MULTICOPTERS AND POTENTIAL SECURITY THREATS IN NEAR FUTURE

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ABSTRACT

Supply and production of multicopters has become easy thanks to technological developments. Multicopters are used in several applications based upon their high manoeuvrability, ability of still standing and easiness to product. Their increasing usage and getting supply of these devices easier have caused security and privacy troubles in terms of both military and civilian. However, it is obvious that new and major threats will be added into these troubles with current developments. In this study, military and civilian usage of multicopters in our days have been examined and these aircrafts may become threat scenarios with scientific developments and the scenarios have been presented under four titles which are aggressive manoeuvres, autonomy, positioning and localization and multi robotics. Also, determination and detection systems, defence systems and laws topics against potential threat scenarios are examined. In order to address the gaps of these topics new proposals and suggestion are presented.

KEYWORDS

Multicopters, Defence Systems, Aggressive Manoeuvres, Autonomous Robots, Multi Robots

1. INTRODUCTION

Nowadays, supply and production of aircrafts like many devices has become easy thanks to technological developments. Increasing usage of multicopter type aircrafts, getting easy to supply has caused trouble in terms of both military and civilian. The most common trouble we had is that airplanes come across with multicopter type aircrafts in airports. Besides, it is also used for information gathering about private life without permission and carrying illegal things (weapons, narcotic, etc.). However, these problems look pretty simple when compared with upcoming problems which result from scientific developments in robotics, control and positioning systems. In this paper, information about Multicopters, threat scenarios, defence systems and laws and lastly solution proposals and suggestions are presented respectively.

1.1. MULTICOPTERS

Multicopters are flying platforms with the help of multiple motor-propeller combinations and they are denominated by its motor number. For example multicopters showed respectively in Figure 1 are tricopter, quadcopter, hexacopter and octocopter. They have no aerodynamic properties without propellers so sometimes they are called as flying brick. Arm of the multicopters that should be placed symmetrically to the centre of gravity are usually produced in order to provide its control convenience and design. Flight and maneuvers are based on differences of speed and rotation locations of rotors.

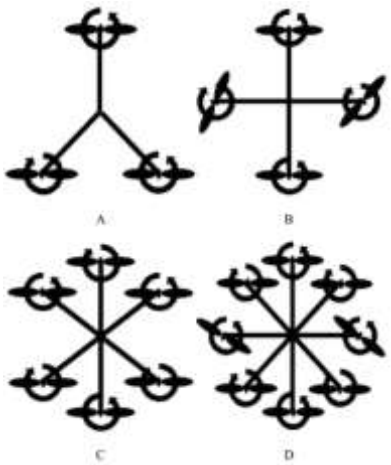

Figure 1. (a)Tricopter, (b) Quadcopter, (c) Hexacopter, (d) Octocopter

The most common one among multicopters is quadcopter with four motors; it is also named quadrotor in some sources. Operation principles and mathematical type of quadcopters are examined in detail in many scientific studies [1]–[3]. Basic maneuvers of roll, pitch, yaw and thrust for "+" type quadcopter aircraft are shown in Figure 2. In the figure, propeller's direction of rotation is arrow direction and drawing in dark bold color shows that propellers rotate faster than others. While propellers shifted are shown in black arrow, inactive propellers are shown in white arrows. Accordingly, descending and ascending movements are done by changing the speed of propellers with trust movement. Forward and backward movements are done with pitch. A left and right movement is done with roll. Roll and pitch movements are made by changing the speed of propellers which are in same axis. Yaw maneuver is rotation on Z axis which needs to difference propeller speed in different axis.

Electronic components of multicopter type of aircrafts consist of control unit, electronic speed controllers (ESC), brushless DC motors, propellers (BLDC), communication unit, battery and remote controller. Besides, first person view systems (FPV) are used on the purpose of surveillance. Image transfer from multicopter type aircrafts is not only done with FPV but also done with high definition cameras. Control unit consist of sensors and processor unit. Data imported from sensor unit is filtered out, and then taken to control algorithm and rotor speeds are arranged with this algorithm. Control algorithm is a code sequence which activates processes according to commands that are sent by control system. PWM (Pulse width modulation) signals produced in control unit for speed regulating process are transmitted into brushless motors. In the subject of basic inspection, there are examples done with PID, Fuzzy logic and Artificial Neural Network (ANN). ESCs are used for drive and change speed of BLDCs. The first one of the ESCs ports is power which comes from battery and second is PWM input which comes from control unit. Remote controllers are devices that send commands of pilot to control unit. The communication link is made on radio frequency (RF) with transmitter and receiver set. Receiver can talk with the controller with many ways like PWM, PPM (Pulse Position Modulation) and UART (universal asynchronous receiver/transmitter)

