IMPLEMENTATION AND EVALUATION OF APM 2.6 - CONTROLLED QUADCOPTER WITH AERIAL IMAGERY AS A CASE STUDY

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ABSTRACT

In civilian applications, the utilization of quadcopters increasing quickly. Still, this deployment experiences some difficulties like flying vibration and instability which lead to inaccurate data of onboard sensors. Determining the size of such inaccuracy assists in improving the future design and provides more precise understanding of data measured in copter applications. This work introduces an implementation of a quadcopter using recently developed hardware and software components. An aerial imagery system was applied as a case study to evaluate the performance of the implemented quadcopter. The quadcopter was assembled mainly from F450 Flame Wheel frame kit, Aurdo-Pilot Mega APM 2.6 controller and a Mission Planner as ground station software. The picked up images were stitched and then compared with the available Google Earth images. Also, the dimensions of targeted buildings and GPS coordinates of certain points were measured on the aerial images. The accuracy of aforementioned dimensions and GPS coordinates in comparing with the actual measurements has been investigated. The clarity and measurement errors found on the taken aerial images were such acceptable that make the quadcopter usage for photogrammetry is quite possible to monitor the changes taking place on the ground such as affected areas and under construction sites.

Keywords: quadcopter, APM2.6, autopilot, image stitching.

1. INTRODUCTION

In the last few years, the market of Unmanned Aerial Vehicles (UAVs) began to increase noticeably [1]. This deployment is due to their light weight and replacement the human pilots in the case of risky missions [2]. Quadcopter is the famous one among the UAV types. The quadcopter popularity is owing to the capability of vertical take-off and landing (VTOL), indoor missions and all types of maneuver [3]. However, in civilian applications, the utilization of quadrotor systems has not reached its full scope. This is due to their relatively high cost, complexity of flight control and legal restrictions [4]. Generally, the UAV system is considered a multidisciplinary field as it involves: Air Vehicle, Controller, Communication, Navigation and Payload [5]. Hence, researchers dealt with these subsystems in different ways and levels.

D. L. Figueiredo [6] implemented and tested the APM 2.6 autopilot and the Mission Planner software of a UAV. The Vehicle was a fixed wing UAV. The testing verified the system flexibility and proper working in most environments. A navigation subsystem for a quadcopter was designed by W. Kinsner and *et al.* [7]. The design addresses the control autonomy of the Vehicle in the challenging environment and mutable payload. Mamdani Fuzzy controller has been selected in Matlab/Simulink design. The proposed UAV navigation perform acceptably in windy weather. Three reasons of errors in the stitching of aerial images was recognized by Saeed Y. and *et al.* [8]. These are: weak homograph, poor camera calibration and the deficiency of choosing the correct transformation model. This diagnosis assist in the mitigation of the effect of these errors. A depth map was used to choose the ground control points. A higher polynomial orders was exploited to correct the geometric distortion. A similarity transformation was utilized to avoid the deficiency of selecting the projection model. In other side, J. H. Chen and *et.al.* [9] proposed a stitching algorithm for indoor quadcopter images. The algorithm depends on the hierarchical image stitching method with the dominant image selection for the same scene. The experimental results show the reduction of motion parallax region in the mosaic. W. H. Robinson and *et al.* [10] found that there are three main challenges face the UAV search and rescue missions: the Mobility, the navigation and the data collection. A testbed structure based on MANET (Mobile Ad-Hoc Network) has been suggested to treat these challenges. Several aircrafts flying simultaneously were considered as nodes of the MANET. A UDP-like protocol was proposed to perform the communication, navigation and data collection among the nodes.

Constantly, manufacturers introduce a new quadcopter models to handle the existing disadvantages. These models include a new structures, controllers, communications and software. Unfortunately, the variety of such subsystems creates technical problems such as mismatching and operational complexity [11]. In this paper, a quadcopter mission has been implemented using off-the-shelf; recently developed components. The implemented quadcopter was evaluated through applying a simple photogrammetry application. A stream of aerial images was captured and then stitched for three different sites. The generated mosaic has been compared with Google Earth maps and actual dimensions of the targeted locations.

