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<td><strong>Citation</strong></td>
<td>Chan, T. H. H. (2017). Real-time multi-sensory monitoring by automated routing of UAV in civil/building construction site and cavern development: To improve safety, health and productivity (Outstanding Academic Papers by Students (OAPS), City University of Hong Kong).</td>
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<td><strong>URL</strong></td>
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Real-time Multi-sensory Monitoring by Automated Routing of UAV in Civil/Building Construction Site and Cavern Development - To improve Safety, Health and Productivity

By

Tsz Hei Heison CHAN

Submitted in partial fulfillment of the requirements for the degree of Bachelor of Engineering (Honours) in Construction Engineering and Management

Department of Architecture and Civil Engineering
City University of Hong Kong

March 2017
Abstract

In every construction project, the requirements on time, cost, quality, safety and environment are stated that main contractor needs to fulfill these entire requirement and achieve on construction site. As the duration of construction project become more limited comparing to the past project completed with client’s requirement, so effective monitoring on work progress and worker’s productivity are the key elements towards success. Besides, multi-layer subcontracting in construction project leading an extra difficulty to project team to manage all the parties involved in construction site. In view of this, a new UAV application is designed and developed, with multiple cameras and sensors integrated to form the UAV system, in order to perform real-time monitoring with air pollutants and noise data collection, aims to provide an innovative and alternative way in monitoring work progress and construction site environment on designed user interface on different platform. This system can help to identify actual work progress, site safety and environment and potential danger for managers to improve safety, health and productivity of workers through real-time monitoring. Thus, numbers of future potential development are discussed to integrate with other innovative technology and apply more innovative technology into construction industry.
Acknowledgements

I would like to take this chance to appreciate my supervisor, Dr. FUNG, Ivan Wing Hong, Assistant Professor, Department of Architecture and Civil Engineering, City University of Hong Kong, for his fully support, encourage and guidance from idea development stage to its completion.

Also, I would like to express special thanks to professional for giving comments, advices in different stages in this project.

Mr. Lai Siu Kei, Peter General Manager, Safety Specialist Services LTD.
Ms. Chen, Weiyi Rebecca Student assistant in Building Information Modeling (BIM)
Mr. Patrick Yip Lab Manager, The Hong Kong Polytechnic University
Mr. Li Koon Wah Plant and Machinery manager, Shui On Building Contractor Ltd.
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CHAPTER 1 – INTRODUCTION

1.1 Background of study
Construction industry is different with other industry in Hong Kong. Construction industry is unique, complex and dynamic, every project with different scope, nature of work, size, locate in different area around Hong Kong, different ground condition and nearby environment, different types of workers involved and numerous parties involved in the whole process, these characteristics make construction industry more special comparing to other industries, which provide more static environment.

Moreover, in recent years, construction companies started to apply new technology on high-level automation method of construction in their project, in order to deal with more complex procedure or work. The construction activities will constantly change, for work that are more complex in nature, will expose to higher risk during the operation of construction process on the site at all times. The application of high-level automation method on construction will also bring greater potential risk to the construction site, which will affect the working environment.

From “Occupational Safety and Health Statistics 2015”, there are 3723 of industrial accidents in construction industry and 19 of the cases are fatal accidents, which the accident rate is 9.3% higher than the average of the previous five years (3339).

![Number of Industrial Accidents and Accident Rate per 1000 Workers in Construction Industry (2006-2015)](image)

Figure 1.1 Number of Industrial Accidents and Accident Rate per 1000 Workers in Construction Industry (2006-2015)
(Hong Kong Special Administrative Region, Labour Department, 2016)
For the fatal accidents, the number of fatalities in 2015 was 19, lower than 20 in 2014 by 5%, and lower than the average of the previous five years (22) by 12%. Also the fatality rate per 1000 workers of the construction industry in 2015 was 0.200, lower than the average of the previous five years (0.285) by 29.8%.

![Figure 1.2 Number of Industrial Fatalities and Fatality Rate per 1000 Workers in Construction Industry (2006-2015)](image)

(Hong Kong Special Administrative Region, Labour Department, 2016)

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Industrial Fatalities</th>
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<tbody>
<tr>
<td>2006</td>
<td>16</td>
<td>0.303</td>
</tr>
<tr>
<td>2007</td>
<td>19</td>
<td>0.379</td>
</tr>
<tr>
<td>2008</td>
<td>28</td>
<td>0.403</td>
</tr>
<tr>
<td>2009</td>
<td>19</td>
<td>0.376</td>
</tr>
<tr>
<td>2010</td>
<td>9</td>
<td>0.163</td>
</tr>
<tr>
<td>2011</td>
<td>23</td>
<td>0.367</td>
</tr>
<tr>
<td>2012</td>
<td>24</td>
<td>0.333</td>
</tr>
<tr>
<td>2013</td>
<td>22</td>
<td>0.277</td>
</tr>
<tr>
<td>2014</td>
<td>20</td>
<td>0.242</td>
</tr>
<tr>
<td>2015</td>
<td>19</td>
<td>0.200</td>
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Table 1.1 Industrial accidents in major industries (2009-2015)
Industrial Accidents in Major Industries (2009-2015)

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<tbody>
<tr>
<td><strong>No. of Accidents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Construction Industry</td>
<td>2755</td>
<td>2884</td>
<td>3112</td>
<td>3160</td>
<td>3232</td>
<td>3467</td>
<td>3723</td>
</tr>
<tr>
<td>Food and Beverage</td>
<td>7470</td>
<td>7541</td>
<td>7158</td>
<td>6216</td>
<td>5740</td>
<td>5566</td>
<td>5386</td>
</tr>
<tr>
<td>Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing Industry</td>
<td>1991</td>
<td>2009</td>
<td>2001</td>
<td>1944</td>
<td>1775</td>
<td>1787</td>
<td>1675</td>
</tr>
<tr>
<td><strong>Accident Rate/1000</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Construction Industry</td>
<td>54.6</td>
<td>52.1</td>
<td>49.7</td>
<td>44.3</td>
<td>40.8</td>
<td>41.9</td>
<td>39.1</td>
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<td>Food and Beverage</td>
<td>35.7</td>
<td>34.7</td>
<td>30.9</td>
<td>26.4</td>
<td>24.2</td>
<td>22.9</td>
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<tr>
<td>Manufacturing Industry</td>
<td>15.9</td>
<td>16.8</td>
<td>17.8</td>
<td>18.2</td>
<td>17.1</td>
<td>17.4</td>
<td>16.8</td>
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In Construction site, there will be numbers of parties involved in a project, which each party will have their own workers, management team and responsible person on site, for some extreme cases, there can be more than 100 parties on the site, so management is of utmost importance in the project, from planning, implementing to monitoring and controlling, each process will contribute great importance to fluent construction progress. In the four main elements, monitoring will act an important role in collecting the data, to rectify or providing solutions on problems raised, as the construction site is dynamic and unique, problems will likely be raised, and the managerial position need to give solutions to keep the work progress on track, to avoid any delay which will subject to liquidated damages.

In the site, the workers will have some poor performance or idle time presented, which these events not only affecting the efficiency of the workers and delaying the work progress, but also
leading to greater potential risk of accidents when workers not following the correct instruction to perform the work.

1.2 Project statement
Therefore, real-time monitoring is essential to apply in monitoring of the work progress in construction site. Traditionally, there is closed circuit television known as CCTV applied on the construction site, which these CCTVs were installed on the fencing or hoarding, the material storage area or inside the building in progress, then the manager could monitor the progress as well as the workers for their performance through these cameras.

Other than CCTVs, newly developed technology is introduced, which is aerial photography and videography. Such technology has a great potential in applying in construction site for real time monitoring instead of using CCTVs. Aerial photography is a new technology to provide photographer another application to take photos and videos of the ground from an elevated position at first, basically the user will control the cameras for capturing photos and videos. Normally aerial photography is applied in several aspects such as cartography, land-use planning, movie production, environmental studies, commercial advertising etc. It is seldom use in construction industry, the only major use is taking aerial photos by Survey and Mapping office of Lands Department, The Government of the Hong Kong Special Administrative Region. Therefore, applying aerial photography and videography is an innovated way provided to real-time monitoring in construction project.

There are several platforms for applying aerial photography technology, such as fixed-wing aircrafts, helicopters, unmanned aerial vehicles (UAV or drones), balloons etc, in this project, the uses of UAVs are introduced. UAV is an aircraft that without a human pilot on board, which can either controlled by operator, or set in an automated route by computers. It mainly used in military aspects for missions that are dull, dirty or dangerous, but recent years, there are applications on commercial, scientific, recreational and other application, which makes the use of UAV more popular in the society.
On the UAV, multiple sensors and types of cameras will be installed, not only for real-time monitoring, but also collecting air quality and noise data, which this technique is different from traditional method used in construction site, to monitor the working conditions as well as work progress on site.

**Main Concept of the project**

1.3 **Research Aim and Objectives**

This research aims to explore and develop the use of drone with multiple sensors and types of cameras attached in order to perform real-time monitoring for managerial position and also monitor the working environment by air quality and noise data, to let the managers to improve the working condition by relocation or make amendment on site layout, and to enhance the safety and health of workers. The following objectives are focused to achieve the major aim of the study:

1. To investigate and understand the working condition and safety and health problem in the construction site;
2. To provide overview of existing aerial photography technology applied in construction industry;
3. To introduce the application of UAV technology for real-time monitoring;
4. To investigate factors and elements related to air quality and noise level around site area;
5. To provide detail information on how the UAVs can be applied in different types of construction site, including Civil, Building, Confined space construction site such as cavern;
6. To introduce the computerized interface for showing the collected data, photos and videos in real-time for monitoring;
7. To investigate the feasibility of UAV technology applied in different types of construction site;
8. To identify the benefits and limitations and obstacles on applying automated UAVs with multiple sensors in different types of construction site; and

9. To study how the collected data, images and videos can be used for the reference materials as a database in future construction project.
1.4 Research Study Outlines
The following procedures carried out for achieving the major aim of the research study:

- Review literatures from different sources, including reference books, government information, newspaper, magazines, journals, research reports and websites;
- Identify type of UAV used for carrying out the work;
- Identify, propose and develop the types of cameras and sensors for collecting data, images and videos;
- Conduct face-to-face interview on the feasibility of the UAV and related information;
- Analyze the data collected from face-to-face interview;
- Develop the application of UAV technology in various types of construction site with stages on development; and
- Identify the potential limitation of applying UAV in construction site and future feasible solution with enhanced development.

In Chapter 3, Research Methodology is presented and explained in more details by stages of development of UAV.
1.5 Organization of research study

The whole research study is divided into eight chapters, which the brief description of each chapter is mentioned as follows:

**Table 1.2 Organization of Research Study**

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Introducing the background of this research study by information on safety and health performance, with the brief introduction on UAV technology and traditional CCTV system in monitoring. Also defined the objectives, research outline and organization of research study in this chapter.</th>
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<td>Review various types of literature related to construction robotics, safety and health issues in construction industry and application on advanced and newly developed technology that have great potential in applying to construction industry.</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Show the various stages in the research study.</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Evaluating various factors affecting the performance of UAV in detail and mechanism behind.</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Identify numbers and types of sensors that are feasible for installing on UAV with considering several factors. Also provided the detail information on choices of the camera.</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Provide detail information on how to apply the automated UAV in different construction site in different stages of development.</td>
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<tr>
<td>Chapter 7</td>
<td>Results and Analysis of Interview</td>
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<tr>
<td>Chapter 8</td>
<td>Discussion and Potential Future Development</td>
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<tr>
<td>Chapter 9</td>
<td>Conclusion</td>
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</tbody>
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CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction and Organization
In this chapter, numbers of literatures are studied and summarized into 4 aspects, including the application of construction robotics in construction industry, the aerial photography technology applied in Hong Kong, the working condition and worker’s safety and health issues and the sensors involved in air quality and noise level aspects. The organization chart of the literature review is shown as below:

Figure 2.1 Organization of Literature Review


2.2 Background of Construction Industry

Construction life cycle includes 1) Requirements identification, 2) Project planning, 3) Design and engineering, 4) Building construction, 5) Operations and maintenance and 6) Decommissioning. (Vähä et al., 2013) According to this, building construction is an important element to the operation and maintenance stage afterwards, the quality of work done in construction stage will directly affect the operation of the building as well as leading to any maintenance of the building.

Warszawski stated that Construction work is operating under difficult condition, such as hazardous and dangerous, which may stop new workers willing to join this industry and perform such high risk work, therefore under such condition, the labour wages is higher (50% higher than the industrial average), and of course the insurance cost will be higher for this industry, mainly due to high accident rate. (Warszawski and Sangrey, 1985) Combining with the Occupational Safety and Health Statistics 2015, safety and health problems are raised in concerning the worker’s conditions on construction site.

Inside Lowell, 2014, information can be obtained on types of accidents commonly occurred in the site, such as work at height, slips, trips and falls, noise, asbestos etc. and more types of minor accident can happened in construction site frequently, such that Lovell thought construction sites are nightmare to workers in terms of safety & occupational health.

Lowell also studied Noise impact in construction industry. Traditionally, there are numbers of heavy machines working in site, working in different trade of work, the most commonly known is foundation work in every project, especially in deep foundation. Therefore, workers are exposed to such noisy environment, in long term may heavily affect their health and safety, causing hearing problems or even causing deafness. He also stated that equiping appropriate PPE is of utmost importance to minimize such problem for workers, simple ear plugs is not a solution to such problem.

The National Cancer Institute has studied that no matter the new or old generation of construction workers in some trades of work, they are still exposing to asbestos problem in UK and the affected number of buildings containing asbestos is around 500,000 in UK. Therefore, it can somehow proved that the workers were exposed to asbestos problem during construction stage, which may heavily affect their health, and most important is the workers may not know
that they have exposed to such problem for such long time. If workers exposed to such asbestos in long term, the probability of having lung cancer, asbestosis will increasingly significantly, especially for those smokers, they have the highest possibility to such problem. (National Cancer Institute: “Asbestos Exposure and Cancer Risk”).