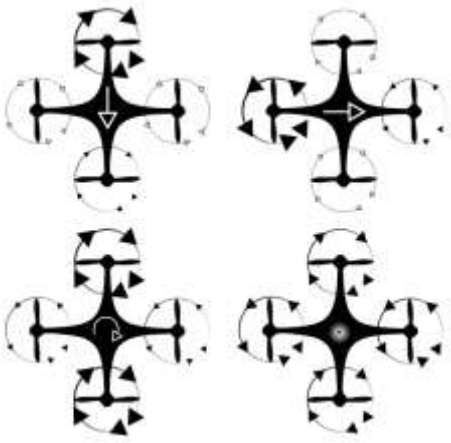

Figure 2. Quadcopter maneuvers (a) pitch, (b) roll, (c) yaw and (d) thrust

Multicopters are sold with the options of do-it-yourself and ready to fly. Possibility of doing modifications on "Ready to fly" kits is possible. It is indicated that multicopter models which can be supplied easily and cheapish can reach at 72 km/h (45mil/h) speed, carry useful cargo about 400gr (14.11 ons) and they have also 25 minutes endurance[4].

People usually have a particular interest in multicopter type aircrafts for hobby. Because of the interest, a lot of international multicopter competitions are staged like World Drone Prix. In these competitions, specially designed racing multicopters are used. Pilots command the aircraft using FPV.

Multicopters have capacities such as ascending to high altitude, standing steady in moving and stable position. Thus, it is used in search and rescue, emergency response, homeland security, surveillance, earth sciences, gathering information in dangerous places [5]. In addition to these, useful cargo carrying is available for every aircraft. Cargo handling capacity of multicopters' is low, but when special designed weapon like bomb, rocket gun or weapon as a load is placed it may damage extremely.

2. SCIENTIFIC DEVELOPMENTS AND POTENTIAL SCENARIOS

Supply of drones and accessing to these aircrafts by simple citizen has become easier with technological developments. This situation reveals the risk of usage drones on the purpose of terror and insurrection and diversifies protests which will occur with this purpose[6]. In this study, the current technological developments' potential scenarios about multicopter type aircrafts are revealed unlike reports prepared by several institutions and associations about threats that drones become. These scenarios are sorted by aggressive maneuver, autonomous multicopters, positioning and localization and multi-robot.

2.1. SCENARIO OF AGGRESSIVE MANOEUVRE

A lot of studies about controlling multicopters are done, but the most interesting study is about the aggressive control among the others. In the study of aggressive maneuver, it is studied about passing from narrow spaces like window, pass through the moving objects, holding on the target and acrobatic movements like flipping [7]. However, the system works with VICON which has external positioning system.

Following threat scenarios may arise in case aggressive maneuver studies are used for the purpose of attack and defense:

- When Omni-directional movement of multicopters combines with aggressive maneuvers, it is used for escapes from an attack carried out own self.
- Flying successfully even in narrow spaces or indoor spaces like forest and building may gettable.
- In the case of using multicopter for attack, it may be used for destruction the target even in a narrow place with point shot by sticking or hitting.

2.2. SCENARIO OF AUTONOMY

The Forming an autonomous system is more of a targeted subject about robotic field and it aims to perform the action that robots will do by deciding completely by itself. According to information that a fully autonomous robot gets from surrounding area, it should perform predetermined algorithm without human interference. Multicopters which are motivated with the idea of flying robot have become popular by virtue of production easiness and mobility. Autonomous quadcopter which is produced by Pennsylvania University flies with only a smart phone control. The aircraft is flown using compass, accelerometer, gyro sensors, camera and communication units (GSM, Wi-Fi, Bluetooth) and processor[8]. These are already found in a telephone. The aircraft can be run autonomously with high process power in smart phone. A study done by Haque, delivery of product is done to a pre-determined targets from map[9]. The greatest needs in these studies are high process power and three dimensional systems of obstacle detection and positioning. Aircrafts are operated in external environment in typical practices and Global Positioning System-GPS which is the most practical positioning system is used. Thanks to embedded system architectures have become cheaper; technology offers us cards which have high speeds like Raspberry-Pi and BeagleBone. Thus, cost of high process power lower and its supply have become easier. Following conditions may arise in case studies of autonomous multicopter are used for the purpose of attack and defense:

- Time or event triggered operation can be organized. It can be cause of triggered attacks to preferred targets without pilot.
- In case of jamming remote signal of autonomous multicopter an complete mission by itself. The system can complete its mission by taking upper hand as long as it keeps in touch with its sensors.

