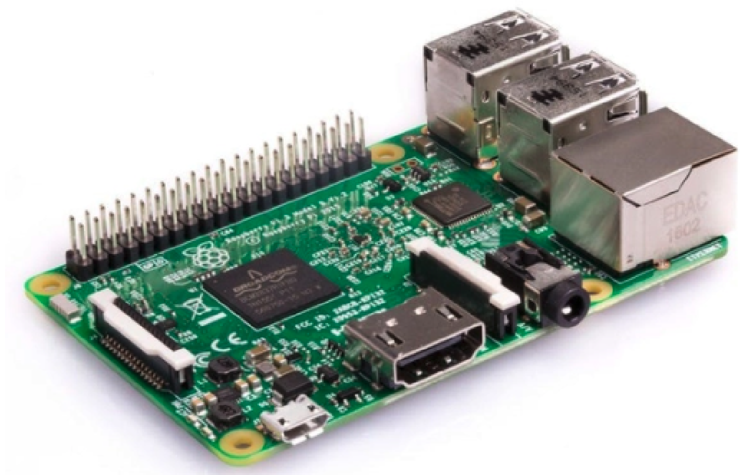

Figure 4-4: The outlook of raspberry pi 3B.[3]

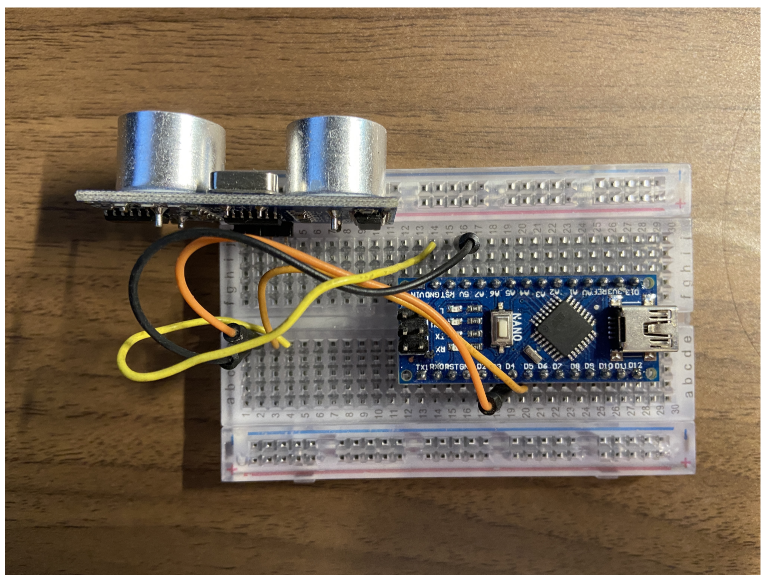

Figure 4-5: The linking part between arduino NANO and HC-SR04

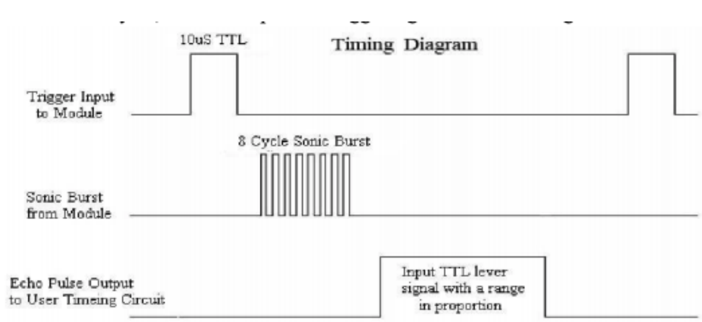

Figure 4-6: The demonstration of ultrasonic sensor's principle from its datasheet [1].

Arduino Nano is looks like the board in figure 4-3.

In our system, because we need a board to uncode the information back from HC-SR04 sensor and trans the sensor to computer or mini-computer like raspberry pi to process the data. So we use this arduino NANO as a bridge between the ultrasonic sensor and raspberry pi.

4.2.3 Raspberry Pi 3B

The computer we use to process the data from ultrasonic sensor and arduino is raspberry pi 3B model. Raspberry pi is the most popular mini computer used in lot of development area. The raspberry pi can be linked by bluethooth or WIFI. We use the SSH to link our raspberry pi which in the same WIFI network.So after the raspberry pi processed the data we can use the remote computer in the same wifi system to receive the data from the drone. The raspberry pi has a Quad Core 1.2 GHz Broadcom BCM2837 64bit CPU with 1GB RAM[3]. So it can not only run our ultrasonic data processing part but also can run the drone control program which we need. The Raspberry Pi 3B is looks like the board in figure 4-4.

