Low Cost High Accurate Areal Mapping with Custom Built RTK Drone

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ABSTRACT: High accurate, high resolution 3D mapping with drones has opened up new possibilities in surveying, engineering, and geoscience applications. Current consumer drones under 2,000USD have lifted the drone mapping industry to a new level as they are capable of making high resolution and high accurate maps at low costs. Geolocation accuracy of drone map products mainly depends on the quality of the ground control points. By establishing well distributed and accurate ground control points, it is possible to achieve 10 cm or better accuracy maps with a consumer-grade drone. It is essential to establish precise ground control points for applications that demand high accuracies. Establishing a network of ground control points is often a tedious, costly, and time-consuming task of a drone mapping project. There are survey grade drones available in the market which can do high accurate mapping without ground control points, but they come at a very high cost. The objective of this study is to develop a low-cost custom-made drone for high accurate aerial mapping without using ground control points.
Our custom-made drone is a hexacopter equipped with high precision RTK GNSS unit and intelligent flight controller, which has the capability of executing autonomous flight missions to capture accurate aerial data. In order to make 3D maps only by using drone images, accurate coordinates of the camera's optical center at the time of exposure are necessary. The GNSS unit and the camera are synchronized, and precise camera positions are calculated with the help of Extended Kalman Filter (EKF) built into the flight controller firmware. The drone can receive differential corrections via the internet or can bypass through the ground control station using the telemetry radio. Sources such as a local base station or Continuously Operating Reference Stations (CORS) can provide differential corrections to the drone, using the NTRIP protocol. The mapping performance of the drone is evaluated by processing the images with eight different GCP configurations, increasing from no GCPs to five GCPs. The 3D accuracy of the generated map was 13cm without using any GCP points, and the accuracy was increased up to 5cm, by introducing three GCPs. The 3,000 USD cost for the hardware is a significantly reduced amount when compared to the survey-grade drones in the market.

1 INTRODUCTION

1.1 Mapping with Drones

Mapping with drones has become a hype in the surveying and mapping industry due to benefits in cost, accuracy, resolution, and control of the data. It is considered that drone technology has filled the gap between traditional areal surveying and traditional ground surveying. Drones offer high-resolution Orthomaps and Digital Surface Models (DSMs) as main map products. Some applications such as monitoring or reconnaissance do not require a high degree of geolocation accuracy of the map products but surveying and mapping applications in engineering, construction, mining demand great geolocation and measurement accuracy. In such accuracy demanding applications, the required accuracy is achieved by either introducing a ground control or by integrating RTK GNSS technology to the drone for direct georeferencing.

1.2 GNSS Technology in Drones

Global Navigation Satellite System (GNSS) is a satellite-based positioning system that plays a critical role in drone-based mapping. GNSS units are integrated into all drones used in mapping, mainly for navigation. It also enables functions such as autonomous flight plan execution which is essential for mapping. The stand-alone satellite-based positioning can only provide accuracy up to 3m with the help of SBAS, which performs well for navigation purposes. If the standalone GNSS positions are used in the images to direct georeference the map products, the errors can be much as 5m.

The key to producing high accurate map products without using ground control is to obtain the precise positions of the camera's optical center at the point of exposure. In order to achieve centimeter-level accuracy of the map products, it is required to have the same or better accuracy of the image locations, which ultimately comes from onboard GNSS receiver. That accuracy can only be achieved with kinematic processing. The kinematic GNSS method can either be Real Time Kinematic (RTK) or Post Processed Kinematic (PPK) which uses a similar principle to enhance the precision of GNSS positioning. In addition to the code based positioning, kinematic positioning utilizes the phase of the carrier wave to compute the position which result centimeter-level accuracy. This accuracy is achieved with corrections provided by a GNSS receiver established on known location known as a base.

High-end survey grade drones are equipped with RTK GNSS receivers with precise synchronization with the camera. By processing the geotagged images obtained from eBee X, which is an RTK enabled survey-grade drone, it is possible to achieve up to 1.5cm accuracy in the map products but at a very high cost.