For causing health problems for workers in dirty and dusty construction site, Lowell explained that the existence of dust, toxic chemicals in site polluted the construction environment and brought lots of negative impacts to those work in site, and simply using PPE is not enough to solve the problem, employers have a duty of care to their workers, to provide a non-toxic and healthy environment to protect workers from diseases. (Lovell, 2014). This showed that there are lots of pollutants in construction site that will really cause serious effect to human body, and point out that enough PPE is needed for each workers for each type of work.

In Hong Kong, according to the Occupational Safety and Health Statistics 2015, Statistics of Confirmed Occupational Diseases (excluding Silicosis, Asbestosis, Mesothelioma, Occupational Deafness and Gas poisoning) by industry in 2015, there are 2 cases on compressed air illness, 1 case on tenosynovitis of the hand and forearm, 1 case on carpal tunnel syndrome, in which the cases on compressed air illness is the only cases among all the industry in Hong Kong as well as the carpal tunnel syndrome.

From the information, it can show that the construction activities which the working condition is different from other industry, generating such air and noise pollution which will bring impact to the construction workers in long term, even though the workers had wore enough personal protective equipment (PPE).

Mass and van Gassel (2005) have stated “Changes in building production are essential if the world of construction is to improve. The changes are also necessary because the next few decades will see an enormous migration into the cities.” Traditionally, the construction industry is complex and dangerous comparing to other industry, in the past, more accidents happened on site due to lack of planning, monitoring and controlling. Time passed, there are more regulations and legislations requiring all the parties involved in the construction site to act at their due diligence to prevent, minimize any risk and accidents happened. But construction industry is still the industry with highest risk among all the industry in Hong Kong, due to the nature of work, the construction method, equipment and tools used.
In view of this, bring innovative and new technology into construction industry is a must, according to Mass and van Gassel, 2015, to improve the construction in all of its context, as there are more people into the cities in the future, demand will increase, while safety and health requirement need to be taken into consideration during planning, monitoring and controlling stage. And one of the innovative technology applying to construction industry, is the robotics.

2.3 Application of Construction Robotics in Construction Industry
Balaguer and Abderrahim (2008) studied the application of construction robotics in construction robotics in recent years, and found that there are numbers of research projects working on robotics for construction field, such as application of robotics in performing some front-line trade of works, but the main difficulty of such application is the varying environment in construction site. There are numbers of factors affecting the application of robotics, such as tolerances, low level of standardization, prefabrication work etc. Therefore, there are still lot of improvement work on both software and hardware before mass application to construction industry.

“A special form of Automation and Robotics is prefabrication. Prefabrication moves work away from the building site to a factory.” (Mass and van Gassel, 2005) Bring in new technology will change the traditional way to construct a building, which the method, material, labour, equipment involved may be different in difficult work process, but the start of applying robotics can be on prefabrication works, as such work is repetitive that did not involve actual varying site condition, robotics can be more easily to apply. To those front-line workers, such prefabrication work by robotics can let them more easily to manage instead of group of workers as well as bringing faster construction period.

“Reproduction is the introduction of an innovative technology capable of simplifying the production of complex goods, of short-cutting long sequential operations. Therefore, achieving more substantial economies than mechanizing, automation or robotizing around the traditional construction methods.” (Richard, 2004).

“We believe that automation in building construction will evolve by the use of advanced sensor
technologies and BIM.” (Vähä et al., 2013). From Vaha’s prediction, using sensors and Building Information Modeling will be the future trend in improving construction performance, as software technology around the world is becoming more mature, quickly updated and more functions, it will soon be a main part in future construction project, from design stage, planning to construction work, the computer can help managers to do difficult works in simple way, and automation of construction robotics can become important when there are less workers in future.

“Automation is the use of control systems and information technologies to reduce the need for human work in the production of goods and services.” (Vähä et al., 2013). In fact, automation can assist human for doing their work to reduce the workload of the human, like the smart phone nowadays, performing multi tasks within single devices for human work, human will be benefit from it, and now the automation technology started to join the construction technology, which has the heaviest workload for the workers among other industries, bringing benefits not only to workers, but the whole construction process. Such application can also solve the lack of fresh workers in nowadays construction industry, which heavily rely on existing workable workers, and due to this problem, the labour cost is keep increasing in recent years, but with the increase in cost, the number of workers is still not enough for market demand.

Automation bring numbers of benefits to all industry around the world. According to Lacouture, 2009, the most important reasons from interviewees of different industries are productivity improvement, quality and reliability from the machine, health & safety, working conditions improvement, reduce labour cost of workers, standardization of work, reduction in project life cycle cost, and simplification of different trade of works performed. The impacts brought by automation are really the solutions to deal with current situation, to solve current problems while enhancing the overall construction system in order to put construction work at a lower risk.

In the market of automation, this topic is always related to robotics, which is the main platform in performing automation processes.

“The robot, for the purpose of this analysis, will be defined as a device which can perform a sequence of production tasks without a direct human intervention. The typical tasks may involve hauling of objects from one place to another, or their processing like painting, drilling, welding, etc. with appropriate tools. For performance of these tasks, the robots, can be completely preprogrammed, "taught on site" by the operator, remotely controlled, or pre-programmed and
allowed to modify their performance according to the perception of the environment obtained through sensing devices” (Warszawski and Sangrey, 1985).

In the past, there are only few companies willing to invest into R&D on robotics due to large amount of uncertainty, but when some successful products developed, many kinds of robots use in construction are developing, and some are developed nowadays. For past condition, the robotics technology was immature and the development cost of such robotic projects can be huge amount of money, by combining all the factors, the investors were unwilling to invest to such high-risk invention in the past; But when the technology keeps improving and developed massively, and nowadays information technology became one of the common topics around the world, more and more investors to invest their money on innovative and new design, and the development of robotics started again. But the robotics applications are still limited by the actual site condition in Asia, especially in Hong Kong, which most of the buildings in Hong Kong are high-rise, with limited working area on each storey, the application of robotics become difficult, and therefore need some improvement or design before actually apply to HK.

Be that as it may, there are still some developed robotics tried to work in construction industry, such as for precast concrete panel production, bricklaying etc. and more robotic projects are still in development.

Robotic precast concrete panel production

“The robotic precast concrete panel factory designed in 1990 uses a multipurpose unit which allows flexible production of unique concrete floor, wall and roof panels.” (Bock, 2007). The robot first to clean the working area before any steps of work performed, then another robot can produce the product with the input of CAD design, afterwards the robot can complete the products with the input. But the disadvantage of this system comparing to traditional method used in construction site will be the size and inconvenience in high rise building construction, as the system need to lift up to another floor after each floor construction, also it need to concern the loading of the system applying on the floor to avoid failure.

Bricklaying robot

This bricklaying robot’s function is simply “Complete the Brick laying work” by picking up bricks from specific location preset in programme, then to apply cement/sand mortar on the
brick, finally to lay the brick in correct position according to the joining details set. This heavy machine applied in construction site required amount of areas when in operation, as the whole machine is huge in size, so the manager should take this into consideration during planning stage, otherwise such robot may bring impact to prolong the construction period instead of helping to fast up the construction work. (Pritschow et al., 1996). For the bricklaying robot, there is a famous robot called Sam, which this kind of robot is large in size, leading to difficulty in constructing high-rise building.

Mobile site robot

Some well-known Japanese construction companies have been studied the development of the construction robotics in the past 30 years. At the beginning, several types of remote-controlled manipulators were developed for working on minor works in construction site, such as delivering materials, applying paint on wall etc. In these years, they have succeed in creating more than 400 prototypes for testing, some of those prototypes succeed, but unfortunately more had failed. But the development had caused positive impact on other companied also working on similar technology. (Bock, 2007).

These developed robots indicated the new era of the construction industry, using manpower to operate all kind of work became a traditional way, and the innovative way is to apply robotics into construction industry, to enhance overall performance of work as well as the working environment, condition and safety consideration, in which the safety must need to be taken into consideration, due to recent year’s concern from different parties and to comply with the statutory obligation. But these developed robots mainly focuses on performing simple work, such as concreting, bricklaying, installing panels etc. it is good to see the development started on simple work, which can test whether robotics are feasible to use in construction industry, and the development of robotics will soon focus on more difficult procedures, in order to help human in performing high risk, unsafe work on the site.

And the innovative technology to be introduced next, which forms the main part of this study, is the aerial photography and videography, will be using in the platform of UAV s.
2.4 Aerial Photography and Videography
“The first aerial photography taken from an airplane was in 1909, by Wilbur Wright. He was in Italy, engaged in marketing planes to the Italian government, when he carried a passenger who took motion pictures of the military field at Centocelli, near Rome.” (Professional Aerial Photographer Association International, 2016). The history of aerial photography was more than 100 years, but in different application, the human at that time needed to fly on airplane to capture photos from sky to ground, and the printing technology was low-level at that time, therefore the quality of the photos, the time needed to perform such operation, the cost of each photos was extremely high, so such application was mainly applied in military aspect at that time. But in nowadays modern world, more advanced technology are developed, the time, cost and quality of aerial photography are become “user-friendly”, and the application of aerial photography is involved in more aspects, such as working for Observatory, Lands Department or even citizens flying the UAV during leisure time. By comparing the past, the aerial photography technology is much more mature and bringing more convenience to nowadays users.

2.5 UAV also known as Unmanned Aerial Vehicle
“The UAV is an acronym for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. UAVs can be remote controlled aircraft (e.g. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems. UAVs are currently used for a number of missions, including reconnaissance and attack roles” (The UAV, 2016).

From Smith (2015) stand of view, UAV is different from other aerial vehicles due to its characteristics and performance is better, using UAV can hover as well as easily control remotely, which put the UAVs on a more advantageous position comparing with other platforms. And Smith also described the development of UAV, by reviewing the UAV first idea came from traditional helicopter with single propeller, developed in stages to nowadays quadcopters, and there are also comparison between UAV and RC plane, which UAV’s overall performance is much better than traditional RC plane. And more important is the application of UAV to risky environment, where UAV can perform in those extreme condition for military aspects, to replace human’s operation.

UAV Components
To build a UAV, various components are needed to form the basic UAV, which then can be functioned to fly in air and controlled by ground user with photo capturing. Here is the list of standard UAV components (the definition of each term refer to Appendix A4), the components including Standard Prop, Pusher Prop, Brushless motor, Motor Mount, Landing Gear, Boom, Main body, Electronic speed controllers (ESC), Flight Controller, GPS module, Receiver, Antenna, Battery, Battery Monitor, Gimbal, Gimbal Motor, Gimbal Controller Unit, Cameras and Sensors. These components form the basic shape of the UAV, and there are variety of modification can be apply onto the UAV for different purpose. Only the components are not enough to let the UAV fly and take photographs, the technology used in the UAV is the main part in the whole system, to perform the tasks.

**UAV technology**

Other than the hardware (UAV components), there is also powerful software to support the whole system, and the technology applied on UAV is listed below:

Radar positioning and Return Home – Important item to locate the UAV when flying or landing.

Gyro Stabilization – is the most important technology for UAV to fly stably without overturning and causing accident.

IMU – In fact, without the IMU, the UAV cannot balance itself in mid-air, which the UAV will fail before lifting, therefore the IMU as described, is the brain of the UAV to control the whole machine in the air to avoid clashing easily.

First Person View (FPV) – The main objective of aerial photography is to let user to see the bird view in first person, which the quadcopter to act as tools to perform such work instead of human flying the plane and take pictures.

High performance camera – As the camera technology is also improved massively, it is easy to buy camera with capturing HD photos and videos, and the cost is also acceptable by users, ranging from several thousand to more than ten thousands according to different specifications.

Gimbal and Tilt Control – This technology can let user to adjust the camera angle to capture the photos and to meet the user’s requirement.
Operating system – OS function in UAV is similar to the OS in mobile, desktop etc. to group all the hardware and software in an interface to let the user to control the whole system.

For the definition of each term, please refer to **Appendix A5**.

Combining the technology with the UAV components, a UAV will be completed for use. It is hard to perform well or even fail if anyone of the components or technology missing or fail, so it is essential to check the specification of the components meet the statutory requirement, follow the instruction when using.

Using UAV for aerial photography is a two-side sword, the UAV is not perfect at all, several advantages and challenges bring out.

**Advantages of using UAV**

Versatility – As the size of UAV can vary, therefore UAV can fly to areas which human cannot reach, and the controllable distance of UAV can operate from ground to more than 100 meters in the air, or even 1 kilometre length when needed. Also UAV can be applied in both indoor and outdoor, some models have the ability to fly from indoor area to outdoor area without having any location problem. Besides, the flexibility of UAV provide convenience to user, as it can rotate or go up and down quickly by controlling, and the camera angle can also be adjusted for user’s requirement (Williams, 2015).

Saving in time – According to the history of UAV mentioned, manual photo capturing technique was mainly applied in the past, which required pilot to fly the plane and a photographer to take photos, one journey may took half day or even more. But with nowadays UAV technology(Williams, 2015).

Full HD quality – As the camera technology has been significantly improved and well-developed, the camera installed in UAV can perform HD photos and videos capture, can provide high-quality output easily. Also due to wide variety of cameras in the market, UAV can change the camera according to user’s requirement (Williams, 2015).

Safety – The UAV has the built-in function that, if the battery level is low or out of battery, it will operate the emergency procedure to land without causing serious crash, leading to accident or safety issues.
Reduce the amount of high-risk work performed by humans (Whirlwind team, 2015) - High risk work such as confined space work needed to be replaced by using other robot in the future to minimize the risk of human accidents because life is priceless.

Catch Major and Minor deviation – With the help of computing technology, UAV can identify and locate any misalignment during the monitoring progress (Whirlwind team, 2015). This technology can really helps in monitoring work progress, as the photos captured can be taken to compare with the planned, any deviation can be quickly highlighted to take any further action immediately to avoid delay or solve problems.

**Challenges on using UAV**

Safety – There are concerns from the community that as the aerial UAV is more popular to the society, more people purchase such equipment for different purpose and use in different way, which the lack of instruction leading to accidents, some of the cases are serious, such as the UAV dropped in Taipei in November 2016, causing a serious injury to a woman, which she was almost blind, afterwards, the founded two chinese travellers claimed they are not familiar with the control of the UAV. And such kind of cases raised concern on UAV safety, especially on the control instruction and lack of legislation to monitor the use of UAV.