After introducing the work in section I, section II presents a brief description of the hardware and software utilized in the work. Section III illustrates the details of the implementation workflow, including system set up, software configuration and experimental flight. Section IV evaluates the quadcopter mission based on the accuracy of measurements and images that have been gained in the air.

Section V concludes both the implementation and evaluation of the system.

2. SYSTEM COMPONENTS

The major components that are used to implement the quadcopter mission consist of the following parts: A quadrotor platform, A Ground Control Station (GCS), an autopilot electronic board, a camera, a Radio Control (RC) transceiver unit, and an aerial image software. These components are described briefly as follows:

2.1. Quadrotor platform

The platform used is F450 Flame Wheel QuadCopter frame kit which is built by DJI (Da-Jiang Innovations) Company [12]. It is an x-shape quadcopter with about 15 minutes flying time and 150 meters remote distance. The quadcopter weighted 282 grams with maximum Take-off Weight of 800g. The typical horizontal speed is 4.5 m/sec. The motor used for the quadcopter propellers is a brushless dc motor. An electronic speed control (ESC) is used to vary the dc motor`s speed.

2.2. Ground control station (GCS)

The Mission Planner software is installed on a windows-based laptop computer and exploited as GCS. The purpose of the GCS is to plan the flight path. The features of mission planner [13] are: Point-and-click waypoint entry using Google Maps, Select mission commands from drop-down menus, Download mission log files and analyze them, Configure APM settings for airframe and Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.

2.3. Autopilot electronic board

The Ardu-Pilot Mega (APM 2.6) is a complete autopilot system. It is used here to allow the user to turn the multirotor vehicle into a fully autonomous vehicle; capable of performing programmed GPS missions with waypoints. It has a 3-axis accelerometer, magnetometer and gyroscope. A sonar sensor, a barometer and GPS receiver is also equipped in APM 2.6 board for altitude and position measurements [13].

2.4. The RC transmitter

The RC transmitter used in this work is of type WFLY07 [14]. It has the features: Large LCD display, Multi-function proportion of 7 channels remote control, and can store 10 group of model data.

2.5. GPS module

The GPS module used is UBLOX GPS module V2.0 [15]. The NEO-6 module series is a family of stand-alone GPS receivers featuring the high performance u-blox 6 positioning engine.

2.6. RGB camera

An off-the-shelf, light-weight RGB camera has been downward-faced and mounted to the bottom of the platform. The camera was set to capture 480p@30fps video images during aviation.

2.7. Aerial images software

Two softwares are used for aerial imagery processing. The Microsoft Image Composite Editor (ICE) and the ArcGIS. The ICE [16] is responsible for image stitching. It is an advanced panoramic image stitcher created by Microsoft research. Given a set of overlapping photographs of a scene shot, ICE has the ability to publish, view and share panoramas on Photosynth website. In other side, the ArcGIS (Arc Geographic Information System) [17] is responsible for finding GPS location of aerial images. ArcGIS is a geographic information system for working with maps. ArcMap is one of the Applications of ArcGIS used on Desktop. It gives geographic layers to analyze, symbolize and compile GIS data.

3. SYSTEM IMPLEMENTATION

Implementing a quadcopter mission is not a straightforward plug and play job. It requires some system preparations such as: software installation/configuration, training on Radio Controlled quadcopter maneuvering and hardware interfacing. Also, the user should be familiar with map utilization including GPS longitude/latitude readings. However, the implementation of APM 2.6 controlled quadcopter is divided into two work phases: preparation and flight. The preparation phase embraces the hardware components setting and the configuration of the necessary software. In the other side, the flight phase involves the three flying tests to record the aerial images.