1.3 Photogrammetric Ground Control Points

Ground Control Points (GCPs) are points of known coordinates in the area of interest which are clearly identifiable in the images. The placement of GCP markers is done before the aerial data collection considering the terrain and the size of the area to be surveyed. In order to make accurate map products, the well-known practice is to use a well-distributed ground control network with an optimum number of GCPs. In addition to GCPs, Independent Check Points (ICPs) are established to verify the accuracy of the map. Both GCPs and ICPs are surveyed to obtain accurate 3D coordinates of the center of the markers using a ground surveying method. The most common and convenient way to survey a ground control network is by using the kinematic GNSS positioning method.

1.4 Costs Associated with Drone Based Mapping

The costs for mapping with drones can be divided into three categories — costs for hardware, software, and human resource.

Table 1: Costs for Mapping with Drones

Hardware	Software	Human resource
• Drone • Imaging system • *GNSS receivers** • *Tripods, surveying poles and GNSS antennas** • *GCP markers** • Insurance	• Flight planning software • Photogrammetric processing	• *Ground surveying and assistance** • Photogrammetric processing

Establishing ground control is often a time-consuming costly and labor-intensive task as it is associated with ground surveying. The components indicated with * in the table, are the costs associated with establishing a ground control network. Furthermore, establishing a good GCP network requires a reconnaissance survey and analysis of the terrain. The difficulty arises when the terrain is undulated or inaccessible in order to place well-distributed GCPs. Considering these facts, drone mapping can be efficient, more straightforward, and cost-efficient if GCPs can be eliminated from the drone mapping pipeline but preserving the accuracy of the map products.

2 OBJECTIVE

Develop a prototype drone for high accurate and cost-efficient aerial mapping

The focus of this study is to establish a method to reduce the cost for accurate areal mapping by custom building a drone that is capable of delivering map products to high accuracy without using ground control network. With the developed drone, it saves the costs associated with establishing ground control as well as reduces the cost for the drone hardware. The drone is built according to the following specifications.

a) Total cost for the hardware is less than 3000USD
b) Integration of high accurate positioning system capable of RTK and PPK
c) Direct transmission of GNSS correction data to the drone via internet
d) Autonomous mission planning and execution
e) Synchronized imaging system