4.2.4 Our sensing system construct

By combining the electronic components mentioned above. We have initially generated our perception system model. The main system model is looks like in the figure 4-5.

We have made some verification experiment of using big incident angle to use ultrasonic sensor to detect the complex area along the wall. The result shows very good. We use this system mentioned in figure 4-5 along a very smooth wall which have a white board, a door and some ditch between 2 piece of building materials. And this system is successfully detect all these parts with an incidence angle of 45 degrees. And the condition with over 45 degrees' result is better. While this system is about to over these complex area, the sensor can give a effective distance feedback signal. When the ultrasonic sensor is facing a very smooth area, it will always feedback 4000 mm result which is the maximum sensing range of this sensor, and that means it is an uneffective signal and that meas sensor did not detect a complex area.

So that verification experiment result means our guess at the first is right. We do can use ultrasonic sensor to sense the complex area along the building. So next step we need to change these complex area sensing result into drone partial control strategy.

4.3 Conclusion of this sector

In this sector, we gived our specific design about how to use ultrasonic sensor to detect the complex area alone the building's surface. We have demonstrate our system's conponent and also we explained how we link these electronic components together. We also did a verification experiment to proved that our system works and it can satisfy our demandation. But only have a system which can detect is not enough, we also need an algorithm to let the drone make partial strategy change while it flying over a complex area. So in the next sector we will demonstrate how we design the drone partial control part to solve our problem mentioned above in the first sector.

Chapter 5

Stage II: Control of partial path planning

In this chapter, we will introduce how we set the drone partial strategy when it facing different situation.

5.1 Principle

Since in the introduction section, we have already introduced that we consider the drone need to deal with the complex area into two main kinds. First is a small area of complex area, second is a large size of complex area. Divided by 1 meter length, if the complex area's length is between 0.25m   1m. it can be a small decoration or some other facilities. If the length can be over 1m that means the complex area can be a door or a window or some bigger parts.

Just like in the figure 1-1 and figure 1-2 shows, while the drone flying over a small size of complex area, it will only increase its photo shooting rate. But when it flying over a large size of complex area, it will not only increase the photo shooting rate but also make a partial flying path around the big complex area to get more information.

Algorithm 1: Partial flying path control

```
while While task not finished do
    "S" shape path flying;
    photo taking rate = 1 time per second;
    if 0.25 second(10 times) constant effective recall then
        photo taking rate raise to 3 times per second;
        effective recall counting;
        if continue 1 second(40 times) effective recall then
            One meter horizontal flight;
            A circular trajectory flight with a radius of 0.5 meters;
        else
            horizontal flight half meter;
            photo taking rate back to 1 time per second;
        end
    else
        "S" shape path flying;
    end
end
```

Figure 5-1: The strategy when the drone facing a normal size complex area.

5.2 Strategy choosing algorithm

The strategy choosing algorithm is as the algorithm shows in the figure 5-1. As we mention before the UAV choose the strategy by the constant time of effective feedback. Because the ultrasonic sensor we choose has a working frequency at 40 Hz so we set the threshold is 10 times constant effective feedback and the length threshold is set at 0.25 meters.

During the flying part, the drone is continue monitoring the incoming of the ultrasonic sensor's feedback information. When the drone receive a 0.25 second continue constant effective signal, it will aware that it will fly over a complex area. At this moment, the drone is about 1.7 second before it is directly over the complex area. So the drone can start raising up it photo taking rate after 1 second. We consider we need to make the drone raising its photo taking rate a little bit early before it directly over the complex area because the complex area maybe have a vertical height so that the drone can get the side photo information of the complex area when it raising its photo taking rate a little bit early.

Since the drone is already start have a higher photo taking rate before it fly over the complex area. We think when it fly over a larger complex area, since we consider only higher photo taking rate is not enough in chapter 3. We think the drone need to make a fully partial round flight path around the complex area. But how does the drone determined the size and the flying path of this partial area? We consider serval steps to let the drone decide it:

- First, setting the threshold value to judge the large complex area.
- Second, when constant signal over the threshold, start recording the length.
- Third, when the effective signal is over, circle fly at the diameter of the recorded length.