2.3. SCENARIO OF ADVANCED POSITIONING AND LOCALIZATION

The biggest problem of autonomous systems is about positioning. Current systems establish their positioning mainly on GPS, but autonomous system can be defused by the way of denying or jamming the system. Various triangulation techniques are implemented as an alternative to GPS system. Some of the most common triangulation techniques are RSSI (Received Signal Strength Indicator) and GSM (Global System for Mobile) which are done taking the advantage of wireless communication. However, deception and breaking can be done even spread spectrum systems are used. Auto position or guidance systems are improved as a solution in this condition. Auto positioning techniques designed for multicopters and other aircrafts and Simultaneous Localization and Mapping (SLAM) techniques designed for guidance systems are used. Three dimensional mapping can be done with the techniques used in SLAM especially for flying robots and this is essential for them [10]. These techniques allow indoor and outdoor navigation and deny conventional jamming techniques. Thanks to three dimensional perceptions which are done

with image processing, robots can calculate path of flight and mapping shaded relief of the region. visual odoemetry is an old topic but still progressing and offers many opportunities in UAV (Unmanned Aerial Vehicle) navigation like image sequence tracking, omnidirectional cameras, stereovision and feature comparison based positioning and localization techniques [11]–[13].

The most powerful and widespread system is Laser Imaging Detection and Ranging (LIDAR) in addition to image processing systems. LIDAR is based on a distance measuring principle using laser on a rotary system and it can compose shaded relief sensitively and swiftly[14]. Path planning can be done with LIDAR very effectively. Following cases may arise in case studies of Autonomous Control and Positioning are used for the purpose of attack and defense:

- With the study of visual SLAM, it is possible to make a guidance system which will be operated with the principle of following a range of unique visual. There are many unique visuals in public domains. Thereby, it is possible to orbit autonomously from a place which had already taken pictures before without using a system like GSM.

- High definition three dimensional modeling can be done by adding LIDAR system to multicopters, thus both detection of attacks comes from conventional air defense systems and path planning processes can be carried out. We may not need both conventional and visual sensors in the event that LIDAR systems are used as three dimensional positioning systems in full.

- Thanks to visual SLAM systems, it isn't necessary to reference basis systems such as GPS, RSSI and GSM. Thus, denying or jamming radio frequency signals may become ineffective to stop any autonomous attack. Those system can only be neutralized in case of breaking down of its' sensors.

2.4. SCENARIO OF MULTI-ROBOTICS

Autonomy in robotic systems is a subject that is developed in many ways and it has been studied for so long. However, robots get more complicated as long as the duties are getting harder for autonomous robots. For this reason, both cost and unwieldiness problems take place. In order to overcome these problems, it is inspired from living communities in nature and multi-robot systems are offered as a solution. It is aimed at developing systems which will get better performances from a robot or a robot can't cope with the system by creating simple and easy robot person with multi-robot systems.

The idea of using robots as swarm provides significant advantages such as scalability, flexibility and healthiness when it is considered for both attack and defense [15]. Those advantages come to light by displaying flock behaviors in different practices. With the typical flock behaviors, the missions that have been done are grouped as aggregation, flocking, foraging, object clustering, sorting, navigation, path formation, deployment, collaborative manipulation and task allocation[16]. Most of the studies about multi-robot systems are the two dimensional projects, but tendency to flying swarm robots is shown in studies that has been done in recent years.

In the studies of flying swarm of robots, Quadcopters are frequently used. GPS was used for positioning in outdoor applications with Quadcopter and applications such as flocking and formation were performed [17]. Many studies which have been practiced by GRASP laboratory in indoor applications and systems performed quadcopter type robots [18]. The robots used in these studies are smaller than the other robots used in outdoor and VICON system which is used

as positioning system is external. Robots can constitute intended structure by carrying it to certain targets in construction practice. While multicopter can carry limited load solitary, collaborator manipulation and image processing are done in another study which is about that if multicopters are used collectively, heavier loads can be carried[11].

sFly project that more applications studies between swarm systems are executed is supported by the European Union. Different types of multicopters are produced in the studies within the scope of the project. Applications like three dimensional mapping and navigation in GPS denied places are done in the project. Threat scenarios which may arise by developing multicopter systems are sorted below.

- There is an abundance of members in multi robot systems. In that case, the system can survive even if there is a member loss because each member has same properties and can take another members place. This can make hard to eliminate whole system down with conventional defense systems.
- Processes of surveillance and mapping and attacking which are done with multi-multicopter systems may occur faster and with higher performance compared to a single multicopter. In those applications, they can carry weapon, ammo, etc. that they can't move them solitary with collaborative work of aircrafts. They can watch more than one point or they can search more space in less time.
- With the techniques of giving different formations to the multicopters, different image of aircraft may be derived on radar, thus deception may be done.
- Robots can make positioning and navigation under favor of gregarious behaviors even if GPS signals are blocked.