3.1 Preparation phase

The APM 2.6 board, shown in Figure-1, comes from the factory already soldered and ready to have the firmware that can be loaded by the mission planner. Still, the following steps should be accomplished before experimenting the quadcopter (main steps only):

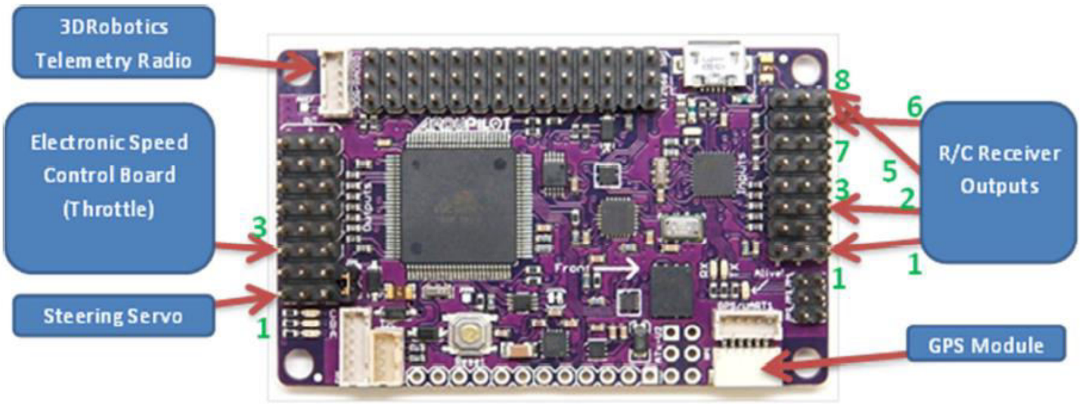

Figure-1. APM 2.6 board.

a) The RC channels should be connected to the APM input pins, whereas; the ESCs into the output pins. Then, each one of ESCs is tied up to the corresponding motor.

b) APM board attached to the laptop. Then, APM board must be configured using Mission Planner as illustrated in the following steps.

c) In the upper right corner of the Mission Planar screen, Arduino Mega 2560 must be chosen and the baud rate 115200.

d) The firmware (quadcopter) has to be selected, and the "connect" icon should be pressed to download its driver to the APM.

e) Since the APM 2.6 of the quadcopter is used for the first time, there is a need to calibrate the accelerometer.

f) The RC also need to be calibrated. The radio calibration changes were seen on mission planner screen by moving the channels buttons on the RC.

g) In flight modes icon, the quadcopter mode can be set according to channel used in the radio. For this work, channel five was selected to change the quadcopter flight mode.

h) Loading waypoints: Since the Mission planner software has the access to Google map, Waypoint loading can be done by clicking at any point on Google Earth map. Mission planner can set many options on the waypoint, such as "command waypoint", which means when the quadcopter reach the desired waypoint, it`ll continue to next waypoint. There are other commands other than "command waypoint" such as take-off, Land, return to home, etc. Mission planner also can set the elevation and distance between the waypoints. Finally, it can show the location (Longitude and Latitude) of the waypoints, as shown in Figure-2. The system during setup process is shown in Figure-3. The quadrotor was connected to the laptop through USB cable, and began configuring the flight parameters using the mission planner.

VOL. 11, NO. 19, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Figure-2. Loading waypoints.

Figure-3. System during setup.

3.2 Flight phase

After loading the waypoints into the autopilot, the quadcopter can do the required mission. Three flight tests have been accomplished on the quadcopter. At each test a unique path is programmed and uploaded to the copter. The path planning and the effect of vibration on both flying angles and velocity have been investigated previously as presented in [18]. Here, to evaluate the quadcopter mission, a series of aerial images was recorded during flying over three different sites. Then, these aerial images were stitched together, using Microsoft ICE package, to get the mosaic map of the three locations. The copter elevation in all flight tests was set to 37 meters with 4.2 m/sec speed. Flight one done over the old building of Al-Khwarizmi Engineering College; flight two over the new building of Al-Khwarizmi College and flight three over the football stadium of the college. Figures 4, 5 and 6 show the captured images before and after stitching for flights one, two and three respectively.