In our simulation experiment, we consider the threshold of judging a large complex area is at 1 second constant effective signal, which is 40 times constant effective signal. When the drone receiver a constant signal over this value , the drone can start recording its flying length, of course it will also count the already flied 1 meter. Then when it flying to the end of the complex area, it can started decide making the partial circle flying base on the diameter of the recorded length. This will make the drone take enough image information of the large complex area as we considered.

5.3 Conclusion of this sector

In this chapter we have introduce our control algorithm of partial path planning strategy choosing method and we have given our strategy choosing algorithm. We have explained why we considered there is two size condition of the complex area and what we need to deal with this two different size conditions of the complex area. Then we have given the pseudo code of our strategy choosing algorithm. Also we detailed explain our algorithm include the threshold choosing and how to decide the diameter length of the partial circle fight path planning. After that is our part of 3D reconstruction generating part. We will give the explanation of that part in the next chapter. Then we will give the simulation experiment and result in the chapter

7. The result of our simulation experiment will show our proposal can make a higher accuracy and efficiency to the task of building 3D reconstruction.

Chapter 6

Stage III: 3D Reconstruction Result Generate

In this sector we will demostrate how we use Structure from Motion to generate the photo set into 3D reconstructon model result and also we will explain how we consider our reconstructon result better or not compare to others' path planning method's results[20].

6.1 3D reconstructon algorithm

In this section we will explain the SfM algorithm and the method how we implemented it.

6.1.1 Introduce of SfM algorithm

Structure from Motion (SfM) is a very widely used photo detecting and 3D reconstruction system. It can auto detect the queue of all the photo in a photo sequence and reconstruct the 3D model by using the rearanged photo set. It is very widely used in many industries, it is very stable and very easy to be used[21].

Since we have already chosen our main 3D reconstructon algorithm, next step is how to implement this algorithm into our system progeam. For this part, we have chosen a open source 3D reconstructon platform which called Alice Vision. This platform is based on SfM algorithm and Multi View Stereo (MVS). It can generates a very high quility 3D models also it can combine GPU into this calculation to get a higher performance. Also this program is very easy to handle.

6.2 Method of result judgment

Since we have chosen our main algorithm and the method to implement it. Next is how we use this algorithm to shows that our method has a better result than others' path planning method's.

We all know that 3D model is constructed by mamy trangles. For example, computer only knows straight line but do not know the curve line[22]. Also it only knows plain surface but do not know curve surface. Also the computer 3D model rendering method is using triangle to construct all the complex model. So there is a conslusion that the more this 3D model's number of triangle which it is made of the more this 3D model has more detail and more accuracy.

In the struct from motion algorithm processing, there are a very important part which is called photo detecting[23]. In this part the algorithm will sensing in each photo and judge its position in the whole photo sequence by Scale-invariant feature transform (SIFT) algorithm. SIFT is an algorithm which is used for detecting the very feature point which can be representing the picture. Many research use these feature point to link two picture together[21]. Also in SfM processing. It will detect all the picture and judge its queue. But if in a picture there is not enough feature points to link this picture to other picture. This picture will be dumped because the computer is not sure where this picture should be. In this case, this picture's image data will not be counted into final 3D model generate part which means the data information in final 3D model will be lesser.

So based on the conclusions metioned above. We consider that we can use three main parameters to shows that our efficiency and accuracy is better than other's path planning method's results. These three parameters are:

- Photo detected rate.
- Total number of feature points.
- Total number of 3D model's triangles.

And we will give the result of these three parameters in the chapter 8.

6.3 Conclusion of thes sector

In this sector we have given a brief demonstration of which 3D reconstructon algorithm we want to choose and how we implement this algorithm into our system. We have Introduce the algorithm and why we want to choose that three main parameters. In next section, we will introduce how we done the simulation experiment.

Chapter 7

Simulation Experiment

In this chapter we will demonstrate how we done the simulation experiment and give a brief introduction of every part of our simualtion experiment.

7.1 Experiment environment

In our simulation experiment, we have use a lot of systems and programs to build out environment. Next we will introduce every one.

7.1.1 Gazebo physics engine

Gazebo is a physics engine designed for robot simulation. This physics engine has been certified by DARPA which means it is very trustworthy. It is very will designed which makes it possible able to test new algorithms and designs or even AI designs. It offers many models which is able to simulate accurately and efficiently in indoor or outdoor envieonments[24].