Adversed weather condition – weather is the most important factor when flying the UAVs, for weather like raining, wind, it is unlikely to fly the UAV as the UAV is not waterproof, it will cause accident when using in rain; But for the windy condition, it depends on the wind resistance capacity of the types of UAV using, in the UAV’s performance table, the maximum wind resistance will be shown as well as the tilt angle to let the user to avoid using the UAV during specific wind level.

Battery life – the lifetime of the battery varies to different types of UAV used, for smaller size of UAV, usually the battery will be using smaller to avoid increasing weight and affecting the uplift thrust ability of the UAV; while larger size of UAV will use large capacity battery which can give better operating time, but it depends on a lot of factors such as power consumption, temperature etc.

**Operations of Unmanned Aircraft Systems (UAS)**
According to the Civil Aviation Department of the Hong Kong Special Administrative Region, the use of the UAV must comply with the following rules, conditions and procedures before commencing any activities.

“Flying Unmanned Aircraft Systems (UAS) weighing not more than 7 kg (without its fuel) for recreational purpose can be classified as model aircraft flying, and no application to CAD is required. Except with CAD’s endorsement, heavy UAS weighing more than 7 kg (without its fuel) are not allowed to fly in Hong Kong for recreational purpose.”

There are numbers of rules setup by CAD to limit and control the application of UAS, in order to avoid any interruption to others or reducing the risk of accidents. The main limitations for UAS application including height restriction within 50m of any person or structure, avoid flying to restricted zone listed out by CAD, enough space for lifting and landing area, the operator should keep the UAV within sight to have better control, the UAV can only be operate on day time, night time operation is prohibited and more rules are setup under the CAD. For more information on the guidelines, please refer to Appendix A6.

All the above rules must be complied before commencing any flight on the UAVs, it set out the conditions that the UAV cannot operate at night time, cannot fly over 300 feet above ground level. These limitations needed to be taken into consideration when considering the design route and the operation of UAVs.

2.6 Thermal Imaging Camera
Thermal Imaging, or Infrared Thermography, is a noncontact technology that measures or “sees” infrared wavelengths emitted from objects, and then converts the temperature information into an image. The image features a color palette that represents a temperature range of the image displayed. Hot spots or a rise in temperature often indicate problems or potential failure. Thermal imagers are fully radiometric by measuring and storing temperatures at every point in the image (FLIR et al., 2012). “Thermal imagers are the imaging systems sensitive to mid-wave and long-wave infrared radiation that generates images of the observed scenery using thermal radiation emitted by the scenery” (Chrzanowski, 2010).

Thermal imaging reads temperature differentials in a defined area. A common reason to do this is to find trapped moisture in metal panels. For example, a roof absorbs heat from the sun. As
the sun goes down and temperatures dip, wet areas of the roof release heat slower than dry areas. The temperature differential is shown on the image through variations in color. Using the thermogram, you can pinpoint where water may have leaked through the roof and into the insulation (Whirlwind Team, 2016). Thermal imaging already applied in construction industry, as there were infrared camera capturing the picture of external wall, to check any cracks by observing any hot air trapped inside the void in the external wall, this application was mainly for building inspection, but the price of the infrared camera can be up to 200 thousand HK dollar, which is very expensive on using this technology.

Benefits of thermal imaging

Lower cost - Incorporating thermal imaging into a predictive maintenance program can save money by locating potential failures and hot spots that could cause expensive manufacturing downtime, production losses, power outages, and fires. Also the extending equipment life with scheduled outages and reducing employee overtime (FLIR et al., 2012).

Increase productivity - Thermal imaging provides fast and accurate measurements of objects that are difficult to reach, altered by touch, or impossible to shutoff. Troubleshoot and make informed decisions by viewing the thermal performance of equipment in seconds (FLIR et al., 2012).

Reduce risk - Thermal imaging allows accurate temperature measurements from a distance for objects that are moving, very hot, and dangerous to contact (FLIR et al., 2012). In construction site, it is hard to figure out which area or place is much hotter than other place in the site, leading to potential injury or accident happened later on, so it is essential to identify different temperature in different area in order to prevent and reduce the risk of getting any accident happened.

Non-destructive – Using thermal imaging is a non-destructive process to the structure or system being investigate, most important is the for the system it do not need to shut down before investigation, while thermal imaging process can be performed during operation. Also thermal imaging will be damage the structure or system to give out accurate and fast results.

Limitations of thermal imaging

Surface imaging – the thermal image can only show the temperature detected on the surface, while it is different from X-rays which can penetrate through walls that provide a interior view of the structure.
Weather condition – Ideal condition need to be without wind, sun, raining etc to avoid getting inaccurate or wrong results.

Range – Affected by many variables such as the types of camera used, atmospheric conditions, the nature of target etc. so photo shooting in closer range will give out more accurate result.

Reflection – as the thermal energy will be reflected on the shiny surface such as glass, thermal imaging is not appropriate to use on glass, only applying on concrete structure will be appropriate.

2.7 Air Quality and Noise Pollution in Hong Kong

Hong Kong has been facing air pollution problems, which there are two types of pollution aspects, street-level pollution and regional smog problem. For street-level pollution, diesel vehicles and plants are the main distribution to such pollution; For regional smog problem in HK, it mainly due to numbers of factors including vehicle pollution, factory or plants pollution etc. in HK or nearby region. (Environmental Protection Department of HKSAR, 2016).

“Air impurities also known as air pollutants, usually refer to substances that are not part of the fresh air content, or those substances that are present in concentration exceeding the normal range in the atmosphere” (Occupational Safety and Health Branch, Labours Department, 2009). The air pollutants in the construction site are mainly NOx (Nitrogen Oxide), SO2 (Sulphur dioxide), CO (Carbon Monoxide), O3 (Ozone), PM2.5 or 10 (Particle Matter) and VOC (Volatile Organic Compound), which these pollutants are from different construcion activities, materials etc that lead to such pollution.

Nearly all Construction activities will cause air pollution, therefore construction sites will contain high level of impurities, causing dusty and unhealthy environment to workers working inside. “Construction dust is classified as PM10 - particulate matter less than 10 microns in diameter, invisible to the naked eye.” The particle matters can go to human’s lung and causing respiratory diseases, or even causing cancer or death if human exposed to such condition in long term. (Gray, 2016).

Occupational Safety and Health Branch, Labours Department also listed out several high-risk work procedures that generate dust particles during working, such as drilling in foundation work,
excavation work, or even finishing materials applied during architectural work stage. When performing those trades of work, worker will expose to harmful environment, which may significantly affect the health and safety of the workers. Also for most of the construction activities will bring out different degree of air pollution, not only from complex or hazardous construction activities, but also as simple as painting, the paints may contain VOCs that harm the workers and create problems to the working environment.

According to the Statistics of Environmental Protection Department, there are 4,851 pollution complaints in total in the construction site & renovation, which 886 of the cases are related to air complaints. And the air pollution complaints of the construction industry is nearly 10% of overall air pollution complaints in Hong Kong Industry in 2015.

Air pollution control in Hong Kong is governed mainly by the Air Pollution Control Ordinance and the Ozone Layer Protection ordinance. This ordinance set out the guidelines to monitor and control the air quality problem in Hong Kong. Inside the ordinance, construction work is a major field in terms of air pollution, nearly all construction activities will generate different levels of pollution, some are minor and some can lead to major pollution such as piling work or foundation work, asbestos etc. Other than the ordinance, there are also Code of Practice to give general guidelines to construction field to solve such major problem in every construction site. For every construction project, it is of utmost importance that the managers should control all works to follow these general government regulations and guidelines to keep the pollution level to accepted level as well as providing a healthier environment in construction site for everyone.

According to Air pollution control ordinance (Cap 311) Section 14A, Air pollution control plan stated that under the ordinance, applicant should submit their air pollution control plan to authority, and which the authority has right to approve or refuse the submission and to grant the licence. Inside the air pollution control plan, applicants should describe the technical information for plants which will generate air pollutant, and the method to measure and monitor such air pollutant level during work, and any measurement can be taken to reduce or limit such air pollutant. Other than that, applicant should also check the impact to nearby building or structure, then to make an impact assessment to show the environmental condition and measurement.

Gaseous Pollutants
According to the Air Quality in Hong Kong 2015, which stated the main gaseous pollutants in air from different industries that leading to air pollution, such as Suplhur Dioxide (SO$_2$) from combustion of fossil fuels, which can cause serious respiratory diseases or even death; Nitrogen Oxide (NOx) and Nitrogen Dioxide (NO$_2$) also from combustion in vehicles or factory and will also bring respiratory diseases to human body; Ozone (O$_3$) generated from the pollutants under sunlight; Carbon Monoxide (CO) emitted from all kind of vehicles, which will also affect respiratory system inside human; Suspended Particle (RSP or FSP) which is from the factory or vehicles’ emission from HK or nearby region, and such particle can go into human’s lung and causing respiratory diseases. For more information on each pollutants, please refer to Appendix A7 Common Gas pollutants in HK.

So after understandings on these types of pollutants, these 6 types are the main pollutant generated in construction work from different aspect, it is important to monitor the pollution level of these pollutants in order to minimize the effect and comply to the ordinance, so a method should be developed to real time monitoring these air pollutant in construction site to obtain a clear and accurate result for managers to know the situation.

Health Hazard
The air pollutants is easily to enter to human’s body due to its colourness and odorless characteristics, when human exposed to polluted condition in long term, such as workers in construction site or factory, numbers of health hazard will appear and significantly affect worker’s occupation safety and health. For examples stated in Occupational Safety and Health Branch from Labours Department (2009), they have listed out several major hazards which additional measurement can be action to reduce the risk of exposing to such condition.

1. Direct contact with acid or alkaline chemicals, in order to reduce such risk, enough PPE shall be provided to workers to avoid direct contact with such hazardous chemicals;
2. Toxic metals and organic solvents for workers exposing to such condition, proper duty of care from employers is important, such as providing appropriate ventilation and PPE to reduce such risk;
3. Suspended particulates containing substances like quartz, asbestos or raw cotton dust may induce occupational lung diseases, some trade of work in construction site may contain such particulates, therefore guidelines should be followed to perform such work with appropriate
handling method and equiping appropriate PPE to avoid over exposure in hazardous environment;

For different air pollutants, which can cause different level of effects to human body, serious pollution can cause fatal accidents to workers and lead to bad working environment, which then the loss of contractor will be huge, not only shown on the penalties or compensation, but more important is the reputation. As the duration of construction project nowadays required short period to finish the project, subject to faster operation, safety and health may be put aside, and putting time as the first priority in construction work, and such issue may lead to have accident or injury easily by less concern on worker’s health as well as working environment.

**Construction Noise**

Other than air pollution generated during construction activities, construction noise will also be generated through these processes, different construction activities or equipment will generate different level of noise (measured in dB), leading to different level of effects to workers in the site.

According to GovHK, 2015, Hong Kong is one of the densely populated cities around the world, noise problem is easily be discovered around the city. Another characteristic of Hong Kong is the huge number of mountain, leading to small size of urban areas, and all types of buildings in HK are very close to each other including commercial and residential buildings. So when every constuction project started in urban area, noise become a huge problem to be solved.

According to Environmental Protection Department, Construction noise was a major problem since the formation of EPD (1986). In common construction site, Pile-drivers need to work over 12 hours each day, which was the longest operation work on site. Later in 1989 which the Noise Control Ordinance setup, the ordinance mainly to control the construction noise from the plants or machine, such as limitation of 3 to 5 hours allowed for piling work and setup guideline on using quieter piling equipment, other noisy activities performed are also controlled under such ordinance.

**Noise Control Ordinance**
Similar to air quality control, there are also regulations required on the noise control, the CAP 400 is the main regulations, describing all the informations and details under noise control, to let the contractor to follow the regulations, submit required documents etc. The regulations are generally as follows:

CAP 400 Noise Control Ordinance
CAP 400A Noise Control (General) Regulations
CAP 400B Noise Control (Appeal Board) Regulations
CAP 400C Noise Control (Air Compressors) Regulations
CAP 400D Noise Control (Hand Held Percussive Breakers) Regulations
CAP 400E Noise Control Ordinance (Exemption from Section 6(1) and (2) (Chek Lap Kok)) Order
CAP 400F Noise Control Ordinance (Exemption from Section 6(1) and (2) (Lantau Fixed Crossings)) Order
CAP 400G Noise Control (Construction Work) Regulation
CAP 400H Noise Control (Construction Work Designated Area) Notice
CAP 400I Noise Control (Motor Vehicles) Regulation

(Department of Justice, The Government of Hong Kong Special Administrative Region, 2016.)

Construction noise permit

“Construction Noise is mainly controlled under a construction noise permit system. A construction noise permit must be obtained from the Environmental Protection Department for either of the following two situations: (i) Using specified powered mechanical equipment or carrying out prescribed construction work in Designated Areas, or carrying out general construction work using powered mechanical equipment, from 7 pm to 7 am on weekdays, and any time on Sundays and public holidays. (ii) Carrying out percussive piling from 7 am to 7 pm on any day other than a public holiday. Percussive piling is prohibited from 7 pm to 7 am on weekdays and any time on Sundays and public holidays. Applications for construction noise permits must be submitted to the Environmental Protection Department for assessment and approval before the commencement of the work” (GovHK, 2015). Before commencing the work, the contractor must apply the noise permit, describing the details of applicants and the details of location of work and all the construction work should comply with the noise permit in order to avoid any dispute or claims or even subject to fine. So the construction work is limited
within certain period that allowed to work, the balance in time, cost, quality, safety and environment is the key to success in every project. In order to achieve these objectives, productivity of workers is important, and to some extent providing workers with a safe and healthy working environment can help to improve the productivity, and finally finish the work on time.