VOL. 11, NO. 19, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

4. SYSTEM EVALUATION

The case study used in this work was the aerial imaging. The F450 - based, APM 2.6 - controlled quadcopter with Mission Planar as a GCS has been evaluated from three different viewpoints. At first, the new picked up aerial mosaic were compared with the available google earth maps. Secondly, several dimensions of the targeted buildings and areas were read in the aerial mosaic and then compared with the actual measurements on the ground. Finally, a comparison was made between the GPS reading of some points in the aerial mosaic and that corresponding points on the ground.

Figure-4. Aerial image of flight one.

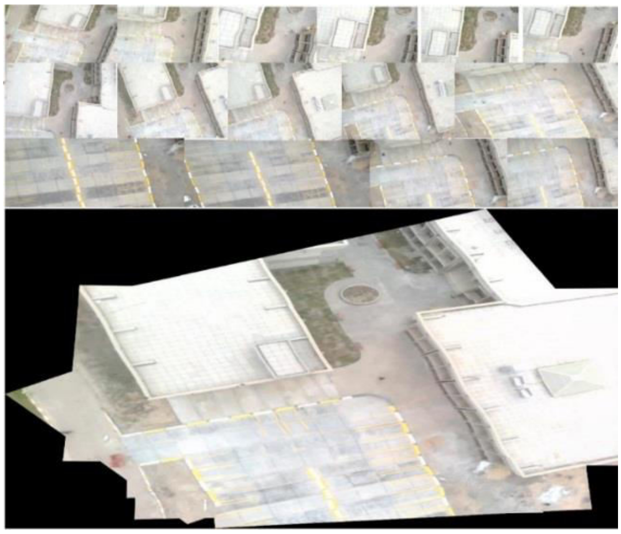

Figure-5. Aerial images of flight two.

Figure-6. Aerial images of flight three.

4.1 Comparison with Google map

A comparison between the new aerial images and the available satellite images was shown in Figures 7, 8 and 9 for flights one, two and three respectively.

As shown, for the three flights, the vision accuracy of Google map images is relatively higher than that of the aerial mosaic. This is clear in Figure-7.a and less clearly in figures 8.a and 9.a. The weak vision accuracy is attributed to the poor quality of the camera equipped to quadcopter. The camera specification was stated in sec. 2.6. The camera of aforementioned properties has been chosen because of its light weight and hence fitting with quadcopter capabilities. In the other hand, it is obvious that the aerial images in Figures 8 and 9 are more updated than Google images do. The park of cars and the street besides the building are clear in both Figures 8b and 9b. In addition, the yard inside the building and the football playground are also obvious in Figures 8b and 9b, respectively. The available images taken by google earth are often old, yet the new ones can be obtained by paying a high price cost.

Figure-7(a). Flight one image from Google map.

Figure-7(b). Flight one image from quadcopter.

Figure-8(a). Flight two image from Google map.

Figure-8(b) Flight two image from quadcopter.

Figure-9(a). Flight three image from Google map.

Figure-9(b). Flight three image from quadcopter.

4.2 Length measurements using aerial images

Each aerial image was examined to see if it could be used to measure lengths and areas. A drawing scale was set to every aerial image according to the law:

$$Drawing\ Scale = \frac{Exact\ length\ of\ object}{Length\ of\ object\ on\ aerial\ image} \qquad [19]$$

The images are printed on A4 page size to determine the scale. The three flight mosaics are shown in Figures 10, 11 and 12. Several lengths of objects on buildings and ground were selected and referred to in these figures. For the three flight mosaics, the drawing scale was determined according to line AB, and the dimensions were measured in meters. Table-1 shows the percentage error when comparing between the lengths indicated on the aerial images and the actual lengths. The percentage error was calculated using the formula:

$$\%\text{Error} = \frac{|\text{ length on image } - \text{ Actual length }|}{\text{Actual length}} * 100$$