3 METHODOLOGY

3.1 System Components

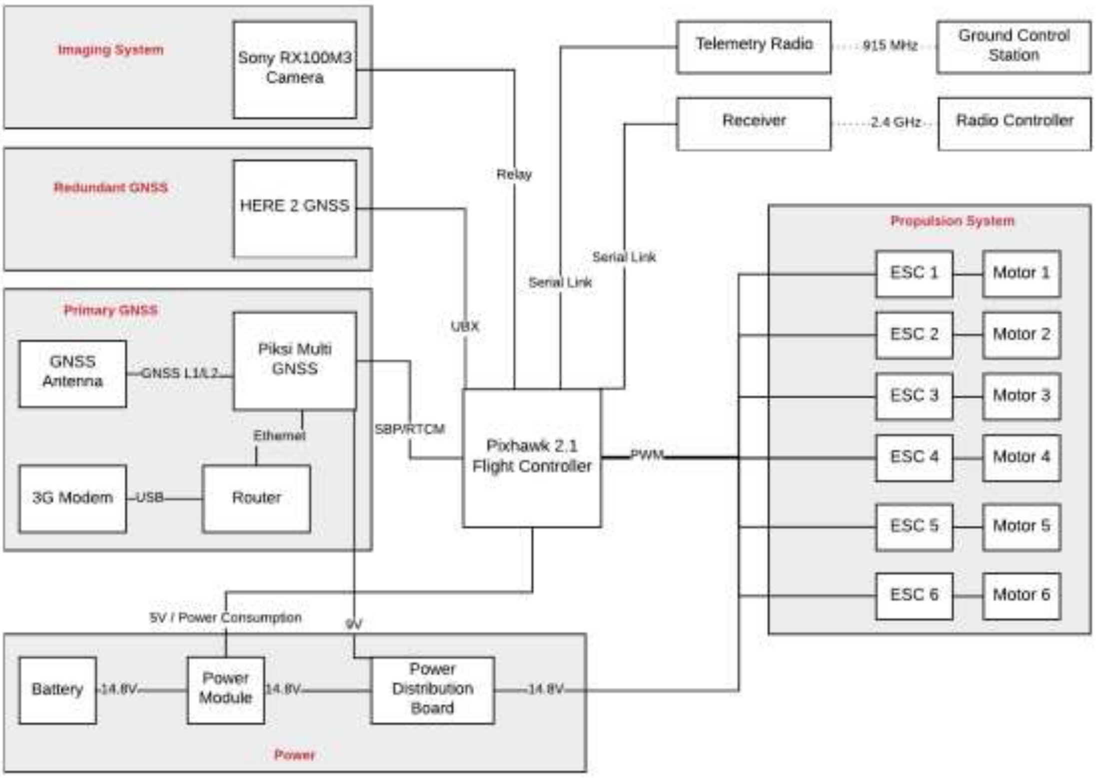

Figure 1: System Components and Connections of the Developed Drone

3.2 Platform and Propulsion

A hexacopter platform was chosen considering the payload, cost, and prototype capability. Multirotor platforms are capable of vertical take-off and landing as well as hovering. These functions are considered more important in the prototyping stage in order to test and verify the hardware functions. A hexacopter platform was selected to provide the required thrust to lift the total 3kg weight of the components. T-Motor propulsion system was selected considering the thrust and power efficiency. The total flying time of the setup is 15 mins.

Figure 2: Completed RTK Hexacopter Platform

Table 2: Hexacopter Platform Specifications

Frame	Tarot FY680
Motors	T-Motor MT2814 710kv
Propellers	Graupner 11-5
ESC	T-Motor 35A
Battery	Multistar 10000mAh

3.3 Flight Controller

The flight controller is the brain of the drone, which controllers all the maneuvers of the drone. It integrates the sensors into a centralized platform and processes the data coming from the sensors to execute functions required to keep the drone up in the air. Pixhawk 2.1, an open hardware flight controller loaded with ArduCopter firmware, was selected considering the reliability and versatility. Pixhawk 2.1 is used in many commercial products as a reliable flight controller. It has multiple redundant processors as well as sensors to provide maximum reliability. In addition to providing a stable flight of the multicopter, ArduCopter firmware in Pixhawk provides essential functions to execute flight plan and trigger camera at desired location to capture images for mapping.

Figure 3: Pixhawk 2.1 Cube Flight Controller

3.4 Positioning system

It is necessary to integrate high precision GNSS receiver, as mentioned in the section 1.2, to the drone to gain the required accuracy in the map products. Swiftnav Piksi Multi receiver is chosen as the primary GNSS receiver to fulfill the accuracy requirements. Piksi multi is low-cost hight precision receiver that is compatible with RTK. Maxtena M1227HCT-A2, a high precision lightweight helical GNSS antenna is used. Studies show that the Swiftnav Piksi receiver can provide highly accurate solutions with a high-quality antenna where there is a minimum multipath effect. The study from Gebre-Egziabher *et al.*, 2018 shows that Swiftnav Piksi provides 2.4cm accuracy with 95.5% RTK fixed availability. The operational environment of the drone has a clear sky view which minimizes the effect of multipath. A metal ground plane is used to mount the antenna as precaution to further minimize the multipath errors which can be resulted by ground features. The Piksi evaluation board is utilized for easy integration as it provides all required

connection ports.
Here 2 GNSS receiver is used in the drone as a redundant GNSS unit for navigation as a standalone receiver. HERE 2 GNSS unit powered by a u-blox Neo M8N GNSS receiver and Honeywell's latest high precision 3-axis digital magnetometer which provides the heading of the drone. HERE 2 unit is assigned to be the primary magnetometer which has the minimum interference from other electronics. The features of the GNSS units are as follows.