Construction Equipment Noise Emission Levels

Table 2.1 Construction Equipment Noise level (Denver Union Station, 2008)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Typical Noise Level (dBA) 50ft from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air compressor</td>
<td>81</td>
</tr>
<tr>
<td>Backhoe</td>
<td>80</td>
</tr>
<tr>
<td>Ballast Equalizer</td>
<td>82</td>
</tr>
<tr>
<td>Ballast Tamper</td>
<td>83</td>
</tr>
<tr>
<td>Compactor</td>
<td>82</td>
</tr>
<tr>
<td>Concrete Mixer</td>
<td>85</td>
</tr>
<tr>
<td>Concrete Pump</td>
<td>82</td>
</tr>
<tr>
<td>Concrete Vibrator</td>
<td>76</td>
</tr>
<tr>
<td>Crane, Mobile</td>
<td>83</td>
</tr>
<tr>
<td>Dozer</td>
<td>85</td>
</tr>
<tr>
<td>Generator</td>
<td>81</td>
</tr>
<tr>
<td>Grader</td>
<td>85</td>
</tr>
<tr>
<td>Impact Wrench</td>
<td>85</td>
</tr>
<tr>
<td>Jack Hammer</td>
<td>88</td>
</tr>
<tr>
<td>Loader</td>
<td>85</td>
</tr>
<tr>
<td>Paver</td>
<td>89</td>
</tr>
<tr>
<td>Pile Driver (Impact)</td>
<td>101</td>
</tr>
<tr>
<td>Pneumatic tool</td>
<td>85</td>
</tr>
<tr>
<td>Pump</td>
<td>76</td>
</tr>
<tr>
<td>Rail Saw</td>
<td>90</td>
</tr>
<tr>
<td>Rock Drill</td>
<td>98</td>
</tr>
<tr>
<td>Roller</td>
<td>74</td>
</tr>
<tr>
<td>Saw</td>
<td>76</td>
</tr>
<tr>
<td>Scarifier</td>
<td>83</td>
</tr>
<tr>
<td>Scraper</td>
<td>89</td>
</tr>
<tr>
<td>Shovel</td>
<td>82</td>
</tr>
<tr>
<td>Spike Driver</td>
<td>77</td>
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<tr>
<td>Tie Cutter</td>
<td>84</td>
</tr>
<tr>
<td>Tie Handler</td>
<td>80</td>
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<tr>
<td>Tie inserter</td>
<td>85</td>
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<tr>
<td>Truck</td>
<td>88</td>
</tr>
</tbody>
</table>

Most of the construction equipment will generate more than 80 dB of noise level, for pile driving, the measured noise level can up to 101 dB, which is a very high level of noise comparing
to daily activities. Other than the noise level, the time of exposure to these activities can determine the risk of health and safety effect to the workers. For high noise level, the time of exposure to such activities should be minimize to avoid serious hearing effects, but for lower noise level, does not mean that time of exposure can be unlimited, workers and management team still need to aware of this issue.

According to Janel Heinrich 2013, the examples of long term effects related to noise exposure are simplified as follows:

Table 2.2 Examples of Long-term effects related to noise exposure

<table>
<thead>
<tr>
<th>Effect</th>
<th>Exposure type</th>
<th>dB</th>
<th>Location of assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing Impairment</td>
<td>Occupational</td>
<td>75</td>
<td>Indoors</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Occupational</td>
<td>&lt;85</td>
<td>Indoors</td>
</tr>
<tr>
<td>Ishchemic Heart</td>
<td>Environmental</td>
<td>70</td>
<td>Outdoors</td>
</tr>
<tr>
<td>Annoyance</td>
<td>Occupational</td>
<td>&lt;85</td>
<td>Indoors</td>
</tr>
<tr>
<td>Performance</td>
<td>Occupational</td>
<td>70</td>
<td>Outdoors</td>
</tr>
</tbody>
</table>

Basically all of the equipment will bring the effect mentioned in Table 1.3 to the workers in different level, depends on the working time, frequency of use, so it is essential to monitor the noise level in real-time, to collect noise data from different zone, level to perform monitoring.

2.8 Cavern Development in Hong Kong

 Normally in Hong Kong, there are two types of construction site, simply civil and building site, responsible for civil work & infrastructure or building construction respectively. But as the aging problem became more seious and the population size is increasing, the Government of Hong Kong started to find ways to “create” more land, in order to solve the housing issue in Hong Kong.

According to the Civil Engineering & Development Department, the Government was working hard to supply new land by considering number of options, including resumption of rural land, redevelopment, land rezoning, reuse of ex-quary sites, rock cavern development
(RCD) and reclamation. Among the options, cavern development is the new options raise in recent year.

“Cavern development is regarded as a new source of land supply.” (Civil Engineering and Development Department of Government of HKSAR, 2014). With cavern development, Government can relocate some government facilities such as debris collection station or sewage treatment plant to caverns, as these facilities may bring negative impacts to neighbour. Afterwards, the original area occupied can be available to other facilities development. The flat land area in Hong Kong are scarce, so cavern development can replace some government facilities and “free” those land area for other purposes, in order to partly solve the lack of flat land area in HK.

In fact, the development of cavern can provide large amount of land for future use on other purpose, after moving some of the obnoxious facilities to the cavern. According to the ARUP in 2011, CEDD developed a cavern sustainability map to show the areas that are suitable to cavern development, from the map below shous that around two-thirds of the land area in HK have high potential for cavern development.

![Cavern sustainability map](from Long-term strategy for Cavern Development)

Not only the Government had mentioned the cavern development, a TV programme from RTHK also provide background information on the early stage of development of cavern, the purpose of using cavern, the benefits of moving the obnoxious facilities to cavern etc. The TV programme provided solid information on this cavern topic and also bring such topic to be popular in the society. The link of the TV programme is: [https://youtu.be/PAJvLvyWIPU](https://youtu.be/PAJvLvyWIPU).
The development of cavern in Hong Kong started in 1990s, including the Stanley Sewage Treatment Works and Island West Transfer Station, in recent years, there is a Western Salt Water Services Reservoirs in the University of Hong Kong.

As the cavern development is still in early stage, the development of cavern still have a long way to go, which from the map with other information, there are so far 48 places suitable for the cavern development, which can create massive amount of land in the future as more caverns are constructed, and this is a great opportunity in applying the real time monitoring technology and the air quality and noise level monitoring during the construction process.
CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Methodology Framework
In Figure 3.1 will briefly outlines the various stages in this research study. And different stages will be discussed in detail in the later part of this chapter.

Figure 3.1 Flow of Research Methodology
3.2 Literature Review and Idea Brainstorming

This is the first stage of the whole research study. In this review stage, literature on the characteristics of construction industry, construction robotics, development of UAVs, aerial photography and videography, air quality and noise pollution and the cavern development will be investigated from journals, news, videos, reference books, internet, government publication, research reports.

The review started from the review of the background of construction industry, the characteristics of the construction industry including high risk construction activities, working condition, nature of work, safety and health issue etc., such characteristics brought out concern on the safety and health issue of the workers, as well as how to minimize the effect of delay on monitoring progress.

For reviews on the construction robotics aspect, the development of the robotics is not started in recent years, generally reviewed the background of the robotics, the basic types of robotics, the application in different construction activities and the application of automation. From these reviews, the types of robotics current developed can be identified, as well as the future development on this aspect.

For the reviews on the aerial photography and videography, those reviews can show the history and development of the aerial photography, also indicated the cost of aerial photography in the past is much more expensive than nowadays.

For the reviews on drone also known as unmanned aerial vehicle, started on introducing the background of the UAV application, from military use to nowadays public use. The reviews also provide information on the components and technology used to form a basic UAV for application, other than the components and technology, the benefits and limitation of UAV are also reviewed for the design in this research study. After that, there are regulations on the application of UAV from the Civil Aviation Department, the regulations are also be reviewed for the operation and testing of the UAV in the later stage, and all of the regulations must be complied before operation.

For the review on the thermal imaging camera, firstly reviewed the background information of the thermal imaging, the brief mechanism on the thermal imaging, then reviewed the benefits and limitations of using the thermal imaging. Such pros and cons need to be taken into consideration in this study.
For the review on the air pollution in Hong Kong, from the reviews first to identify the general types of air pollutants in Hong Kong and their characteristics and background information. Next is to review the air quality control ordinance to know what the contractor should do and follow the regulation to monitor the air quality. After review the air pollutants and ordinance, next to review the potential health hazard on exposure to environment with such pollutants. For the noise pollution, first to review the background on reason of noise, next to review the noise control ordinance, which provided the regulations that parties need to follow during process. After that, to review the construction noise permit, which is important in construction work, the conditions of the noise permit. Noise level of different kinds of construction equipment needed to be reviewed, comparing with the potential health effect on human, indicated the health effect for using each construction equipment.

The final part of the review will be on the cavern development, from the review on government publication, to know the past, current and future development on cavern. Also gain more information from the video review. Also to review the cavern application in Hong Kong now and in the past.

3.3 Design and Development
After reviewing the robotic application in construction industry and the background of UAV application, the design and development of the whole application can commence, which the design will include the elements needed to form the product.

The aim of this design is to:

1. Real-time Monitor Work progress
2. Real-time measuring air pollutants and noise data
3. Integrate real-time videos and sensors’ data into one interface
4. Managers to improve working environment from data obtained
5. Safety risk of workers can be minimized
6. Increase productivity as final target
3.3.1 Development of UAV
The idea of using UAV as the base in this application is from the brainstorming stage. In that stage, several ideas pop-up but the reason choosing UAV in this project will be base on the popularity and innovative characteristic in recent year. As more UAV applications are developed in recent years, with the popularity of the UAV itself, the UAV has huge potential to be applied in many other aspects, such as real-time monitoring developed in this project.

3.3.2 Cameras and Sensors
The extra modifications added on the UAV are considered after reviewing the situation and problems related to safety and health problem in construction industry, which many accidents occurred related to working environment, also the worker’s health is another key point in maintaining suitable productivity in order to keep work on track. Therefore, several sensors are discussed in order to collect air pollutant data and noise data, to discuss the effects to the workers and the measurements to be taken to reduce the harm to workers.

3.3.3 Testing
After the design and development stage, the UAV will take several test, based on the stages of development discussed in Chapter 6, minor modifications and error fixing may be need to improve the performance of the UAV.

3.4 Evaluation and Feedback Collection
During the development of this project, interviews will be conducted in different stages, from the idea consolidation stage to the feasibility stage, the comments from different parties will be collected in order to improve the design and development. Target interviewees will be professionals in UAV application, the safety related person and professionals in construction management.

3.5 Discussion
After collecting the comments from different parties, the data can be analyzed and discussed, the feasibility of applying UAV with multiple sensors in different types of construction site under current situation, the benefits and limitations at this stage will also be mentioned. Moreover, the UAV application has huge potential in more advanced application, so the future development of this application will also be presented and discussed.
CHAPTER 4 – DEVELOPMENT OF NEW UAV APPLICATIONS IN THIS PROJECT

4.1 Introduction
As the UAV technology is becoming more popular from military use at first, nowadays there are variety types of UAV in the market, there are different size, which can small as the size of hand or large as a television, and the equipment and function of the UAV varies due to the size and price. Nowadays, professional photographer will make use of the UAV to take aerial photography or videography, which such technology can provide a bird view that is different from normal view and difficult to take aerial photograph in the past, but the UAV can now easy and cheap to take such photos and videos.

By reviewing on the construction robotics, normally the robots designed were for some simple work progress such as compacting concrete, bricklaying, demolition, which the development of the robotics in construction was still in early stages, and more development can be seen in the future. Other than those robotics, it seems that there are not many application on UAV in construction industry, for the local construction company (Gammon), they used the aerial photography on the surveying, which is using the UAV own’s function to perform such work, leading to minimize the cost for taking aerial photography. Combining with the knowledge from the UAV application, it seems that the UAV platform provide large potential on different application by different degree of modification on the UAVs.

The aerial videography and photography provides a solid foundation on construction progress monitoring in this design, in which by first person view (FPV) monitoring, it will be much better than reporting through hierarchy of work structure or traditional site walk. The target users of this application are the site managers and the safety officers, which the first person view of photos and real-time videos can provide a platform for the managers to monitor the site progress as well as the quality of the working environment with real-time technology in the site office instead of walking around the site frequently.

4.2 Proposed Model of UAV used in this study
As mentioned before, there are large amount of types of UAV in the market due to the popularity of using this technology in different aspects. In the market, there are different size, function, equipment installed for different purpose. But mainly in this study, the UAV selected will be different from the UAV for daily leisure use. For those UAV for leisure or simple use, their size will be small and the function is simple, just to take aerial photography from the bird view, and
the height of operation will be around 10-20m, and the price will be relatively cheaper than professional types of UAV. Moreover, the price of the UAV determines the quality of the camera, cheaper camera usually gives out lower resolution of images and vice versa.

The requirements of the UAV used in this study are as follows:

1. Capture high resolution (4K) images and videos
2. More than 20 minutes of operation time
3. Take up loading of the extra multiple sensors system installed
4. Can install two cameras instead of one with changeable lens
5. With certain level of wind resistance
6. Self weight must be light
7. Number of axis

1. For the normal camera installed, the images and videos must be captured with high resolution, as in the construction site, every things need to be observed in details. Blurry images and videos will give inaccurate information to the managers as well as causing dizziness to the managers. Therefore, high-resolution camera is essential to install on the UAV for capturing high-resolution images and videos. But nowadays, most of the professional model of UAV will provide the original camera which can capture images and videos in 4K resolution, which 4K is enough in this study to meet the requirement of providing clear images and videos to the managers.

2. For the operation time, it really varies in different types of UAV. For smaller UAV, the battery usually with smaller capacity, while for larger or professional UAV, the battery capacity will be much higher, and providing longer operation time. The designated operation time for the UAV used need to be more than 20 minutes without any modification added, it will be better if the operation time can up to 30 minutes or more using professional UAV model.

3. Besides the basic components to form the UAV, there will be some modification add on the UAV to perform air quality and noise level data collection, in order to do this, multiple sensors will be installed on the UAV. The weight of each sensor is not so heavy, range from few grams up to hundred grams. Other than the sensors, there must be a circuit board connecting all the sensors and the power supply to perform the data collection and real-time send back the data to the interface. The weight of the whole system needs to be taken into consideration when considering whether the UAV can take up such loading. But in current market, the extra weight that the UAV can take up can be up to few kilograms.
4. For most of the UAV model in the market, there is only one camera installed for taking aerial photos or videos, there are seldom companies that publish UAV with multiple cameras. But in this project, both normal high resolution camera and thermal imaging camera are needed for capturing images and videos. Therefore, the UAV used must be capable to carry two cameras instead of one camera with changeable lens, as one camera is not enough to carry out the work of both normal and thermal imaging.

