An Analysis on the Development of Unmanned Aerial Vehicles

Submitted to Prof. Hartaj Sanghara

By Jian Gao, Jacky Yu, Matthew Lee, Tiffany Wang, Ziqi Su

Source: https://static.bhphotovideo.com/explora/sites/default/files/styles/top_shot/public/topshot6_1.jpg?itok=nCfsaZDt

The University of British Columbia

ELEC 281

April 5, 2019

ABSTRACT

"An Analysis on the Development

of Unmanned Aerial Vehicles"

This report discusses the development of modern Unmanned Aerial Vehicles, also known as drones, which are automatic aircraft controlled by remotes and on-ground control stations. Our analysis focuses on the perspectives of drone history, principles of operation, common applications, relevant technologies, advantages and disadvantages, and possible improvement.

Originating from a simple idea during World War I, UAVs set foot on a long path of innovation and development. Over 100 years, due to the breakthrough in aerodynamics and electrical engineering, the sizes and shapes of drones took a significant change as well as the purposes they have been serving. That makes it another classical example of technology transformation from military to civil.

Nowadays, drones and their variations have profoundly improved the quality of our lives by delivering packages in 30 mins, capturing exciting aerial video footage, and tracking livestock and the growth of crops etc. On the contrary, as killing machines, they are also known for their efficiency and dramatic effect on the battlefields.

Although the ethical dilemma remains, the discussion on further improvement and integration of new technology with UAVs continues. With future achievement in miniaturization and autonomy, more categories and functionalities are expected from drones.

TABLE OF CONTENTS

List of Illustrations

Glossary

Aerodynamics:	The study of the properties of moving air and its interactions with objects moving through it.
Bootloader:	A program that initializes computer hardware before the operating system launches.
Closed-loop systems:	A category of functions in which a portion of the output is used in the input to influence the operation of the next cycle.
GIT:	A version control system that engineers can use to keep track of changes in code, allowing contributions from multiple developers. Open source projects are supported by GIT which allows anyone to contribute to source codes.
Microcontroller:	A small computer on an integrated circuit that is used to control part of an embedded system
Peripheral devices:	Hardware devices accessed by the controller to achieve particular functions.
Propulsion System:	A system that converts motion generated by an engine into thrust.
Remote-controlled vehicle:	A vehicle that is controlled from a distance using a remote.

Remote sensing:	The acquisition of electromagnetic waves coming from a distant object for the purpose of analyzing its shape, composition and other physical properties.
Dynamic range:	The capability of a camera to capture details in both low light and high light conditions

List of Abbreviations

UAV	Unmanned Aerial Vehicle
I2C	Inter-integrated Circuit
FAA	Federal Aviation Administration
RPAS	Remotely Piloted Aircraft System
UGV	Unmanned ground vehicle
UCAV	Unmanned Combat Aerial Vehicle
GPS	Global Positioning System
HRI	Human-Robot Interaction
FPV	First-Person View
OCUs	Operator Control Units
VLOG	Video Blog
FLIR	Forward-looking Infrared
POV	Point of View
WWI	World War I

1.0 INTRODUCTION

The purpose of this report is to investigate Unmanned Aerial Vehicles. This report examines drones from the history of UAVs, the principles of operation, the benefits and drawbacks of drones, a few applications of modern UAVs and several possible future improvements.

With newly developed technology and designs, the reliability and stability of the UAVs have rapidly increased and the costs have decreased exponentially. UAVs have been used in a growing number of applications in commercial and military fields over the last decade. Thus, it is significant to have a brief understanding of what drones are and how to apply them in various fields. Drones have been widely used in the engineering field, so it is important to know the advantages and disadvantages and foresee the possible features in the future.

This report will briefly introduce the history, principles and technologies of drones, and analyze the applications from the aspects of military, aerial photography and rescue. Drones are involved in these fields to allow precise mapping or executing for surveying service while improving crew safety. While there are many benefits and advantages when it comes to modern drones, there are as many shortcomings as well. Several controversial ethical issues of using drones in future are keep discussing by experts. This report also includes three main possible improvements on modern drones which are miniaturization, autonomy and swarms.