In our simulation experiment, we have use Gazebo's standard model library's House model. And all the drone's flying, the photo shooting and the target model we all conducted it in the Gazebo enviroment.

7.1.2 ROS melodic robot system

For the communication between sensors, raspberry pi and drone control board. We think that the ROS melodic system is the best choice.

ROS melodic system is the most widely used robot communication system. It is a simple subscribe and post system. For example, the sensor want to give center computer the sense data, it can make a post to the ROS core, and the computer calculate module can subsecribe this post from ROS core. Because in the whole system, there are many parts need to communicate to each other, not just dorne and sensor and computer calculate part. But also inside the drone, there are many part such as, motor, IMU, hight sensor, accleration sensor. So if we only write a system to link all theese part, it will be very complicated and not reliable. So we have chosen the ROS melodic system to make our system stable.

7.1.3 Mavlink

Mavlink is a drone communication protocol. Just like the protocol of ROS system. Its communication is base on the ROS communication way. It is also the public-subscribe sustem[25].

In this protocal, drones, ground control stations and other mavlink systems use the same generated libraries to communicate. This is fully opensourced and without any limits.

We use mavlink to connect our drone use the mavlink-python package and using the code below.

```
def connectMyCopter():
print('[method] connectMyCopter()')

parser = argparse.ArgumentParser(description='commands')
parser.add_argument('--connect')
args = parser.parse_args()
```

```
    connection_string = args.connect

    if not connection_string:
        import dronekit_sitl
        sitl = dronekit_sitl.start_default()
        connection_string = sitl.connection_string()

    #vehicle = connect(connection_string, wait_ready=True)
    vehicle = connect('tcp:127.0.0.1:5763', wait_ready=True)
    return vehicle
```

7.1.4 Ardupilot code set

Ardupilot is a widely used coding set which enable developers create very trustable auto vehicle. Such as drone, ship or UGV cars. Because it is fully opensourced, so it has a very good user community. Ardupilot is not produce any hardware, but it can be easy implemented on the Pixhawk control board. Since many good brand of drone has not opensource their code at all. So we consider to make our simulation environment, ardupilot is the best coding set we can use[26].

7.1.5 DroneKit library

Dronekir library is a very easy to hand on python library which can make us use python to link the drone and control the drone with ardupilot code set. Its only drawback is it can only works on python 2.x or C++. The code below is our coding to drag dronekit library to control the drone's flying.

```
from dronekit import connect, VehicleMode, LocationGlobalRelative
import socket
import exceptions
import argparse
from pymavlink import mavutil
```

Vertical distance from drone to wall	1.5m
Drone horizontal flying speed	1 m/s
Ultrasonic incident angle to the wall	60 degrees
Ultrasonic data sampling frequency	40 Hz

Table 7.1: Some parameters of simulation experiment

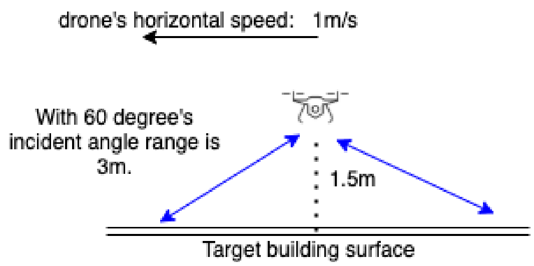

Figure 7-1: Schematic diagram of flight distance and measurement angle

7.2 simulation experiment

Since we have already introduced all the component packages we need to use, now we are introducting our spectific way to conducted simualtion experiment.

In this simulation experiment, we use gazebo physics engine and as a 3D reconstruction target, we have chosen the House 1 and House 2 model in the default model library. We let the drone fly alone the wall at a speed on 1m/s, and drone's vertical distance to the building structure's wall is 1.5m to ensure the enough range of area for camera taking one photo. Then we let the ultrasonic incident angle against the wall to be 60 degrees as we mention before we found that when incident angle over 45 degree the ultrasonic wave can sense the complex area. We have done the normal "S" shape flying path planning method and out proposal method each by five times. And we have record all the results. Table 7.1 shows the main parameters in the simulation experiment. The figure 7-1 is the schematic diagram of flight distance and measurement angle.

7.3 Conclusion of this sector

In this sector, we have introduced our simualtion environment setup and also introduced every tech components we need to use. In next sector, we will give all of our simulation experiment result and explain every result detailed.