5. Wind resistance is another important factors in considering the UAV model to be used. For most of the concern from the society, they are concerning the accident of the UAV during windy weather condition. In fact, for mini or smaller size of UAV, their purposes are to provide basic function of aerial photography instead of providing the user to fly the UAV during windy condition. And for those lower class UAVs, the risk of causing accidents will be higher as the UAV cannot resist different level of wind and leading to overturning of the UAV, causing accidents. But for professional model, there will be an information list in the specification of the UAV, providing the maximum wind resistance of the UAV. The UAV used in this project need to take up specific wind resistance in order to minimize the risk of causing accident due to windy condition or overturning of UAV. By using the UAV with wind resistant ability, it can operate in windy weather condition, but the wind must not exceed the UAV’s maximum wind resistance.

6. Self-weight of the UAV is also another important factor in operation. According to the regulations from the Civil Aviation Department stated that there is no need for application if the total weight of the UAV not exceeding 7 kg, in this project, as the sensors system will be installed with other modifications, the self weight should be keep as light as possible, to avoid exceeding the limitation of 7 kg, but more important is to reduce the power consumption of the whole UAV. For heavier UAV, it needs to consume more energy in lifting and hovering, which the operation time will significantly decrease when comparing two UAVs with difference in self-weight.

7. In the market, it is common to see that there are different numbers of axis, including 4-axis, 6-axis and 8-axis. To determine the appropriate number of axis for the UAV, it depends on the weight of the whole UAV system, for heavier system, more axis may be needed to lift up the whole system, thus leading to larger power consumption. Therefore, during consideration of choosing the UAV, this factor need to be taken into consideration, but the whole sensor system designed to be installed is not as heavy as a digital camera, and it is acceptable for most of the professional UAV model to carry such weight.
4.3 Performance and Specification of suitable UAV system

After considering the above requirements that is essential to be obtained for this design, there are few models in the market that can meet most or all of the requirements mentioned.

**Powereye from PowerVision**

This UAV is the latest development from PowerVision, which will be released at the end of 2016. The main characteristics of Powereye is the multiple camera installed on the UAV, other than the normal camera installed under the main frame of the UAV, there is another set of camera installed in the front side of the UAV on the main frame, providing the First Person View (FPV) sighting for user, therefore two cameras can be supported for giving out two different view of images or videos.

![Powereye from PowerVision](image)

**Figure 4.1 Powereye from PowerVision**

In the UAV market, there are only Powereye and DJI Inspire 1 that support two person for controlling the UAV, but the Inspire 1 only support single camera, which the flight operator cannot see the image captured from the UAV. Powereye provide better function for both the flight operator and the camera operator can see different point of view from different camera on the UAV.

The general specifications are listed below:

(from [http://www.powervision.me/uk/html/pv/poweyeParameter.html](http://www.powervision.me/uk/html/pv/poweyeParameter.html))
Weight : 3950g (Battery and propellers included)

Physical dimension : 340mm x 285mm x 296mm (close)

513mm x 513mm x 310mm (Flight)

Hover accuracy : 2 m/s (Professional Mode) Vertical: +/- 0.1 m (When Vision Positioning is active, 0.2-0.4m); +/- 1m Horizontal: +/- 0.2m (Surface with clear pattern and adequate lighting); +/- 1.5m

Maximum Flight speed : 18 m/s (Professional mode)

Power : 400W (Hover), 800W (Max)

Max Flight time : Approx. 29.5 minutes

GPS mode : GPS and BeiDou

Wind Resistance : <= 5 level

For the specification of camera,

Image max. size : 4640 x 3480

Photography modes : Single shot / Burst shooting (3/5/7 frames) /Auto Exposure Bracketing / Timer shooting

Video Recording mode : 4K 4096 x 2160

UHD 3840 x 2160

Max Video Bitrate : 60 Mbps

For this Powereye model, it supported dual cameras which is suitable to meet the requirement 4 mentioned in Chapter 4.2, which this is the most important in the design, as by adding another thermal imaging camera to a UAV model not supporting dual cameras, the UAV needs to have lots of modification on the main frame, the system and the program inside the UAV. Also the camera located under the main frame of Powereye can be change to thermal imaging camera provided by PowerVision, which is perfect without finding another thermal imaging camera used on the UAV. Also the maximum operation time of Powereye is approximately 29.5 minutes, with the modification added in the design, the performance of the UAV is enough for
this project. Moreover, the provision of wind resistance characteristic makes the UAV more powerful to adopt in windy weather condition.

The pre-order price of Powereye professional mode is 3,988 US dollars, but for the pre-order price of Powereye with thermal camera is not confirmed yet.

To conclude, Powereye meet all of the requirements of the UAV required for this project, the weight of Powereye is light enough that even install the multiple sensors system, the overall weight will not exceed 7 kg under the regulations from Civil Aviation Department. The overall performance of the UAV is good enough to handle the task under this project, and the price of the whole system, including the UAV with the multiple sensor system installation will be around HK$60,000 per UAV.

Panasonic Ballooncam

Other than traditional model of UAV, there is new types of UAV designed and developed by other companies in the market, the main difference of this new type of UAV model comparing with traditional type is the characteristics. The traditional UAV models are constructed by steel frame, which provide high rigidity, stability but heavy in self weight and the maximum flight time will be around 30 minutes; but this new type of UAV model is like a balloon floating in mid-air, the size of this new type of UAV is generally larger than normal UAV, as it needs more air inside to keep it float in mid-air, there will be the standard prop similar to normal UAV to provide up thrust force to lift up the “balloon”, and most important is that the maximum flight time of balloon UAV can be up to an hour, and the safety level of balloon UAV is much higher than normal UAV. Recently, when looking up to news, there are few accidents related to UAVs, e.g. crashing to trees or people causing injuries, the main reason of these accidents is human mistakes, if the UAV is controlled properly, it will not crash or overturn causing accidents, the UAV itself met the safety standard before selling to users. But the balloon UAV provides a higher level of safety, by using the material for the main frame, which is similar to a balloon, even it crashes, it will not causing serious accident to human on ground, or the structure in contact with the balloon UAV, it slightly improve the safety to human and target structure.

On the other hand, the wind resistance level of balloon UAV is lower than normal UAV, which is a limitation when considering using which type of UAV.
4.4 Automated Routing of UAV (Proposed in the UAV system)

For the UAV using in this system, the innovative technology used in here will be the automated routing of the UAV in application to different types of construction site.

Normally, the UAV will be controlled by the operator, which takes control of the controller on the ground, to perform different action and command towards the UAV, then the UAV will according to the command to perform the designed action or move. The brand new way added to the UAV development will be on the automation.

Automation is becoming more popular and important to different industry, as automation can reduce human’s workload, human just need to control it instead of performing actual work. Automation in robotics provide large degree of convenience to the workers, to reduce their workload by performing simple and repetitive work such as bricklaying and compacting concrete.

In the use of automated routing of UAV, the UAV will be installed a designed program, stating the specific route for the UAV to fly, then to collect real-time images, videos and the air and noise data. The application in the construction site depends on the types of the construction site, mainly including civil construction site, building construction site and confined space application, and these application will be discussed in Chapter 6. With the program installed in the UAV, the UAV will no longer controlled by the operator, but to follow the command from the program to move around the construction site.

The route is designed using the Global Positioning System (GPS) technique to identify the numbers of coordinates to form the designed route at outdoors, the GPS system provide accurate coordinates that can minimize the risk of having large error.

During the interview and visit in Science Park at 24 Nov 2016, it shows that using GPS to determine the coordinates then to design a route for the UAV application is possible, and the result is very accurate in outdoors. Therefore, using GPS for the route program is the most accurate way in this study to get accurate data and results.

In indoor environment such as confined space environment, the GPS signal will be weaken due to the characteristics that GPS cannot detect the location in indoor environment, as the signal will be sent from the GPS satellite to the device, and sent back to the satellite, then calculate the time taken for the signal to travel, finally the position can be calculated out. If in indoor, this techique will not be accurate and most likely GPS will fail in indoor environment.
Therefore, in indoor environment, another technology is used to detect the location where the GPS signal is unavailable, that is the use of ultrasonic technology. By using ultrasonic technology, it is easy for the UAV to identify the distance travelled and the position of the UAV in indoors, giving a huge boost in flying the UAV where there are no GPS signal. Some of the UAV in the market included this function, like the Phantom 3 & 4, and Inspire 1 from DJI. The Phantom 4 not only use the ultrasonic sensor, but also included the optical flow sensors that can determine the ground condition to provide more accurate results. The Phantom 4 also added the obstacle sensing system, there will be two cameras in the front legs of the UAV, then from the image can generate a 3D map of the environment to collision and maintain balance in indoor environment. So such technology can also be implemented to the UAV used in this project, to let the UAV can be apply in the place where GPS signal is weak or not found, that is the main application in current situation in this project, the cavern application.
CHAPTER 5 – APPLICATIONS OF MULTIPLE SENSORS & CAMERAS

5.1 Cameras on the UAV

Other than the components listed under Chapter 2.5 to form the basic UAV, there will be modifications on the UAV to successfully carry out the expected purposes.

High resolution camera (4K)

For taking aerial photographs and the videographs, as one of the purposes is to provide real-time monitoring, therefore the normal high resolution camera is needed to capture high quality images and videos as well as sending the images and videos in real-time, to provide real-time and accurate information to the managers. Usually nowadays, for most of the professional models of UAV in the market, the original camera attached on it are most likely support 4K photos capturing, try to capture most clear image for user, but of course for these professional models, the price will be more expensive comparing to small and simple function UAVs.

Thermal imaging camera

Besides, thermal imaging camera will also be installed on the UAV. The purpose of using thermal imaging camera is to take thermal image on the external elements, as one of the limitations of the thermal imaging is that it cannot penetrate through walls, therefore only the external elements can be captured, but in this design, thermal imaging is mainly for the use of checking the external wall. The construction method of the external wall can be either by precast or cast in-situ concrete, the quality needs to be checked and reviewed, to minimize the risk of occurrence of crack on the external wall which can lead to serious structural problem in later stage. Even for precast concrete unit, the quality control will be better when fabricating in factory, however, the precast unit still need to be checked to avoid any risk due to damage or other issues.

The thermal imaging on the external wall is suitable for installing on the UAV as the UAV will be applied in different types of construction site, including civil construction site, building construction site and the confined space application. In building construction site, thermal imaging can be used for checking the crack or honeycomb on external wall. It is similar to the use of infrared camera by taking photos of the external wall, then undergo the analysis to find any crack or potential problem on the external wall, but by using thermal imaging on the UAV, which in building construction project, the UAV can fly closer and higher to take the photos, leading to more accurate result and resolution of images than using infrared camera.
While in civil construction site, thermal imaging can provide the image for the temperature difference between equipment, plants and different working area that can determine the condition of the working environment for the whole construction site. The real-time video will be shown on the interface, for the managers to monitor the temperature of different areas including the plants and equipment, or nearby environment, therefore to determine the level of risk of working environment to the workers based on temperature condition. On the interface, the real-time video from thermal imaging will show the captured environment presenting in different colour according to the different temperature. Higher temperature will present red on the screen, while lower temperature will be presenting in green or blue, so this can indicate the objects or area with high temperature for the manager to be aware, when workers performing work under such high temperature environment for a long period, safety and health issues will appear, such as illness or decrease in productivity. For example, when the thermal image detected the object above 38°C, which is high temperature than human beings, the object will be shown in red on the screen, then the managers need to aware of these areas that generate high temperature, and to remind the workers under this condition or area. Also the system will pop up alert on the screen when detecting such high temperature to assist managers to easily identify such problem on the site.

To conclude, for both the normal high resolution and thermal imaging camera, the function is to capture real-time images and videos, then by real-time technology sent the videos back to the site office control room for real-time monitoring the whole construction site. The real-time monitoring can provide managers the work progress of the work, also with the application of thermal imaging, any crack or honeycomb exist on the external wall can be checked and avoided. Other than that, from the images and videos, the managers can check any illegal activities (e.g smoking) happened in the site that are restricted under the instructions, and also can ensure whether the workers have equipped enough personal protective equipment for performing different work. Moreover, a side benefits from these photos and videos is to save these images and videos for evidence to any claims or disputes in the future.

**5.2 Proposed Sensors applied on the UAV system**

After mentioned the types of cameras needed to be installed on the UAV to capture high-resolution images and videos for real-time monitoring, another purpose of the UAV is to capture air quality and noise data for monitoring the working environment. From the literature review,
several general air pollutants are identified, which are mainly CO, NOx, PM, Ozone, SO\textsubscript{2} and VOC.

Therefore, in order to monitor those air pollutants, individual sensor for monitoring the existence of each pollutants will be installed on the UAV, the sensors are listed below:

**Carbon Monoxide (CO) Sensor**

In order to take accurate reading on carbon monoxide, as there are emissions in lots of construction activities, such as generated from the fuel of the vehicles, and the chemical elements, therefore carbon monoxide sensor is needed to monitor such serious pollutants appeared in construction site.

![Carbon Monoxide Sensor](https://www.olimex.com/Products/Components/Sensors/SNS-MQ7/)

**Nitrogen Oxide (NOx) sensor**

Such pollutant can be generated from the combustion of fossil fuels (coal, gas or oil), also from welding or using explosives, refining of metals, these activities is common in construction site, therefore, NOx sensor need to be installed in order to collect Nitrogen Oxide data.

![Nitrogen Oxide Sensor](http://www.ngkntk.co.uk/index.php/technical-centre/techtalk/sensitive-about-nox/)

**Particle Matter Sensor**

Particle Matter both 2.5 and 10 are also a main pollutants for most of the construction activities generating dust, as these particles can be really harmful to human bodies, causing lung diseases or even death. One of the purposes of the provision of Personal Protective Equipment is to prevent workers absorbing this pollutants, causing serious injuries. Therefore, the PM sensor
will be installed in order to measure the existence of Particle Matter in air by using principle of laser scattering, the diameter and number of particles existed in the air will be processed through analysis. And such results can help the managers in planning of the work or equipment in the site in different area, or provision of extra protective equipment in order to mitigate the seriousness of problem.