2.0 FUNDAMENTALS

2.1 History

Unmanned aerial vehicles are a relatively new technology, having existed for less than two hundred years. One of the earliest forms of UAVs was used on July 1849, when Austrian forces launched unmanned hot air balloons to drop bombs while besieging Venice. Although this was a novel idea, the plan ultimately failed as most of the balloons missed their targets due to changing winds and lack of control.

Shortly after World War I, many countries began developing and testing methods to fly unmanned aircraft. Early versions of UAVs used gyroscopes and autopilot systems, but these required the route to be planned prior to launching the aircraft, limiting its potential applications. These were mostly used as cruise missiles as their flight paths can be calculated beforehand. However, in the 1930s, radio-controlled aircraft were developed, allowing precise control over the aircraft after launch without having crew members on board. One of the first radio controlled planes developed was named DH.82B Queen Bee. This is where the term "drones" originated. Although drones were very versatile, the development was geared towards military applications due to the high cost.

2.2 Principles of Operation

Modern drones use motors and propellers to generate thrust, lifting the aircraft. The majority of drones use a pair number of rotors, with half of them spinning clockwise and the other spinning counterclockwise. Drones with an odd number of propellers usually have a small side-facing propeller to ensure the aircraft does not spin uncontrollably due to Newton's third law of motion. This is the same reason why many helicopters have a tail rotor. An alternative solution is to use contra-rotating propellers, which consists of two sets of blades rotating in opposite directions to cancel out the torque. Contra-rotating propellers are more efficient, but these are noisier, heavier and more complicated to build.

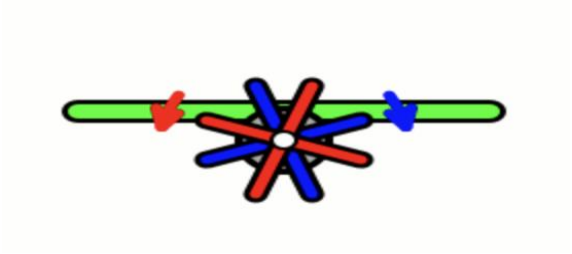

Figure 1. Contra-rotating propellers

Source: https://en.wikipedia.org/wiki/Contra-rotating_propellers#/media/File:Contra-rotating_propellers.gif

A microcontroller controls the drone by varying the speeds of each rotor. This gives the aircraft six degrees of freedom, allowing it to move forward/backward, up/down, left/right, as well as rotate in the pitch, roll and yaw directions. In addition to manual control, a GPS can be used to direct the drone to a specific location, or tracking software can allow it to follow an object or a person.

2.3 Related Technologies

Given the basic principles, various technologies are listed hereby as to optimize the reliability of UAVs and their user experience.

- Stabilization platform
- Optical zooming
- Colour profiles
- Real-time tracking with AI
- Obstacle detection
- Lithium-ion battery improvement

3.0 ANALYSIS OF THE MODERN UAV

3.1 Fields of Application

Integrating the new features, nowadays modern drones are aimed towards a broader range of applications and customers. Generally, the drone market has two major areas- civil and military. The missions they execute are traditionally costly and dangerous: inspection of utilities, law enforcement, disaster and crisis management, and fire fighting (Nonami, 2010). To maximize the efficiency of the operations, certain drones are modularized and highly customized for the tasks.

In this section, we will discuss modern UAVs' performance in the fields of aerial photography/film industry, military, and search and rescue.

3.1.1 Aerial Photography/Film Industry

Aerial photography and videography are the most common applications of drones in our daily life. In the view of hobbyists, these battery-powered robots have brought to them a quick FPV (First-person View) journey of the sky. Regarding professional filmmakers, they benefit from the drones offering various angles of shots which makes their video content more creative and visually appealing.

On 23rd August 2018, DJI Technology Co., Ltd. launched its 4th generation drones lineup featuring Mavic 2 Zoom and Mavic 2 Pro; they are equipped with large capacity batteries and 1-inch sensors for better low light images compared to their predecessors. "Mavic 2 footage has amazing dynamic range and cinematic colours," says Casey Neistat, a leading vlogger who has 11 million Youtube subscribers.