Chapter 8

Results

In this sector we will give all the result of three parameters we mentioned before and we will give the explaination of each parameter.

We have done 5 times simulations on both model House 1 and House 2. The results for each of the key parameters mentioned above are shown in the three figures below.

Result in figure 8-1 is the result of image detected rate. During the 3D reconstruction algorithm, the photo set need to be queued into a right order first. This queue detection is mainly based on SIFT algorithm. By detect compare each photo's feature point and arrange pictures with the same feature points together. Then generate the model according to the parallax method. So around one complicated area, more photo has been taken means more common feature point can be detected. Because SfM only takes queue detected photo into 3D model generation part, so higher photo detected rate means more image information can be generated into 3D model. As figure 2 shows, on both two models, using our proposal system can always have a higher photo detected rate which means, the efficiency with the drone control by our proposed system is higher.

Result in figure 8-2 is the result of 3D point cloud's feature point number. Because it is not easy to objectively judge the pros and cons of 3D reconstruction results through observation. So we considered use this parameter as part of our result. The feature in 3D point cloud is not same with feature point in 2D image. During the 3D

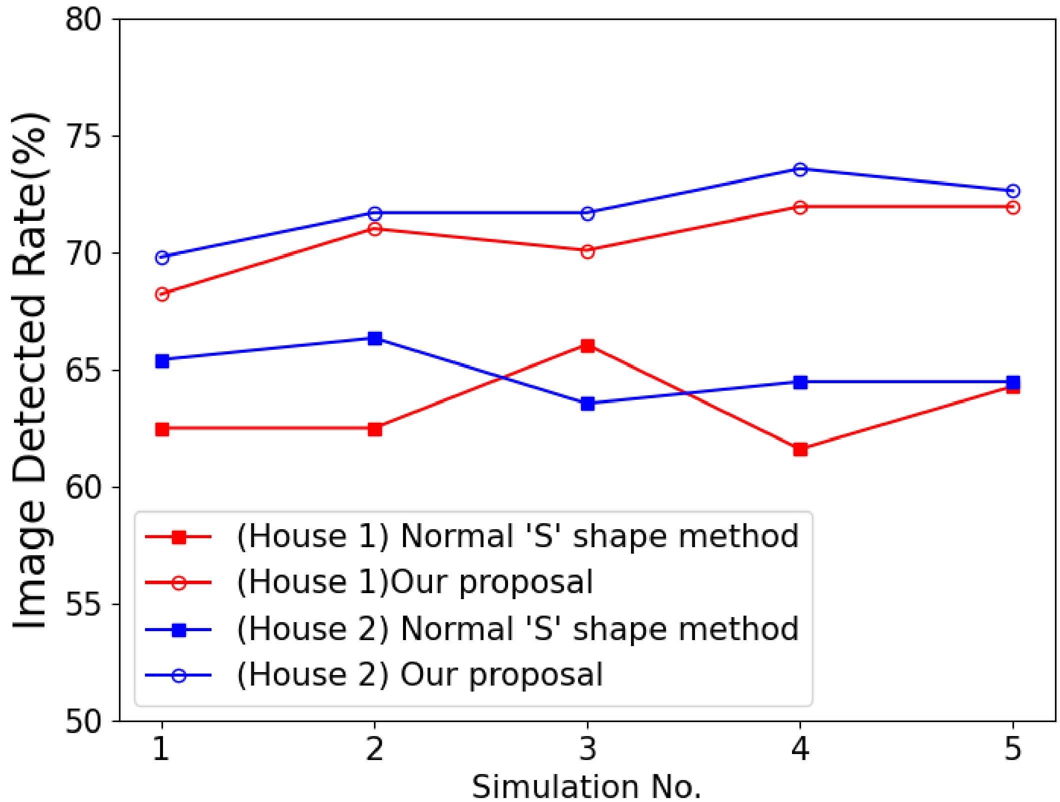

Figure 8-1: Result of image detected rate

reconstruction algorithm, it will calculate the 3D feature point by parallax first, then base on these feature point to finally generate the 3D models. So more feature point can be detected means that the algorithm has generated more information of target models from photos. Based on our simulation result, using our proposed system can also extract more information of target model than normal 'S' shape path planning method.

Result in figure 8-3 is the result of triangles number in the result models. Because the 3D model is not constructed by curve surfaces, all the curve surfaces is constructed by plain surfaces (triangles). So more triangles means the result is more detailed and more close to original model. Based on our simulation result, using our proposal system the number of triangle can average increase 10 percents. Which means our proposal does have a higher efficiency.