Figure 5.3 Particle Matter Sensor (from https://www.aliexpress.com/item/PM2-5-Air-particle-dust-sensor-SDS018-laser-inside-digital-output-SAMPLE-SDS018-Laser-PM2-5/32601595344.html?spm=2114.40010308.4.9.6iyWRE)

Ozone Sensor

Ozone is formed due to emission from vehicles, power plants, industrial boilers, chemical materials, the concentration of ozone will be high in hot sunny days, which is a main characteristic of construction site, where the temperature in site can up to 38-40 degree Celsius in summer time, it is easy to cause serious health effects to worker. Ozone can bring breathing difficulties, serious lung diseases, or even damage to lungs to human body, it also depends on the time of exposure to this pollutant in the working environment, long-term exposure will even cause more serious effect to human body. Therefore, Ozone sensor will be installed in order to monitor the general existence of this pollutant in the construction site, and managers can response to problem when the data detected is over standard.

SO₂ Sensor

The main source of sulfur dioxide is from combustion of fossil fuels, smelting or coal burning etc, and this pollutant can lead to serious effect to human body. The effects caused by Sulfur
dioxide are breathing difficulty, eye irritation, heart failure, which can cause fatalities, and it is also associated with asthma.

![Sulfur Dioxide Sensor](https://www.aliexpress.com/item/Semiconductor-type-gas-sensor-module-detects-sulfur-dioxide-SO2-qualitative-detection-sensor-module/1256473095.html?spm=2114.40010508.4.159.hYe1jg)

**Figure 5.4 Sulfur Dioxide Sensor** (from https://www.aliexpress.com/item/Semiconductor-type-gas-sensor-module-detects-sulfur-dioxide-SO2-qualitative-detection-sensor-module/1256473095.html?spm=2114.40010508.4.159.hYe1jg)

VOC Sensor

The main emission of VOC in construction activities will be on the application of coatings or paving activities, which amount of Volatile Organic Compound will be generated, and VOC can lead to serious health problem such as eye, nose and throat irritation, headache, damage to liver, kidney and central nervous system, therefore, it is important to monitor the existance of VOC in construction site in order to reduce the risk that workers expose to such dangerous environment by appropriate replanning or propose ways to improve the ventilation indoor.

![VOC Sensor](https://www.aliexpress.com/item/Semiconductor-type-gas-sensor-module-detects-sulfur-dioxide-SO2-qualitative-detection-sensor-module/1256473095.html?spm=2114.40010508.4.159.hYe1jg)
Figure 5.5 Volatile Organic Compound Sensor (from http://www.dhgate.com/product/-long-ge-electronics-wsp2110-voc-gas-sensor/233087351.html\#s1-0-1;onsh|2184789867)

Noise sensor

Other than air pollutants sensors, another aspect will be on collecting noise data. As most of the construction equipment and activities will generate high noise level, which can bring hearing effects to the workers under that working environment, noise level must be monitored and develop method to minimize the noise impacts to the working environment by giving guidelines to front-line workers or replanning or relocating the equipment or site layout.

Figure 5.6 Noise Sensor (from http://www.ebay.com/itm/Adjustable-Sensitivity-Sound-Sensor-Arduino-PIC-AVR-Compatible-\US\Ship/322302695048?hash=item4b0abcd688:g:3sAAAOSwUEVYC5Io)

After introducing the sensors to be installed on the UAV applied, each of the sensor will collect their respective air pollutants, and sending the data back to the interface for showing the data to managers for real-time monitoring. The figure below shows the design of installing the sensors on the UAV in different position, after considering the situation that installing the sensors under the main frame may influence the view of the camera, so the design will be installing the sensors on the “legs” of the UAV, in order to have a better connection in the development of the whole sensor system in later stage.
During the design stage of this sensor system, the first design is hanging all the sensors right below the center of UAV, to maintain a better balance for the UAV to fly, but this idea quickly be rejected after discussing with supervisor, as hanging sensors in mid-air when operating, the sensors will move with the UAV movement, and the sensors don’t have enough support. So this design is the latest design, showing the sensors attached to the landing gear of the UAV.

![Diagram of sensor system on UAV](image.png)

**Figure 5.7 Sensors located on the UAV (Preliminary design)**

### 5.3 Proposed Computerized Interface on Laptop display / iPad

The collected data from number of sensors, the captured images and videos from the high-resolution camera and thermal imaging camera, these information need to be presented to the managers through an interface. And the purpose of developing the user-friendly interface is to integrate the information captured and collected to an interface which can show all the information in real-time, instead of the original interface provided by each camera and sensor, then managers can read all the information needed in one interface instead of numbers, which convenient the user in monitoring different data.
By using this interface, managers can not only read the real-time information in the station in site office, instead when manager is performing site walk, while the UAV is in operation, manager can read the information from the Tablets or mobile devices, this increase the mobility of taking the data needed for the managers, and this will not limit the managers, which need to get the information they need in the site office station.

Figure 5.8 User interface (Preliminary design)

In the interface, the data presented are the real-time high-resolution videos and the thermal images on external elements, the air pollutants data and noise data. For the images and videos captured, those information will be show in real-time and save to the database for revision later; For the air pollutants and noise data, the desired presentation style is to presented the data in marked line graph, where the present data can be compared with the previous data collected, in order to observe any sudden increase in value, and check that specified area with the value to be reasonable or not. For the data shown in the interface, when the detected value is higher than the Government standard, the figure will be shown in yellow colour, indicating a minor warning to managers; For the detected value is 50% higher than Government standard, the figure will be in orange colour, indicating a potential health effects; For detected value doubling the standard, the figure will be shown in red colour with a pop-up alert to the managers in order to check that specified area. This system can provide a better indication on the data detected, comparing with standard, then to define the detected value into different level of risk and present to the managers.
At the first stage, there will be no database for managers to compare with, the standard from Environmental Protection Department is the only indicator for monitor the air pollutant and noise data. But after certain time, where the UAV collected more data, database can be formed, the data collect then can make comparison with both the Government standard and the past data in database, which will be a better indicator to identify the increase or decrease in different air pollutant and noise level in long-term, the overall performance of the working environment is better than the past or not, and the database become an important role for the comparison. The end of project does not mean that the data in database become useless and meaningless, but for future project nearby or with similar types of construction, this database can help in improving the working environment and work progress tracking, in order to maximize the productivity and bring a healthy working environment to workers in earlier stage, which will be a great benefit to start the project in future.
CHAPTER 6 – APPLICATION OF AUTOMATED UAV IN VARIOUS TYPES OF CONSTRUCTION SITE

In construction industry, there are multiple types of construction around the city, constructing different structure, contributing to an important element forming the society nowadays. But simply the target construction site for this application are civil construction site, building construction site and the main application at current stage, the confined space application.

6.1 Application on Civil construction site
For the background of the civil construction site, comparing with building construction site, the size of the civil site is usually much larger than the building site, as civil work like bridges, roads, dams, airport, canals etc. the scale of work is much larger than building construction. Other than the scale, the manpower involved in civil site is significant comparing to building construction site, the number of parties involved is very large. So having a large size of manpower, management is the most important element in the project, and effective monitoring can provide better information for the management team through the whole construction progress, finally to complete the work on time without delay, to keep the good reputation.

For the application in civil construction site, the UAV used was mentioned on Chapter 4 & 5, with multiple cameras and sensors, such professional UAV will be performing the real-time monitoring as well as collecting real-time air quality and noise level data around the construction site.

The first idea on the automated route designing for civil construction site was moving in circular path in construction site (Fig 6.1), which start from site office, moving in circular path with each round closer in order to capture videos and data, but after consulting comments from IT professional, this designed route is not efficient and the program will be hard to develop, and leading to decrease in efficiency for managers to see and understand.

The updated designed route (Fig 6.2) for the UAV will start from the site office, which an outdoor area of the site office is for the start point of the automated route, also with an area for storing and charging the UAV when not in operation. After the departure from site office, the UAV will be moving with the grid developed based on the civil construction site. By moving with the grid, the managers can have better understanding on the position of the UAV during the operation, as civil construction site is usually in large scale, using the grid system the managers is easier to identify the position of the UAV in the construction site, therefore to locate
the problem or any issue found from the images or videos quickly and to perform any further action.

Figure 6.1 Preliminary design route for civil construction site (example)

Figure 6.2 Revised design route of UAV for civil construction site (example)

Normally the operation time for the UAV will be around 20 to 30 minutes, and the charging time of the UAV will be around 60 to 90 minutes for full charge, therefore one UAV is not
enough to monitor the whole civil construction site. Then multiple UAVs will be required to cover all the area of the civil site, to avoid missing any part of the site to be monitored.

After flying in grid line system or the battery level is low, the UAV will return to the site office, which is the original position to finish one cycle of work and recharge the UAV for another use later on.

The hovering height of the UAV will be around 10 meters high in order to perform the monitoring and collecting data. Such height will provide clear and broad image and video for real-time monitoring, and managers can obtain the information of work progress and air and noise data in the construction site from the real-time monitoring.

In current situation, as the regulation from civil aviation department stated that the Unmanned aircraft system cannot flow close to any facility that would present a risk to safety in the event of damage due to any impact by the aircraft system. Therefore, the only limitation in the construction site is the crane, either tower crane or mobile crane. So the UAV needs to fly when the crane is not in operation to avoid any risk of causing collision and leading to accident.

For stage 2 development, the whole system will not only consisted of UAV with multiple sensors, automated routing by the program, as there are limitations stated in previous paragraphs, leading to difficulties in applying the UAV system in the site. But stage 2 development will eliminate these problems and make it easy to apply. In next stage, the system will also cover the cranes, both tower crane and mobile crane, as the main limitation of first stage design is the concern on the relationship between cranes and UAVs, that may lead to crash if not properly control, but in stage 2, there will be sensors installing on the cranes, showing the position of crane in construction site, on the other hand, when the UAV operates, the UAV will calculate the distance between the crane and the UAV. If the distance is within limited range, the program for the UAV will stop the UAV and keep it hovering or moving backward instead of still moving towards the crane. This function can eliminate the risk of causing crashes as well as improving the stability and functionability of the whole system.
Figure 6.3 Civil Construction Site Demonstration using Building Information Modeling (captured from video snapshot by Ms. Rebecca Chan)
6.2 Application on Building construction site
For the application in building construction site, it is different from the application in civil construction site. As the scale of building site is much smaller than civil site, all the plants, equipment and workmanship will concentrate in a small area, the managers will be easier to monitor the ground working environment, but building construction usually consisted of multi-level construction, which the manager need to know the work progress as well as the working condition in different level, then the UAV can be apply.

The designed route of the UAV used in building construction site will be different from application in civil site, but the first part will be similar for both applications. The UAV will depart from the site office, firstly to move along the site boundary to capture ground level videos and data for real-time monitoring, not only there are construction activities within the building, other activities such as steel-bending, loading and unloading of materials will be performed in other area, those construction activities on ground cannot be omitted as those activities will also generate air pollution and noise that the managers need to monitor also. After finishing the ground level monitoring, the UAV will then fly up to the first floor of the building under construction, hovering outside the external wall with a distance of 3 to 5 meters, then move around the first level in order to capture real-time video with high resolution camera, thermal images on external wall and the air quality and noise data detected. The next step will be moving upward to another level, repeating the procedure of moving along the external side of building to collect data.

Figure 6.4 Designed route of UAV for high-rise building construction site (example)
As the operation time is limited on around 20 to 30 minutes, and the UAV need to hover and fly slowly to capture accurate data and videos, so it can only fly around 8 to 10 floors. Comparing to the building construction nowadays, usually consist of more than 30 floors, apparently one UAV is not enough. But for the other UAV, the program should be adjusted, to reduce the flying path by deleting the ground data collection, and directly fly to the specific floor from the site office, to save the power for lifting upward to higher level.

One of the major benefits of apply UAV technology in building construction site will be on skyscraper construction, which can be more than 80 storeys high, it will be a difficulty for the management team to monitor all the information on each storey and get the accurate information needed. By using UAV s, the managers can save the travel time and get the accurate and exact information from the UAV. With the UAV, the frequency of performing site walk can reduce, but will not affect the efficiency of monitoring work progress of the manager as the UAV will help the managers to collect the general information on the work progress.

However, a regulation published by Civil Aviation Department stated that the use of UAV should not exceed 300 feet (around 100m) from the ground level, this rule limited the UAV to apply in skyscraper construction in current stage. Therefore, the application of UAV on building construction site in this project shall be divided into different stages in order to develop the use of UAV step by step.

First stage

As the height of flying UAV is limited, in current situation, the UAV can be apply on existing building structure. The first idea developed is to use the dr UAith both high-resolution camera and thermal imaging camera attached, without any sensors installed, to be applied in checking the quality of the external wall of existing building under Mandatory Building Inspection Scheme (MBIS).

One of the scopes under MBIS is to inspect the external elements and the physical elements, which normally for existing building constructed for a long period, the external elements will consist of different problem, such as cracks on external wall. Related to this problem, the UAV can apply in this inspection. Although the infrared camera can be used in taking photos in order to check whether there are crack exist on external wall, the application of UAV can fly much
closer to take photos or videos with more accurate results, rather than taking pictures from the ground.

The UAV can support both manually or automatically with program installed, the route is similar to building construction site, hover along the external wall of each floor to capture images and videos for inspection, and such application for inspection can give a better, accurate and clear results on the external elements that minimize the risk of unexpected accidents or provide clearer image of the existing building.

Second Stage

In the first stage, it is similar to that the tower crane in building construction site is the main difficulty for this UAV application, also the regulations from Civil Aviation Department may limit the application nowadays. But in the future, everything may change. Take a look in Japan, the original regulations for UAV system had changed, due to Government’s willing to support public in using UAV system in an innovative way, such as the UAV to carry object and transport to another place, which an experiment in Japan successfully transport an object for 12 kilometers, a great way to show public and government that there are still a lot of potentials using UAV system and those innovative scene shown in movie may become real soon.