Figure 2. French company Malou Tech's "Army" speed drone,
mounted with a Go Pro Hero3, performs during a demonstration flight in Paris.
Source: Morning Mix, The Washington Post, 2015

In a more standardized field such as the film industry, the manufacturing process of UAVs varies to perform complex operations with a higher level of accuracy and reliability. In the US, since FAA gave out clearance to film with UAVs in 2014, they have thrived in numberless Hollywood scenes, such as *Skyfall*, *The Wolf of Wall Street*, and *Game of Thrones*. Having the advantage of the ability to shoot from the angles hard to reach conventionally and cost less than low-flying helicopters, drones serve perfectly for close-up and POV (Point of View) shots.

Undeniably, drones have become a well-known productive force in entertainment, and those flying robots have brought different perspectives to the broader audience. In addition, with the development of battery technology and optical image system, the entry-level and pro drones are likely to be integrated into one single product line in the long term.

3.1.2 Military

UAVs also play an essential role in the military to carry out dangerous missions in remote areas. As mentioned in section **2.1**, the prototypes of drones were initially implemented in WWI. With the dramatic increase of military budgets in the last decade (Figure 3), the research and experiments on UAVs have gained a strong push in the United States. Up to January 2014, the U.S. military had deployed 10,000 unmanned aerial systems on the battlefield to spy on specific targets, interfere with local telecommunication, and destruct enemy air defence.

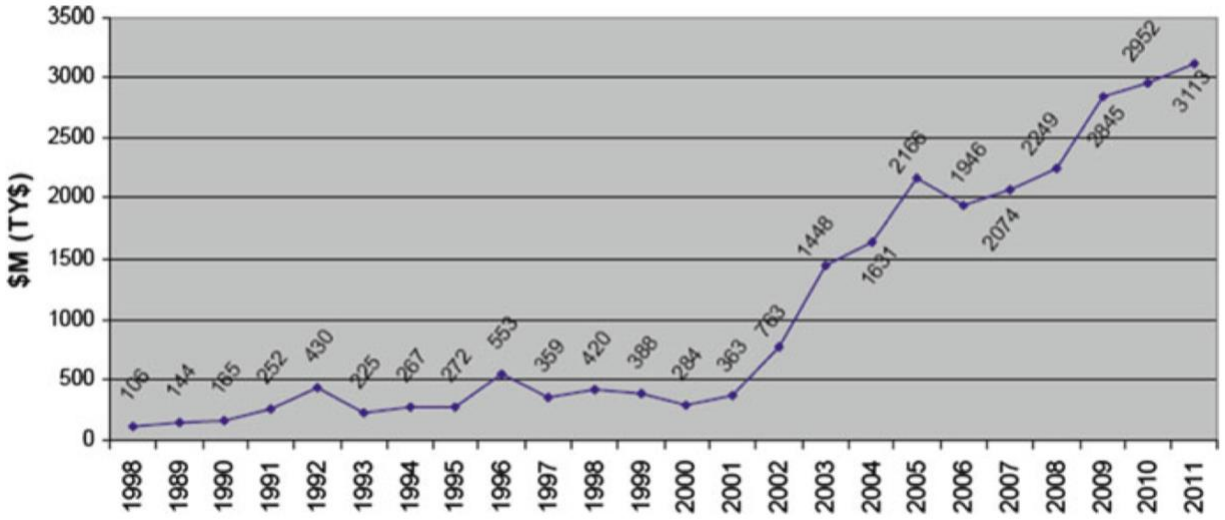

Figure 3. Annual funding profile of the U.S. Department of Defense

Source: Nonami, 2010

The operations on military unmanned aircraft intimately involve HRI (Human-Robot Interaction), GPS (Global Positioning System), and remote sensing. Piloted by a ground control system, an autonomous attack can be initiated with little human involvement. As a new category of drones specifically designed for air strikes, Unmanned Combat Aerial Vehicles (UCAVs) were introduced with longer operation time and deadly weapons in 2001. So far, 28 countries have managed to manufacture and equip the troops with operational armed aircraft, and we are likely to spot a significant upward trend of this number in the next 20 years according to Maurer (2017).