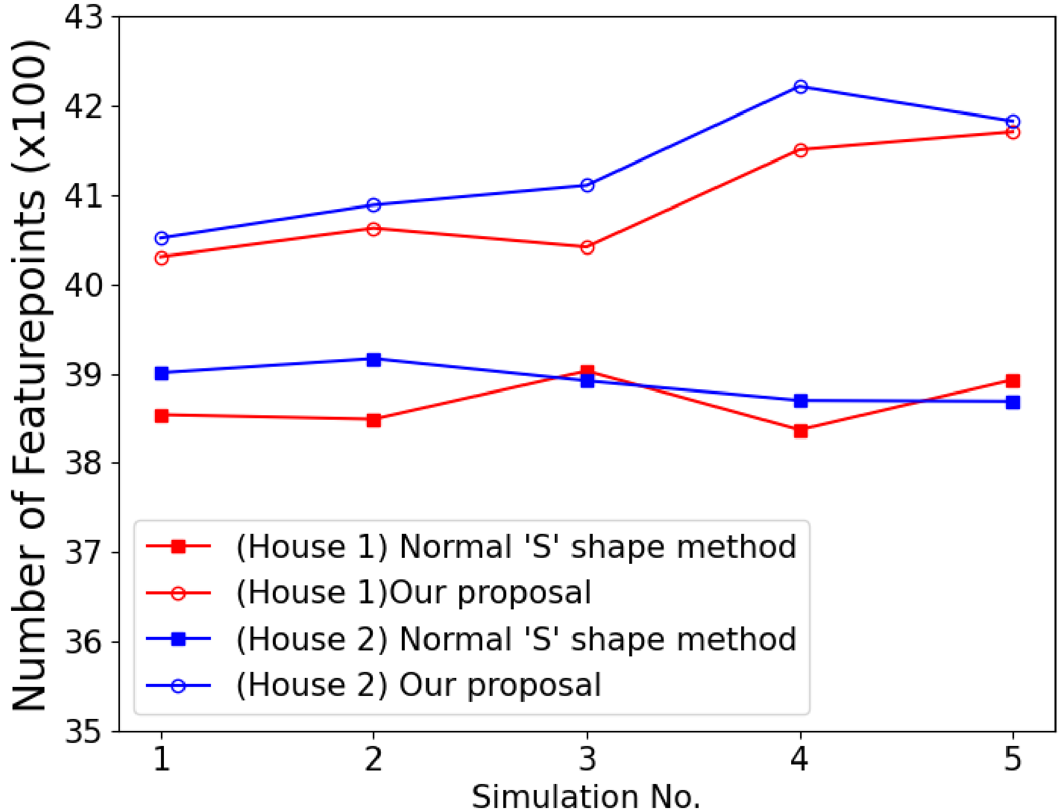

Figure 8-2: Result of number of feature points

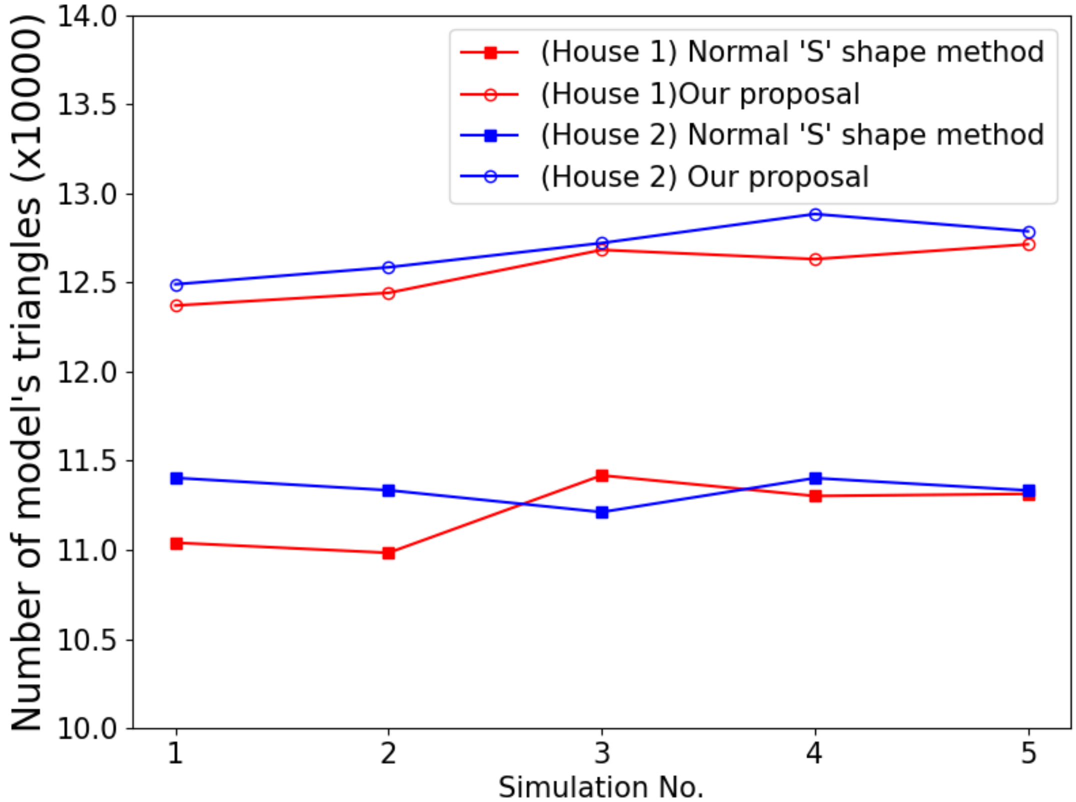

Figure 8-3: Result of number of model's triangles

As for power consumption part, compare to other researchers' proposed path planning method. Because by our proposal, the drone can finish taking more photo over complicated area within only one flight. But other researchers' proposal need at least 2 flight to achieve this goal. And HC-SR04 does not like other sensors, it has a very low power consumption only around 0.075W compare to other studies' using depth camera this power consumption is really low. So our proposal system can also help drone save the energy which is the most valuable resource in drone system.

These result show that compared to normal "S" shape fully cover path planning method, the photo taken by our proposal method has more efficiency and the result model is more accurate and more detailed [6] . Because our system is on-time adjusting the partial flying path and photo taking rate, so the dense area detection and photo taking can be completed with only 1 flight. It can make 3D reconstruction task cost less time and get higher efficiency. It can also save drone's power consumption because of less flight time.

8.1 Conslusion of this sector

In this sector we have given a detailed explaination of three results of three parameters we mentioned above. And all the result shows that our proposal has a better accuracy and efficiency compare to normal path planning algorithm. In next chapter we will make a brief conclusion of our research.

Chapter 9

Conclusion

In this paper, we have presented a UAV automatically camera photo shooting strategy and path planning system. We have explained out motivation of why we want to do this research is because we found that in other researches around this area, there is no research focusing on how to use least flight to achieve a higher efficiency. Then in the main part of this thesis we give the explanation of our three main parts of our proposal system. Also we have given the elaboration of how we implemented each part in detailed.

Then we explained that how we choosing the simulation experiment environment and why we choose these environment also we explained the hardware of the simulation experiment. Then we gave the simulation experiment's result on three parameters which we chosen as the key parameter of 3D reconstruction model efficiency judgement.The simulation experiment result shows that this system can make drone automatically shooting more pictures while it flying over a complex area of the building surface. The result shows that our proposed system can raise 3D reconstruction efficiency and accuracy in the reconstruction efficiency point of view. In the power consumption point of view, because using our proposal the drone can do the complex area focus image information taking automatically during only one flight and the ultra-sonic sensor is very low power consumption compare to other high-end sensors. So our proposal can also save the drone's power during the 3D reconstruction task, which is also raise the drone's power efficiency. Because after the simulation experiment, we consider we need to use the real environment other than the physics engine to verify our proposal so our next step is conducting experiment on a 650mm quad copter system and evaluate the result.