Therefore, in second stage, the tower crane will also be covered, as well as any equipment or plant that will affect the UAV’s path in building construction application, sensors will be attached to these equipment or plant, and the program will be upgrade with the function that it will continuously calculating the distance between the UAV and these plant, in order to avoid crashing or accident by stopping the UAV go further or force the UAV to go backward.

And then for the user interface showing all the data, images and videos, the interface will also show the map of whole construction site, including the location of UAV and other equipment or plant with sensors installed, to provide the managers a better and all-round view of whole construction site.
Figure 6.5 Building Construction Site Demonstration using Building Information Modeling
(captured from video snapshot by Ms. Rebecca Chan)
6.3 Application on Confined Space Environment: Cavern Development

The application in confined space is the main application in current situation, from the literature review on the cavern development, there will be more cavern development in the future in different place around Hong Kong, the potential of cavern development is very huge that there will be more cavern project in construction industry in near future.

The main reason applying UAV in confined space is to replace human being from going into confined space environment, as the air pressure or air pollutants inside the confined space are unstable, it is dangerous to send a worker into the confined space. But with the use of UAV, by installing specific sensors and night vision camera on the UAV, it can detect different data and capture images and videos for the environment of the confined space. The value of a life is uncountable while the value of the UAV can be calculated, it can reduce the risk of any unexpected event in the confined space by replacing the job by human, in order to reduce the risk of any accident and protect the workers from harmful environment.

In the cavern application, the UAV is responsible for image and video capturing with collecting air and noise data during construction stage, managers can fly the UAV on a specific interval to record the work progress. For the tunnel drilling in cavern construction, the use of UAV may need to be manually control rather than controlled by program, as the program needs to be constantly adjusted due to different stage of drilling completed, manually control may be better in this application.

The image captured can be processed and generate a 3D model each time after flying the UAV into the cavern, and the models generated can form a database, and managers can compare between different models generated, to record and get information on the work progress. Moreover, during the comparison, managers can identify any changes on the structure, as high-resolution images with advanced modeling technology can generate very high accuracy model, to let the managers to see the difference. This function can be important in cavern construction, although detail site investigations are performed before commencing any work, it is better to further reduce the risk of any accidents happened referring to the structure of cavern.
Figure 6.6 Example on flying UAV in cavern construction
(Background illustration from: http://www.cavern.gov.hk/suitability.htm)

Figure 6.7 Possible routes of flying UAV in cavern development in different construction stages
CHAPTER 7 – RESULTS AND ANALYSIS OF INTERVIEW

In different stages of this project, interviews were conducted to present the whole idea, aiming to receive comments and improvements on this whole design and development, in order to improve the design and solve challenges faced in different stages of this project.

7.1 Idea consolidation stage
At the beginning of this project, lots of ideas came up during brainstorming with my supervisor, and the topic related to UAV was then quickly developed, and the idea started to be more solid instead of just focusing on the UAV field. After finishing the first solid idea, I met the innovative manager from Gammon Construction Limited to have an idea consolidation present and interview in October, 2016, simply presenting my idea to him, then seeking comments and recommendation for improvement on this project.

Figure 7.1 Meeting with Innovative Manager from Gammon Construction Limited
During the presentation, the whole idea of using UAV with multiple cameras and sensors was presented, also with the potential application on different construction site, but the application part at that time was not solid at all, and I was seeking any comments on the application of UAV. The whole presentation is around 15 minutes, presenting the whole idea.
After the presentation, Andy Wong (Innovative Manager from Gammon Construction Limited) gave me comments on my whole project. He first addressed that they had UAV application in their company, which can also be seen on newspaper that the UAV was used for land surveying, which was a basic application of UAV. And the most important difficulty to apply this project into construction site will be the relationship of UAV and crane in the site, he commented that the UAV may crash towards the crane and causing accident. And this issue became the second stage development of my project stated in application in construction site, and at that time, I was not very familiar with the regulations from Civil Aviation Department on the use of UAV system, so I didn’t considered this issue during idea developing stage, and I found that Mr. Wong’s comments was very useful for me during that stage and really helps me in improving my design and development, as well as application in construction site.

Figure 7.4 Photo taking after presentation and idea incubator workshop
7.2 Design stage
After the idea consolidation stage, the whole idea was improved by adding more features and application to become a more solid idea, such as the cavern development application which will be a main development in future construction industry due to shortage of land problem.

So one of the features of this project is the automated routing for UAV, which is a program developed to guide the UAV to fly in a specific designed route, in order to perform real-time monitoring for managers in construction site. In order to learn more on automated routing for UAVs on programming, I have visited an IT company in Science Park in November 2016, which Tony is the director of this technology company.

![Figure 7.5 IT company visit in Science Park (accompanied with Professor Andrew Leung)](image)

During the company visit, one of the main aspect of the company is on the UAV application, which they did wrote a program installing to the UAV, and fly on top of Science Park, to capture photos in order to generate a bird view mapping of Science Park. The technology they used was the GPS technology, indicating the location of the UAV then setting a specific route using the program to control the flight path of the UAV. And the flight path is flying in grid system, which can help to identify the location easily and more efficient way to collect data.
During the visit and a short interview, Tony thought that writing a program to guide the UAV to fly was not difficult, it can be achieved by programming without any interference nearby to affect the accuracy of GPS. And he commented that the same technology can be applied into construction site, given that the designed route will not have significant interference that leading to error on the accuracy of GPS, other than that, UAV is in fact can be applied in construction site, if the operator use it safely and follows all the guideline and comply with all statutory regulations.

Figure 7.6 Product of UAV with computer program installed

Figure 7.7 Smart City Exhibition in Science Park
After the company visit, I have also participate in this Smart City Exhibition in Science Park, showing some new innovative technology and concept related to Building Information Modeling (BIM) and other computing technology that will be apply into market very soon, and these information helps me in the future potential development part, which I can integrate the UAV system to these new technology and create more application that can be applied in construction industry.

![Smart City Exhibition in Science Park](image)

**Figure 7.8 Smart City Exhibition in Science Park**

After the exhibition, the new part of Science Park is under development, which is the construction site shown below (Fig 7.9), consisted of numbers of mobile cranes in the construction site, which can cause huge interference for the UAV system to fly inside the site, the cranes are moving within limited site area, so my supervisor and me brainstorm and discuss for how to apply the UAV in this kind of congested construction site, in order to have a higher efficiency in real time monitoring.
Figure 7.9 New phase of Science Park (Construction Site) (Site layout planning and Locations of Cranes observed)

Figure 7.10 New phase of Science Park (Construction Site) with Dr. Ivan Fung, Supervisor
7.3 Development stage

Sensor system development
After the design stage, the development stage is mainly carry out in Semester B 16/17, which the first thing to do is to develop the multiple sensors system, and during the development of the sensor system, I have phone interview with Mr. Patrick Yip, Lab manager from Poly University of Hong Kong. He gave me some useful comments on the sensors system development.

First of all, the sensors that I decided to use is appropriate to be applied on the UAV, which all the sensors can be purchased from TaoBao and deliver to Hong Kong within few days, which can help me to start the development faster as well as lower the cost of the sensor system.

Secondly, the platform of the sensors to connect with should be the Arduino, using the same platform, it can connect to all sensors, thus can obtaining the data from the sensors at the same time, to speed up the time to obtain data as well as making the whole system more easily to be developed.

Lastly will be on the location of the sensors attached on the UAV, Mr. Yip suggested that cover should be provided to avoid errors on data collection, as the props of the UAV will generate upthrust force that pushing air downward, the data obtained may contain error that cover should be installed to minimize the effect from these wind and get more accurate result.
**Employer’s Luncheon 2017**

This event was held in 16 March 2017 by the Student Development Services, City University of Hong Kong, the exhibition located in Convention Foyer, Hong Kong Conventional and Exhibition Centre (Old Wing). Department of Architecture and Civil Engineering invited me to join this exhibition to present this innovative UAV system to potential employer from different field or industry. I was the only one from Construction Engineering and Management Year 4 joining this exhibition and during conversation with different professional from different field, there are more ideas and improvements towards my design.

![Setup in Employer’s Luncheon Exhibition](image)

**Figure 7.11 Setup in Employer’s Luncheon Exhibition**

Figure 7.11 showed the basic setup of my exhibits during Employer’s Luncheon, which consisted of a A0 poster showing all the details of my whole idea in final year project, and there is a example on the professional model of UAV, DJI’s Inspire 1, and the computer is mainly for showing the potential employer the demonstration on UAV system in Civil construction site as well as Building Construction Site.
The first honorable guest to my exhibition is Dr. Allan Zeman, which is an alumni of City University of Hong Kong. I have presented my whole idea to him, also showing the demonstration of using UAV system in Civil Construction Site and Building Construction Site. And he commented that the whole concept and idea was very clear and good that is innovative to construction industry and he was looking forward to seeing the completion of this project and encouraged me to keep it up and think of more innovative idea to contribute to construction industry.
After presenting with Mr. Paul Chan, Chief Designer of shopping+, he was impressed by my idea, saying that more UAV application will be developed soon, to be used in different industry, e.g. construction industry. And he also stated that his company already working on some of my suggested future potential development, like UAV integrated with Building Information Modeling (BIM), combination with RFID technology etc. And the UAV can become an important role in different field. He then invited me to exchange idea after the Luncheon Exhibition, and maybe in the next few month, as he was seeking for potential target that with innovative mind to work in his company.

DJI’s company visit (accepted invitation, to be arranged)

In April 2017, I am looking forward to visiting Da-Jiang Innovations Science and Technology Co. Ltd. after sending the letter of company visit in February 2017. As DJI is the world’s most famous company developing UAV, it will be a great opportunity to present my idea as well as seeking the comments from their design managers working on UAV aspect, and I hope that given the company visit, I will have more knowledge on the UAV development nowadays and may develop new idea based on what I know in current stage.
Shui On Plant Maintenance Factory Visit on 15 March 2017

During the factory visit in Ta Ku Ling, Hong Kong, my colleagues and me visited the factory and met the current assistant plant manager and plant and machinery manager Mr. Li Koon Wah and we discussed on our final year project to have a short interview for seeking comments and improvement on our projects.

![Photo of the visit](image1.jpg)

**Figure 7.15 Factory visit with Mr. Li Koon Wah and Mr. Ben Tam**

After sharing our ideas from our final year project, Mr. Li gave us comments project by project, and he doubted that using multiple CCTV system is enough for real-time monitoring, using UAV maybe an innovative way to perform the real-time monitoring, but he thought that using traditional way (CCTV) was more reliable as the cost of UAV system is unknown and the CCTV system and zoom in and out to get accurate information. The CCTV system with 7 cameras need more than 100 thousand HK dollars to setup, but for larger civil construction site, using CCTV maybe difficult due to data transmission issues or cost issues.

![Photo of the visit](image2.jpg)

**Figure 7.16 Photo taking after the factory visit**
CHAPTER 8 – DISCUSSION AND POTENTIAL FUTURE DEVELOPMENT

Designing a new product or technology to be used in construction industry is difficult as the concept of most of the people working in this industry are traditional, not willing to try and invest in new and innovative technology, the design maybe much easier than implementing this concept to construction industry and further apply it in construction site.

During the brainstorming stage, it was very difficult for me to come up the idea on UAV system, as the original Final Year Project aspect was on Construction Robotics, and looking into the market as well as reviewing literature, the development of robotics started from 1980s, which there were different kind of robotics developed to help simple construction work such as bricklaying, demolition and mini site robots, and in recent years, there were more concept showing to public that more kind of robots can be designed and developed to perform more advanced construction work, and I believed that there will be no workers in the future construction site performing each step of the work, replaced by these robotics, and only the robots operator need in construction site to monitor and manage the robot to perform the work quickly and efficiently. Developing the idea in UAV aspect in brainstorming stage was started after looking to some video clip in social media, stating that Japan was started to develop using UAV to transport materials and this can be a huge improvement in sending materials to a specific point in the future, eliminating the risk of traffic congestion and speed up the transportation time.

During the design stage, the number of UAV model in the UAV market was very large that the price range can vary from hundred HK dollars to 40 thousands HK dollars, and the function and specifications of each UAV are different, it was difficult to find certain model that was suitable for this project, but soon 2 types of UAV were chosen that was suitable to be used in this project, and the application method of each UAV was different due to their different specification and characteristics. Also in the multiple sensor system design, the design was keep revising after consulting comments and improvements from electronic engineering professional, and the multiple sensor system will be presented in the final present in April, showing the product integrated into the UAV system.
In the development stage, I have undergone several meetings with different professionals through Employer’s Luncheon or company visit, and the comments and improvements received were all very useful to my current and future development of this system. And I was glad to hear some concern on the application at current stage, due to limitation from statutory regulations, or concern about the effectiveness comparing with traditional CCTV system. In current stage, there are several limitations, such as the regulations from Civil Aviation Department limited the height of flying the UAV, and the UAV cannot affect the movement of cranes that may leading to crash or accidents, but these limitations can be solved in next stage stated in Chapter 6 the application part, in future development, more plants and machinery can be added into the whole system and try to digitize most of the plant and equipment in construction site, to monitor the whole site with just one platform, then the efficiency will be improved thus give advantage towards the time, cost and quality, as well as safety and environment in construction site.

For this final year project, there were lots of challenges during different stages and different aspects, it was very difficult to finish the whole idea within one year, the user interface designed in Chapter 4 was not yet finish developed before submitting this report, and I would like to have future stage 2 or even stage 3 to keep improving my design and development in future, and hoping that there will be student doing this topic to have future idea in next year.

For the future potential development, this UAV system can be integrated with Building Information Modeling (BIM), such as translating the aerial photos captured to automatically update the Building Model combining with the master program developed to show the time condition of the construction project; Other than integrating with BIM, UAV system can also combine with RFID technology, as RFID technology started to be applied in construction site, UAV can act as a moving receiver to capture data or perform checking in construction site. Besides these two aspects, there are still more potential development that can be integrated with UAV system and contribute to construction industry soon.
CHAPTER 9 – CONCLUSION

The whole idea of this final year project is that using the popular aerial photography technology platform, which is the Unmanned Aerial Vehicle system, with high-resolution camera and thermal camera installed, also integrated with 6 air pollutant sensors and 1 noise sensor to collect air quality and noise data in different area in construction site. All these photos, videos and data collected will be real-time showing on the user interface, then the managers can watch these real-time data on mobile, tablets or computer in order to know the actual work progress as well as the condition of working environment in construction site. This system will be developed in various stages, the current development will be applying the UAV system in civil or building construction site, which the demonstration of application in both civil and building construction site are shown in Chapter 6 application part. Other than civil or building construction site, this UAV system can be also applied in cavern development, which will be a major development in future land development. In next stage, more machinery in construction site will be added to this system to form a more stronger and advanced system in order to have a better monitoring and management in the future.