3.1.3 Search and Rescue

Thermal drone, a drone operator equipped with a thermal imaging camera, is one of the most popular applications in search and rescue fields. In an emergency scenario, drones equipped with a thermal camera are able to inspect the area, detect the objects, and direct the crew to their precise position. With a cost-effective FLIR (Forward-looking Infrared) camera, drones can translate heat energy into visible light by focusing the infrared light emitted by objects so they are able to analyze a particular object accurately. Therefore, thermal drones are essential for emergency services. Compared to traditional rescue methods, this solution is more cost-effective. Drones can complete extensive search in a large area quickly and overcome the limitations of low-level flying. Additionally, a thermal camera has the ability to search at night and provide high-quality live video in areas with low visibility, increasing the chances of finding victims.

On January 17th, 2018, a drone saved the lives of two swimmers in Sydney, Australia. The lifeguard supervisor, who was testing functionalities of a new drone, was cautioned by the video incidentally taken by the drone. In the video, two swimmers were caught in turbulent surf. The drone accurately located the rescue site and dropped a rescue pod. The process took 70 seconds which was a few minutes shorter than regular rescue crew.

In addition, the Chinese government approved drone applications assisting in rescue operations in earthquakes. In 2008 Sichuan Earthquake, rescue teams used drones for checking road conditions to optimize rescue routes, which saved unnecessary rescue period. While the responders deployed drones for locating survivals and destroyed tunnels and bridges, drones were also used to extend cellular signals and networks for enhancing survival rate.

Figure 4. Drones in fields of search and rescue

Source: DJI-M200 Series, Search and Rescue in Extreme Environments, 2017

3.2 Modern Drones

Fields of applications are largely impacted the way we view modern drones. Decisions to apply modern drones in specific fields largely depend on the trade-offs in using modern drones, in which we will discuss below. Additionally, overcoming technological constraints and resolving ethical concerns will further the usage of drones in many fields.

3.2.1 List of Advantages and Disadvantages

While drones are advantageous in many areas, it is critical to review the shortcomings of drones so we can comparatively see which areas drones are worthy to be applied in and to be cautious of the drawbacks. Below are the advantages and disadvantages when it comes to modern drones.

Advantages:

- **Ability to fly -** Drones in the past strictly relied on land navigation instead of aerial piloting. The ability to rise up in elevation allows for far greater flexibility in movement and allows for a greater field of view for all forms of recording and observations.

- **Media Presence -** Due to the mass media, modern drones are propagated in popular culture and is often a means to further elevate the popularity of promotional online videos. The popularity is due to the widespread perception of drones being efficient with video capturing.
- **Logistics -** Modern drones elevates the quality of delivery services. Companies such as Amazon and eBay are now considering the use of drones as part of their logistics. A large motivation for doing so is to reduce the cost of transportations.
- **Time-saving/Less effort -** Aerial footage can be taken with drones with very little sophistication as autonomous algorithms are built in. Little to no professionals are often needed and the data is easily transferable.

Disadvantages:

- **Shorter Lifespan-** Lifespan of drones are far smaller compared to conventional cameras and battery designs of drones are usually less than 4 hours.
- **Animal Attacks -** Drones are often mistaken as other animals when flying in areas with high concentrations of wildlife. Animals such as eagles often raid aerial drones while taking important footage.
- **Cyber vulnerability -** There is a possible displacement of control authority of the drones by hackers. This allows criminals to steal valuable information and possibly steal/destroy the drone as well.
- **Spying** - When drones reach a certain altitude, sounds projected by the drones will no longer be noticeable. The prevalence of drones will satisfy greater criminal ambitions especially when it comes to criminal intents in areas of privacy.

3.2.2 Current Challenges

An analysis performed by an environmental scientist at Lawrence Livermore National Laboratory shows that delivery drones can save 58% of greenhouse gas emission on average compared with traditional trucks delivery, which can relieve the environmental burden. However, due to the limited carrying capacity, the benefits of delivery service is constrained by the size and weight of the packages. According to the initial design specifications, most drones can carry about 3 to 5 pounds of weight. This reduces the range of drone delivery service and may bring inconvenience to customers. Additionally, drone delivery increases existing noise

pollution in urban cities. In particular, the sound of a drone in flight is about 75-80 decibels on average, which is similar to busy traffic or a washing machine. The drone companies need to consider quietness levels when selecting engines.