Appendix A

Code of dronekit-python control part

```
from dronekit import connect, VehicleMode, LocationGlobalRelative,
    APIException
import time
import socket
import exceptions
import math
import argparse
from pymavlink import mavutil

############# FUNCTIONS #############
def startit():
    a = input("Start")
    if a == "start":
        return 0

def connectMyCopter():
    print('[method] connectMyCopter()')

    parser = argparse.ArgumentParser(description='commands')
    parser.add_argument('--connect')
    args = parser.parse_args()
```

```
    connection_string = args.connect

    if not connection_string:
        import dronekit_sitl
        sitl = dronekit_sitl.start_default()
        connection_string = sitl.connection_string()

    #vehicle = connect(connection_string, wait_ready=True)
    vehicle = connect('tcp:127.0.0.1:5763', wait_ready=True)

    return vehicle

def arm_and_takeoff(targetHeight):
   print('[method] arm_and_takeoff()')

   while vehicle.is_armable!=True:
      print('Waiting vehicle be armable...')
      time.sleep(1)
   print('Vehicle is armable.')


   vehicle.mode = VehicleMode("GUIDED")
   while vehicle.mode!='GUIDED':
      print('Waiting vehicle be in GUIDED mode...')
      time.sleep(1)
   print('Vehicle is in GUIDED mode.')


   vehicle.armed = True
   while vehicle.armed==False:
      print('Waiting arm...')
```

```
        time.sleep(1)
    print('Vehicle is armed!!!')


    vehicle.simple_takeoff(targetHeight) #meters

    while True:
        print("Current altitude: %d"
            %vehicle.location.global_relative_frame.alt)
        if vehicle.location.global_relative_frame.alt >=.95*targetHeight:
            break
        time.sleep(1)


    print('Simple takeoff finished')

    return None

def land_down():
    print("Now let's land")
    vehicle.mode = VehicleMode("LAND")

#######send a velocity command with +x being head of the drone#######
def send_local_ned_velocity(vx, vy, vz):
    msg = vehicle.message_factory.set_position_target_local_ned_encode(
        0,
        0, 0,
        mavutil.mavlink.MAV_FRAME_BODY_OFFSET_NED,
        0b0000111111000111,
        0, 0, 0,
        vx, vy, 0-vz,
        0, 0, 0,
```

```
        0, 0
    )
    vehicle.send_mavlink(msg)
    vehicle.flush()

##############High level control funcs############
def move_front(sp, t):

    counter = 0
    while counter < t:
        send_local_ned_velocity(sp, 0, 0)
        counter += 1
        time.sleep(1)
        print("Moving front of drone")
    time.sleep(1)
    counter = 0
    while counter < 1:
        send_local_ned_velocity(0-sp, 0, 0)
        time.sleep(1)
        counter += 1
    time.sleep(1)

def move_back(sp, t):

    counter = 0
    while counter < t:
        send_local_ned_velocity(0-sp, 0, 0)
        time.sleep(1)
        print("Moving back of drone")
        counter += 1
    time.sleep(1)
    counter = 0
```

```
    while counter < 1:
        send_local_ned_velocity(sp, 0, 0)
        time.sleep(1)
        counter += 1
    time.sleep(1)

def move_right(sp, t):

    counter = 0
    while counter < t:
        send_local_ned_velocity(0, sp, 0)
        time.sleep(1)
        print("Moving right of drone")
        counter += 1
    time.sleep(1)
    counter = 0
    while counter < 1:
        send_local_ned_velocity(0, 0-sp, 0)
        time.sleep(1)
        counter += 1
    time.sleep(1)

def move_left(sp, t):

    counter = 0
    while counter < t:
        send_local_ned_velocity(0, 0-sp, 0)
        time.sleep(1)
        print("Moving left of drone")
        counter += 1
    time.sleep(1)
    counter = 0
```

```
    while counter < 1:
        send_local_ned_velocity(0, sp, 0)
        time.sleep(1)
        counter += 1
    time.sleep(1)

def move_up(sp, t):

    counter = 0
    while counter < t:
        send_local_ned_velocity(0, 0, sp)
        time.sleep(1)
        print("Moving up of drone")
        counter += 1
    time.sleep(1)
    counter = 0
    while counter < 1:
        send_local_ned_velocity(0, 0, 0-sp)
        time.sleep(1)
        counter += 1
    time.sleep(1)

def move_down(sp, t):

    counter = 0
    while counter < t:
        send_local_ned_velocity(0, 0, 0-sp)
        time.sleep(1)
        print("Moving down of drone")
        counter += 1
    time.sleep(1)
    counter = 0
```

```python
while counter < 1:
    send_local_ned_velocity(0, 0, sp)
    time.sleep(1)
    counter += 1
time.sleep(1)
```

Appendix B

Achievement

Y.Bai, K.Yoshii, S.Shimamoto "Ultrasonic Sensor Based UAV 3D Reconstruction Path Planning System" in 2020 IEICE Society Conference.

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