By implementing this system into construction industry, more effective monitoring and management in different aspects can be achieved, the project managers or construction managers can obtain faster and more accurate information on work progress, working environment or identifying any illegal activities inside construction site; also it can help safety managers in obtaining safety level, potential danger or working environment from thermal image and air quality data collected in construction site. Finally hope that this UAV system can be applied in construction industry and bring in new concept to people working in this industry.
Appendix A1 – Meeting Schedule

The meetings with supervisor started after the appointment of supervisor in June 2016.

In the first few meetings with supervisor, mainly focusing and discussing on the potential topics for this research study. Following by idea consolidation meetings, supervisor provided lots of suggestions and supports during Semester A in 2016/17.

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<tr>
<th>No. of meeting</th>
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<th>Brief summary of discussion</th>
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Appendix A2 – Progress Plan for Semester A in 2016/17

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## Appendix A3 – Progress Plan for Semester B in 2016/17

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Appendix A4 – UAV Components Definition

From Corrigan, 2015 defined the UAV components as follows:

Standard Prop - The “tractor” propeller are the props at the front of the quadcopter. These props pull the quadcopter through the air like a tractor. While some UAVs like the DJI Phantom look more or less the same from any angle, there is a front and back. Most UAV propellers are made of plastic and the better quality made of carbon fiber. Better prop design will assist with giving a better flying experience and longer flight times. There is also some big innovation towards low noise uav props.

Pusher Prop - The Pusher props are at the back and push the uav forward hence the name “Pusher props”. These contra-rotating props exactly cancel out motor torques during stationary level flight. Opposite pitch gives downdraft. Again, can be made of plastic with the better pusher props made of carbon fiber.

Brushless motor - Practically all the latest UAVs use a brushless electric “outrunner” type, which is more efficient, more reliable, and quieter than a brushed motor. Motor design is important. More efficient motors save battery life and give the owner more flying time which is what every pilot wants.

Motor Mount - Sometimes built into combination fittings with landing struts or can be part of the UAV frame.

Landing Gear - UAVs which need high ground clearance may adopt helicopter-style skids mounted directly to the body, while other UAVs which have no hanging payload may omit landing gear altogether.

Boom - Shorter booms increase maneuverability, while longer booms increase stability. Booms must be tough to hold up in a crash while interfering with prop downdraft as little as possible. In many UAVs the boom is part of the main body. Other UAV have a definite boom as a separate part.

Main body - This is the central hub from which booms radiate like spokes on a wheel. It houses battery, main boards, processors avionics, cameras, and sensors. Most UAVs are not waterproof so it is vital that the internal components of the main body do not get wet. A hard landing may not break the body of the UAV but the shock could damage the internal UAV components in the main body.
Electronic speed controllers (ESC) - An electronic speed controller or ESC is an electronic circuit with the purpose to vary an electric motor’s speed, its direction and possibly also to act as a dynamic brake. It converts DC battery power into 3-phase AC for driving brushless motors. Electronic Speed Controllers are an essential component of modern quadcopters (and all multirotors) which offer high power, high frequency, high resolution 3-phase AC power to the motors in an extremely compact miniature package.

Flight Controller - The flight controller interprets input from receiver, GPS module, battery monitor, IMU and other onboard sensors. Regulates motor speeds, via ESCs, to provide steering, as well as triggering cameras or other payloads. Controls autopilot, waypoints, failsafe and many other autonomous functions. It’s central to the whole functioning of the UAV.

GPS module - Often combines GPS receiver and magnetometer to provide latitude, longitude, elevation, and compass heading from a single device. GPS is an important requirement for waypoint navigation and many other autonomous flight modes. Without GPS UAVs would have very limited uses. Along with FPV, UAVs can navigate long distances and be used for exiting applications such as lidar and photogrammetry. GPS stands for Global Positioning System. It is an American standard which provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.

Receiver - Often a standard r/c radio receiver unit. The minimum number of channels needed to control a quad is 4.

Antenna - Depending on your receiver, it may be a loose wire whip or helical “rubber ducky” type. Circularly polarized cloverleaf antenna gives you further video signal distance and improves the video stability. A very good antenna stops the problem of the multi-path effect and also blind angle.

Battery - Lithium polymer (LiPo) batteries offer the best combination of energy density, power density, and lifetime on the market.

Battery Monitor - Provides in-flight power level monitoring to flight controller. The battery is critical to flying safely. If the UAV fly to far out and runs out of battery then it will either make an emergency landing or will crash.
Gimbal - The UAV gimbal is the pivoting mount that rotates about the x, y, and z axes to provide stabilization and pointing of cameras or other sensors.

Gimbal Motor - Brushless DC motors can be used for direct-drive angular positioning, too, which requires specially-wound coils and dedicated control circuitry that have only recently become commercially available.

Gimbal Controller Unit - Allows control of direct-drive brushless gimbal motors as if they were standard hobby servos.

Cameras and Sensors - GoPro or other compact high definition video unit with onboard storage. Real-time streaming is possible on the latest UAVs.
Appendix A5 – UAV Technology Definition

According to Corrigan, 2016, the general technology used in the UAV are defined as follows:

Radar positioning and Return Home – The flight radar displays the current position and location of the UAV in relation to the pilot.

Gyro Stabilization – Gyro stabilization technology is one of the components which gives the UAV its smooth flight capabilities. The gyroscope needs to work almost instantly to the forces moving against the UAV. The gyroscope provides essential navigational information to the central flight controller.

IMU – The inertial measurement unit (IMU) works by detecting the current rate of acceleration using one or more accelerometers. The IMU detects changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes. The flight controller is the central brain of the UAV.

First Person View (FPV) – What FPV means is “First Person View” which means a video camera is mounted on the unmanned aerial vehicle and broadcasts the live video to the pilot on the ground so the pilot is flying the aircraft as if he/she was on-board the aircraft instead of looking at the craft from the pilot’s actual ground position. FPV allows the unmanned aircraft to fly much higher and further than you can from the looking at the aircraft from the ground. FPV control allows for more precise flying around obstacles especially with unmanned aerial vehicles which can easily fly indoors and through forests via FPV where you would not be able to see obstacles from a fixed position.

High performance camera – Many of the earlier UAVs used cameras which were not fully suitable for aerial filming. Many of these aerial videos had barrel distortion because of the wide angle lens.

Gimbal and Tilt Control – The gimbal allows you to tilt the camera while in flight, creating unique angles. It uses a 3 axial stabilized gimbal and has 2 working modes. Non-FPV mode and FPV mode. Practically all the latest UAVs have integrated gimbals and cameras.

Operating system – Some unmanned aircraft use MS Windows operating systems. However more and more UAV innovators are now using different versions of Linux. The Linux Foundation recently launched the Dronecode project. The Dronecode Project is an open source, collaborative project that brings together existing and future open source unmanned aerial vehicle projects under a nonprofit structure governed by The Linux Foundation. The result will
be a common, shared open source platform for Unmanned Aerial Vehicles (UAV). UAVs in some ways are flying computers. With an operating system, flight controllers, main boards with programmable code, they can also be hacked into.
Appendix A6 – General Guidelines on using UAS from CAD
The following are the general operational parameters for safe operations of non-recreational UAS under Civil Aviation Department:

1. Area of operations
   a) UAS shall normally not be flown within the Aerodrome Traffic Zone (ATZ) or within 5 km of any aerodrome.
   b) UAS shall not be flown over or within 50 m of any person, vessel, vehicle or structure not under the control of the UAS operator; except that during take-off and landing, the UAS must not be flown over or within 30 m of any person other than the person in charge of the UAS or a person necessarily present in connection with the operation of the UAS. Further conditions on flight safety clearance may be imposed on the operation of the UAS as necessary.
   c) The UAS operation site (including emergency operation zone and any safety zone for the operation of the UAS) shall be under the operator's full control.
   d) The take-off and landing area should be properly segregated from public access.

2. Control of UAS
   The UAS operator shall be on site and keep the UAS within Visual Line of Sight (VLOS) during the period of the flight. Operating within VLOS means that the UAS operator is able to maintain direct, unaided (other than corrective lenses) visual contact with the UAS, and is able to monitor the UAS flight path in relation to other aircraft, persons, vessels, vehicle and structures for the purpose of avoiding collisions.

3. Other related issues
   a) The UAS operator is responsible for ensuring that no person and property would be endangered by the UAS, and shall not fly the UAS unless he has reasonably satisfied himself that the flight can be safely made.
   b) No hazardous material may be carried nor objects be dropped from the UAS in order to avoid endangering persons or property on the ground.
   c) The person in charge of the UAS shall not fly the UAS unless before the flight he has satisfied himself that the mechanism that causes the UAS to home and land in the event of a failure of or disruption on any control systems, including the radio link, is in working order.
   d) The UAS operator shall maintain records of each flight made pursuant to the permission and makes such records available to CAD on request.
e) A site safety assessment has been completed by the UAS operator, and can be made available to CAD on request.
f) Permission of the land/property owner on whose land/property the UAS is intended to operate has been obtained.
g) The operation is carried out in accordance with the operations manual submitted to CAD.

4. Altitude of Operations
The altitude of UAS shall not exceed 300 feet above ground level.

5. Altitude keeping performance capability
The UAS operator shall describe the means of altitude keeping to ensure that the actual altitude flown is accurate.

6. Time of Operations
a) UAS operations shall be conducted during daylight hours only.
b) No more than one UAS will normally be permitted at any one time within the same block of designated airspace.

7. Weather Criteria
a) ground visibility of not less than 5 km - visibility of more than 5 km may be required depending on the nature and area of operations;
b) cloud base not lower than the approved altitude of operations;
c) surface wind of no more than 20 knots, unless otherwise specified by the manufacturer (the surface wind speed limit may be reduced if the controllability of the UAS is in doubt);
d) the UAS operator shall have a hand-held anemometer to monitor surface wind speed on site; and

e) the UAS operator must not launch the UAS when Rainstorm Warning, Tropical Cyclone Warning or Strong Monsoon Signal is in force.

8. Pilot Qualification
Evidence of pilot competency is required when making an application for permission to operate UAS.
a) The UAS operator is required to submit an operations manual covering the procedures to be followed for all envisaged operations of the UAS. This document is a key requirement to enable CAD to accurately assess the application and the safety case before deciding whether to grant a permission.
b) Guidance for the compilation of the UAS operations manual can be downloaded.

10. Communication with ATC
a) The UAS operator shall inform the CAD/Aerodrome Supervisor before launching and on completion of the UAS operation.
b) The UAS operator shall provide his/her contact phone number to the CAD/Aerodrome Supervisor, who may instruct to stop the operation when necessary.

11. Frequency spectrum and Radio Frequency Interference (RFI)
The UAS operator is required to seek approval from the Office of the Communications Authority on the use of radio frequencies and to ensure that no RFI is caused to air traffic operations and air navigation equipment.
Appendix A7 – Common Gas Pollutants in HK

According to Air Quality in Hong Kong 2015, the primary pollutants in HK are listed below with definition and sources of emission described:

Sulphur Dioxide (SO$_2$) - Sulphur dioxide (SO$_2$) is formed primarily from the combustion of sulphur-containing fossil fuels. In Hong Kong, power stations and marine vessels are the major source of SO$_2$, followed by fuel combustion equipment and motor vehicles. Exposure to high levels of SO$_2$ may cause impairment of respiratory function and aggravate existing respiratory and cardiac illnesses. Prolonged exposure at lower levels may also increase the risk of developing chronic respiratory diseases.

Nitrogen Oxide (NOx) and Nitrogen Dioxide (NO$_2$) - The various chemical species of the oxides of nitrogen are collectively termed as nitrogen oxides. From an air pollution standpoint, the most important nitrogen oxides in the atmosphere are nitric oxide (NO) and nitrogen dioxide (NO$_2$). In the context of air pollution, these two gases are often mentioned as nitrogen oxides (NOx). They are usually produced in combustion processes. Emissions from power stations, marine vessels and motor vehicles are the major sources of NOx in Hong Kong. NOx emissions from motor vehicles have greater impact on roadside air quality. NO$_2$ is mainly formed from the oxidation of NO emitted from fuel combustion. Long-term exposure to NO$_2$ can lower a person’s resistance to respiratory infections and aggravate existing chronic respiratory diseases.

Ozone (O$_3$) - is a major constituent of photochemical smog. It is not a pollutant directly emitted from man-made sources but formed by photochemical reactions of primary pollutants such as NOx and volatile organic compounds (VOCs) under sunlight.

Carbon Monoxide (CO) - Carbon monoxide comes mainly from vehicular emissions although a small amount of which may also come from flue gases of factories and power stations. When it enters the bloodstream, CO can reduce oxygen delivery to the body’s organs and tissues. Typical symptoms of CO poisoning include shortness of breath, chest pain, headaches, and loss of coordination. The health threat from CO is more severe for those who suffer from heart diseases.

Respirable Suspended Particulates (RSP) - Respirable suspended particulates (RSP or PM10) refer to those suspended particulates with nominal aerodynamic diameters of 10 micrometres or less. In Hong Kong, the ambient particulate matters including RSP and FSP are contributed mainly by the regional sources. Combustion sources, in particular marine vessels, diesel vehicles and power plants, are the major regional and local sources of RSP and FSP.
Fine Suspended Particulates - Fine suspended particulates (FSP or PM2.5) refer to those suspended particulates with nominal aerodynamic diameters of 2.5 micrometres or less, which is the finer component of RSP. FSP is able to penetrate to the deepest parts of the lung because of its small size, hence poses a higher risk to health. Besides, FSP also causes visibility impairment in air.
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