3.2.3 Ethics

The biggest ethical concerns about the use of unmanned aerial vehicles involve the protection of privacy, the decision-making abilities of autonomous machines, and the military application of drones. Currently, there are no definitive laws concerning the protection of privacy when operating a drone. This concerns many people about potential privacy violations from stalkers or from police monitoring. Even if privacy regulations were implemented on UAV operation, they would be very difficult to enforce.

The decision-making abilities of autonomous drones are also a major ethical concern. In the case of a mid-air collision, is the drone owner liable for the damages, or is the company who coded the UAV software responsible? The answer is not clear and governments are struggling to keep up with laws to govern the use of autonomous drones. Military drones in the future may also be tasked with finding, identifying and eliminating specific targets autonomously. This is by far the most controversial topic in drone use, as many people do not want to hand over such decisions to machines. Drone use in warfare can also be dangerous, even when operated manually, as it distances the operator from his/her actions. This disconnect between action and consequence could lead drone operators to commit atrocities thoughtlessly and without remorse.

4.0 THE FUTURE OF DRONES

The future of drones has been one of the most controversial topics over the past five years. The drones are used in both commercial and military aspects.

4.1 Possible Improvements

Further technical development of current drone technologies will allow for a larger range of applications. Therefore, three possible improvements of drones: miniaturization, autonomy, and swarms. These improvements will enable drones to become more functional and significant in the future.

4.1.1 Miniaturization

One of the current developments in drone technologies is further miniaturization. To accomplish that, materials, batteries and electrical elements need to be very compact. The miniaturization of drones will not only cut down drones' production costs but also help explore more fields where drones can be used. Smaller sizes enable them to travel in narrow spaces and easily conceal themselves. The miniaturization of drones may cause some illegal or ethical issues, which were discussed in the ethics section.

4.1.2 Autonomy

Modern drones are often equipped with a degree of autonomy. Autonomous vehicles have the ability to "think" in comparison to conventional vehicles. Greater autonomy allows modern drones to have the ability to accomplish complex tasks without manual control. There are several applications of autonomous drones. For one, autonomy allows drones to participate in disaster relief and plays a critical part in delivering supplies. Autonomous drones are also increasingly used for military purposes. Drones are incredibly effective in reconnaissance, as they can map out unknown territories and enemy areas. Its effectiveness in reconnaissance is also increasingly taken advantage by domestic police work in both the US and Canada. Frequented areas are mapped out using drones for tactical responses for emergencies. In search and rescue missions, the speed of drones is also a great advantage in comparison to conventional human search methods. Bomb threats investigations are transitioning into the use of drones as well, since the destruction of a drone is a small price to pay in comparison to a human officer's life.

Aerial footage is a great way to utilize autonomous drones they can automatically balance themselves and find the correct positions for filming, and they are gradually replacing conventional aerial footage techniques using helicopters.