3. PRECAUTIONS AND DEFENCE SYSTEMS

3.1. DETECTION AND IDENTIFICATION

Systems of pursuit and passive radio frequency catching, infrared search, forward looking infrared (FLIR), optical sensing and radar have been used for identification and detection of aircrafts nowadays [19]. The most popular systems are radar and optical sensing within these systems. Systems of radar are based on the detection of object principle under favor of sending radio waves and taking reflection and it has been used for detection and identification of big aircrafts fly at high altitude. Beside this, reduction of radar track has been carried out in military designed aircraft, thus it has been provided that many aircrafts cannot be detected or identified. Bird radars are used in order to detect both birds and small aircrafts [20]. Movements of birds and small aircrafts have been tried to detect in those studies. However, sizes of multicopters on the markets are smaller in comparison with both manned and unmanned air vehicles and they fly at low altitude. Also, traces of radar are not very different from a bird because body materials are made of carbon fiber, fiberglass, plastic, etc.

Optical sensing system is a process that determines the aircrafts looking up to the sky in a specific direction with several camera or cameras. The systems run in this way work with array and scan principles. The camera periodically takes picture of area which remains within specific angle in scanning system. Aircraft is sought in image and when it is found, depth is calculated with image processing. Location of aircraft is used to specify with distance and angle data[21]. On the other hand, many cameras look up in arranged systems. The device gives a warning when an aircraft crosses over from one of them in arranged systems, thus location of the aircraft is confirmed[22].

Characteristic of identification is high in optical systems, but optical systems being dependent on environmental conditions take disadvantage.

3.2. DEFENCE SYSTEMS

When the aircraft which has threat risk is confirmed, defense should be applied against those devices. Traditional air defense systems interfere with the threat which is perceived on the basis of kilometer. This status is not dissuasive for a small aircraft flies flow and moves quickly. For this reason, improved devices should destroy or defuse the aircraft without damage to useful factors at close range. The most powerful weapon is laser gun developed for this aim. With this gun, destruction of aircraft by getting hotter should be occurred as directing laser gun to aircraft determined visually. Laser should be used for a length of time for destroying the aircraft and this status gains favor to minimize the harm to ally factors which may get in the way. Laser system is an effective way in order to destroy the aircraft when viewed from this aspect. Another way is neutralization by breaking communication. Studies in this way are mainly done with the devices like jammer. Jammer is run in determination moment now that long standing usage shouldn't block or damage to ally factors. Also, signal jammers which can be activated in detection moment are developed for civil uses [23].

3.3. LAWS AND RESTRICTIONS

Except from all these systems, potential of aircrafts has been found out by legislators and limitation should be tried with laws. Today, regulations about aircrafts within civil aviation are issued in many countries and processes of operator certified are done [24]. Also, it is opened under the name of "No Drone Zone" for some special cases. Existing legislation involves only citizens who obey laws. Since potential usage of aircrafts for privacy and weapon is high, there isn't any study about controlling places which were founded for supply and production.

4. CONCLUSION AND DISCUSSION

It is seen that a lot of different problems may be arise when threat scenarios of multicopters are examined. There is no sufficiency in legal regulations or system about defense or deny especially by building four different multicopter scenarios to use them for terror and insurrection.
In order to prevent and get under control these threats, legal measures which should be done are below:

- Electronics communication or electronic signature licenses should be organized in the name of noticing flying multicopter whether it is ally or not. Aircraft sensing system and license detection system should be developed for identification.
- Selling license should be given to points which sell control units and remote control which are critical pieces of multicopters. In order to keep track of total items sold, product they bought and consent certificates which are taken from government agencies should be recorded in database which will be constituted.
- Areas that aircrafts to be used should be limited. Determined places should be allocated to hobby users. Flight ban should be implemented consistently in risky and specially protection places such as town centers, state buildings, and military places. Each craft entered into the area should be neutralized by relevant department in any case.

Legal regulations may only secure dissuasion and precaution, however air defense systems have to be developed in order to defense against threats. Things to do for those systems:

- Physical obstacles can be used as temporary and alternative solution. Net or web may be spanned to undesirable areas. Propellers can be defused by placing balloons to the environment in order to hinder flying the multicopter. This solution is practical and economical but it should be carried out intensely. There may be some problems in terms of denying works of allies and cause of aesthetics disorder in case it is carried out in long term.
- Optical or radar systems for the use of distant and close detection are insufficient for detecting the multicopters. Sensing systems which are fast and can work at low-altitude, distinguish the multicopters from allies should be developed. These systems should be placed not only official and military places but also it should be placed to all places where an impact to civil life have.
- Laser weapons and jammers are enough for small numbers of multicopters. However, when the number of multicopters reach at the large numbers expressed as hundreds and when it is thought that they work as full autonomous, these systems will not be enough. Air defense systems which can defuse the multi target without damaging any allies should be developed for these conditions specially.
- Researchers that will work on multicopters with four scenarios which have been mentioned before should be brought up and air to air systems for active protection should be developed against the systems.

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