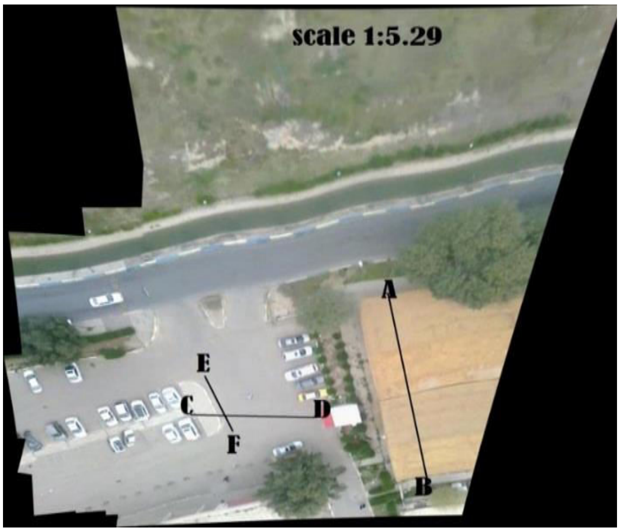

Figure-10. The drawing scale of aerial image of flight one.

Figure-11. The drawing scale of aerial image of flight two.

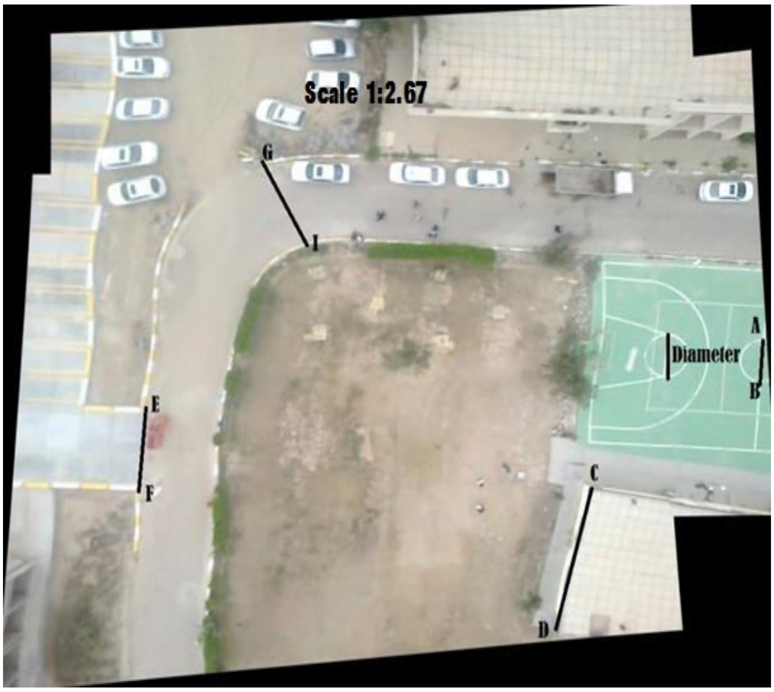

Figure-12. The drawing scale of aerial image of flight three.

Table-1. Percentage error found between objects' lengths in aerial images and on the ground.

Flight	Line	Exact length	Length in image	% Error
one	EF	8.6	8.92	3.8
	CD	13.45	13.77	2.3
two	EF	4.4	4.375	0.568
	GI	40	40.6	1.5
	GH	10.59	10.85	2.45
	CD	6.5	6.475	0.3846
three	CD	12	12.282	2.35
	AB	3.55	3.471	2.22
	EF	6.7	6.675	0.373
	GI	7.57	7.3425	3.005

As demonstrated in Table-1, the percentage error in all flights didn't exceed 4% of the actual lengths of various objects. It is an acceptable result and opens the door widely to utilize the quadcopter in many applications such as monitoring the progress of new buildings' construction or facilitating locating (injured) persons during rescue operations.