4.1.3 Swarms

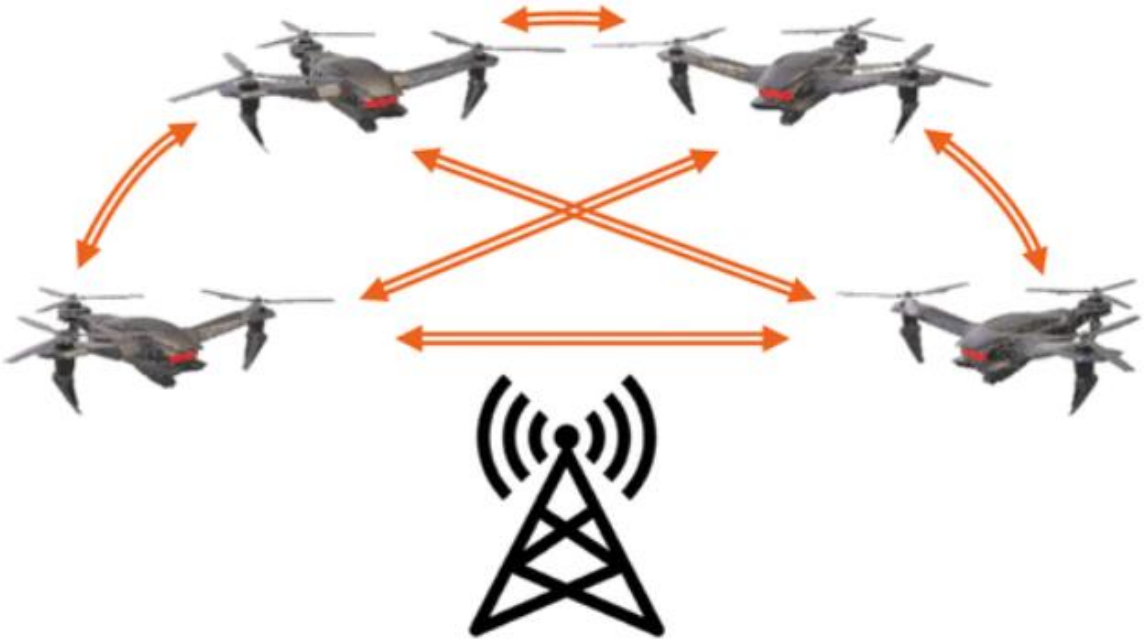

Figure 5. Possible Communication Architecture
https://www.theuav.com/uav_photos.html

Current envisioning includes drones being able to complete the missions in swarms or teams. They will have different work distributions for different drones, so the drones can be designed and manufactured according to their purposes. For example, small drones will be spying on enemies on the ground, while the larger drones will be able to deliver bombs. These drones will be able to receive commands from the ground control station and also communicate with other drones during the missions. There are several current architectures designed for swarms such as Infrastructure-based swarm architecture and Flying ad-hoc network (FANET) architecture according to Prakash (2018). However, there are still some challenges to make drones work in

swarms. As Bart (2016) said, using drones in swarms requires much more communication channels on each drone, which requires further technical development on signal communication. As an aside, it might be difficult to decide the priority of the received information from other drones.

4.2 Potential Applications

More and more drones have been developed in recent years. The commercial demands of drones also rapidly increased due to the development of technologies and a decrease in costs.
Figure 6 below shows the top five small UAV markets in 2020, estimated by the Federal Aviation Administration.

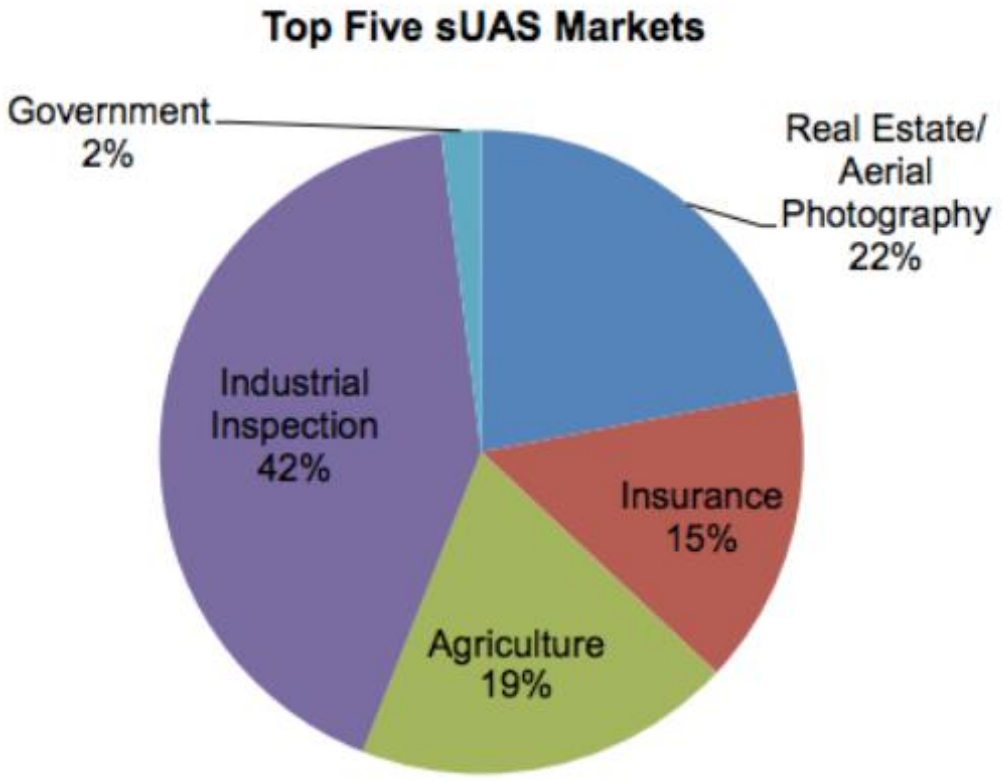

Figure 6. Top Five Small UAV Market in 2020
https://www.faa.gov/uas/commercial_operators/

This figure illustrates that by 2020, drones will be used mainly in industrial inspection (42%) and real estate and aerial photography (22%). In industrial, drones will be able to safely and quickly check the status of the structures or identify defects, leakage, and corrosion issues, without having to spend on additional personnel and equipment. It meets industrial companies demands well. Therefore, industrial inspections will become one of the main applications in the future. Drones used in agriculture and insurance will account for 19% and 15% respectively. Comparing with that 42.9% of drones are used in photography in 2016, we can conclude that drones will be used in more industrial companies instead of by individuals, such as inspecting equipment in industries in the future to ensure workers' safety.

5.0 CONCLUSION

As a relatively new form of technology in human history, drones have surprisingly achieved relevance rapidly in human society. Many facets of human society now employ modern drone technology, namely aerial photography/filming, military, and search and rescue missions. As well, recognition in areas in which drones gain an upper hand in comparison to conventional technologies and vice versa will allow us to achieve greater efficiency in the use of modern drones. Further establishment of the niche of drone technology in human society will require further discussion of ethical concerns and overcoming current technological constraints.

Overall, we recommend focusing on the discussion surrounding ethics to mainly involve the protection of privacy, autonomous abilities of drones, and military use. Policies in privacy protection will be difficult to enforce and will require creativity. Parties in which are liable for damage are yet unclear for drones with autonomy, and the handover of warfare decisions to autonomous drones is highly controversial. Ultimately, a further discussion involving all stakeholders in human society is highly recommended to resolve these ethical concerns. Initiatives that will further discussions in ethical concerns will require acknowledgement and assistance from the government as well as businesses to direct financial funding and initiate open forums.

REFERENCES

Agiwal M, Roy A, Saxena N. 2016. Next generation 5G wireless networks: A comprehensive survey. IEEE Commun. Surv. Tutorials, 18(3): 1617-1655

Arques, P., Aznar, F., and Sempere, M. 2013. Swarm behaviour for UAV systems, search and rescue tasks. Actas de la XVI Conferencia CAEPIA Albacete. Available from http://simd.albacete.org/actascaepia15/papers/00001.pdf

Barnes, Michael Joseph, and Florian Jentsch. Human-Robot Interactions in Future Military Operations. CRC Press, 2017.

Bart Custers, The Future of Drone Use, 2016, T.M.C. Asser Press

BOUSQUET, A. (2018). *The Eye of War: Military Perception from the Telescope to the Drone*.

Faruque. P. R. S. F.(2018), "UAV swarm communication and control architectures: a review," Journal of Unmanned Vehicle Systems. [Online]. Available: http://www.nrcresearchpress.com/doi/abs/10.1139/juvs-2018-0009. [Accessed: 01-Apr-2019].

Foley, B. (2019, January 22). Package Delivery By Drone Still Faces Practical Challenges. Retrieved March, from https://www.forbes.com/sites/brianfoley1/2019/01/22/package-delivery-by-drone-still-faces-practical-challenges/#34692c847c5a

Maurer, K. (2017). Visual power: The scopic regime of military drone operations. Media, War & Conflict, 10(2), 141–151. https://doi.org/10.1177/1750635216636137

Minneapolis; London: University of Minnesota Press. Retrieved from http://www.jstor.org/stable/10.5749/j.ctv6hp332

Nonami, Kenzo. Autonomous Flying Robot: Unmanned Aerial Vehicles and Micro Aerial Vehicles. Springer, 2010.