4.3 Extract GPS locations for specific points

Using ArcGIS software, the GPS location of some points on the aerial image was found in Decimal Degree units. The Decimal Degree units were converted into the Degree: Minute: Second units [20], to compute the difference in GPS coordinates of certain points on both the aerial mosaic and on ground. The change in one second of the location of the point is equal to 31 m in longitude and 37 m in latitude. The Error could be calculated according to the Equation [20]:

$$Total\ Error = \sqrt{(Longtitude\ error)^2 + (Latitude\ error)^2}$$

The accepted error is up to 6 meters in civilian applications according to the official U.S Government information about the GPS Topics [21]. The three flight mosaics are shown again in figures 13, 14 and 15 to refer this time to the randomly selected points to check GPS coordinates accuracy.

VOL. 11, NO. 19, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Figure-13. GPS Points on aerial images of flight one.

Figure-14. GPS Points on aerial Images of flight Two.

Figure-15. GPS Points on aerial Images of flight Three.

Table-2. Error between GPS coordinates' values of some points using ArcGIS and exact corresponding GPS values of Flights one, two and three.

Flight	Point	Location in ArcGIS	Exact GPS location	Error (m)
one	A	Long: 44.37290053 Lat: 33.2721135	Long:44.37290760 Lat: 33.2721495	5.16
	B	Long: 44.37279738 Lat : 33.27193465	Long: 44.37277638 Lat: 33.27194135	2.507
two	A	Long:44.3730637 Lat:33.2708301	Long: 44.37305891 Lat:33.27083358	0.707
	B	Long:44.3730066 Lat:33.2708365	Long: 44.3730054 Lat: 33.27085759	2.79
	C	Long:44.3730475 Lat:33.2706989	Long:44.37303154 Lat:33.27071615	2.9
	D	Long:44.3729299 Lat:33.2707124	Long:44.37293801 Lat:33.27069525	2.46
	A1	Long:44.372993 Lat:33.270611	Long: 44.373002 Lat: 33.270631	2.847
	B1	Long: 44.373074 Lat: 33.270595	Long:44.373064 Lat:33.270570	3.97
	C1	Long:44.373054 Lat:33.270687	Long:44.373082 Lat:33.270680	3.26
three	A	Long:44.3727966 Lat:33.270956	Long:44.3728011 Lat:33.2709651	1.312
	B	Long:44.3730364 Lat:33.271171	Long:44.3730426 Lat:33.27118897	2.128
	C	Long:44.3729936 Lat:33.271321	Long:44.37300562 Lat:33.27135189	4.323
	D	Long:44.3730649 Lat:33.2708648	Long:44.3730637 Lat:33.2708301	4.15
	A1	Long:44.372993 Lat:33.271072	Long:44.373010 Lat:33.271070	1.913
	B1	Long:44.373051 Lat:33.271104	Long:44.373048 Lat:33.271070	4.27

Table-2 summarizes the comparison between GPS coordinates values obtained by the aerial mosaic using ArcGIS, and coordinates values obtained by the GPS module on the ground. The Error is calculated in meters. From the table, it is noticed that the error is in the accepted zone for all points and this is due to the good processing of the images with Microsoft ICE software.

5. CONCLUSIONS

In spite of the efforts spent by manufacturers, the effect of quadcopter vibration was appeared clearly in the vision quality of images, and accordingly affect the accuracy of measurements. Nevertheless, the results show that the aerial images can be used to measure lengths and areas at percentage error not exceeds 3.8% of the actual values. In addition, the new aerial images can be used to extract GPS location for specific points including the updated points that do not exist in the Google Satellite images, but with error within the range (0.1 - 5) meters. However, controlling the quadcopter maneuvers is not so easy to put it into wide scale civilian applications. It still requires several hours to learn how to install and control the robot. The produced aerial mosaic maps contain more accurate details than the Google earth do. Still, the aerial mosaic require more complicated stitching algorithm to get non blurred images.

ACKNOWLEDGEMENT

Authors like to express their gratitude towards Mechatronics Engineering Department at Al-Khwarizmi Engineering College, University of Baghdad for their support and encouragement during this work.

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