Table 3: Features of GNSS Units Used in the Prototype Drone

	Piksi Multi	HERE 2
GNSS tracking	GPS L1/L2, GLONASS G1/G2, BeiDou B1/B2, Galileo E1/E5b	GPS L1, GLONASS G1, QZSS L1, Galileo E1, SBAS
RTK output frequency	10Hz	10Hz
RTK horizontal accuracy	0.01m	-
RTK vertical accuracy	0.015m	-
Standalone accuracy (SBAS)	0.75m	2m
Velocity Accuracy	0.03 m/s	0.05 m/s
Communication	2 x UART, 2 x CAN Bus, Ethernet, 2 x USB	1 Serial Port, 1 x CAN Bus

Piksi multi uses Swiftnav Binary Protocol (SBP) to send and receive data that is enabled in Arducopter firmware of the flight controller. The communication between the Piksi and Pixhawk flight controller is done using serial interface using SBP protocol.

Two methods were used to send the RTK correction data to the drone in real-time

a) Integrating 4G modem to the receiver
b) Using telemetry radio

The primary way to transmit the RTK corrections was using NTRIP protocol via a direct internet connection to the drone. A router and 3G modem was connected to the receiver to provide internet connectivity. During the situations where no internet connections available, correction signals are transmitted trough telemetry radios of drone and the ground control station. Piksi multi UART 0 port is configured to send the position and UART 1 to receive corrections from telemetry radio connected to the flight controller when the internet connection is not available. Also, GNSS raw data is recorded to microSD card to provide PPK capability

3.5 Imaging System

Ultimate data provided by drones for mapping purposes are the images, so the quality of the images directly affects the quality and the accuracy of the map products. Several parameters are considered when choosing the camera for the drone. Which are resolution, resolving power, sensor size, shutter speed, focusing compatibility, triggering compatibility, weight, and price. Sony RX 100 M3 was selected considering the above-mentioned factors. The camera is mounted to a custom build wire rope isolator to minimize the effect of vibration. The camera is triggered by the autopilot by using the relay function. The selected camera provides superior images, but it lacks a hot shoe to provide feedback to the flight controller to determine the exact time of exposure. In order to minimize the camera's reaction time, it is set to manual focus and set the focus to infinity since the object distance is significantly larger than the focal length and distance to image plane.

Table 4: Specifications of Sony RX 100 M3 Camera

	Sony RX 100 M3 
Sensor	20.1 MP Exmor R BSI-CMOS sensor
Min shutter speed	1/2000s
Maximum aperture	f/1.8
Focal length	8.8 - 25.7mm
Field of view	34 – 88 deg
Remote Trigger mechanism	Switch
weight	290g

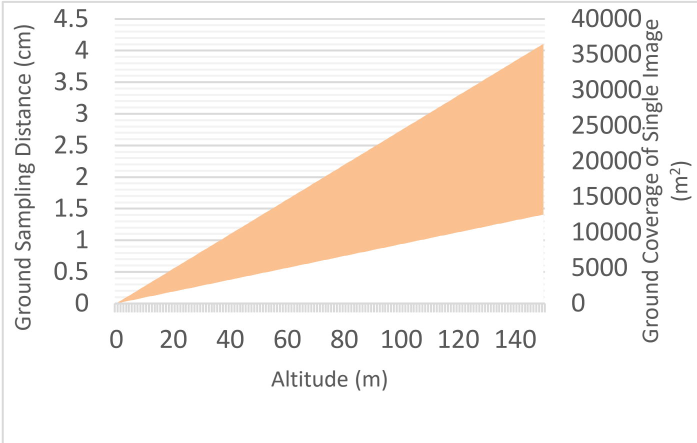

Figure 4: Relationship Between Altitude, GSD, and Coverage of a Single Image of the Imaging System

3.6 Ground control station, Telemetry and Radio Control

The Ground Control Stations (GCS) runs Mission Planner software in a portable laptop connected to the telemetry radio. The connection between the GCS and the drone is established by long-range 915Hz telemetry radios made by Hobbywing. The GCS provides the functions to configure and calibrate the drone as well as to plan and execute autonomous flight missions to capture aerial images for mapping. Even though the mapping missions are autonomous it is essential to provide the functionality to manually control the drone which was provided by using Frsky Tarranus X9D radio controller and Frsky X8R receiver.

4 RESULTS

4.1 Mapping Performance

The drone's performance in mapping is assessed by mapping a total area of 0.05 km^2 in the Asian Institute of Technology, Thailand. Before the flight, 8 Independent Check Points (ICPs) were established using a total station to assess the geolocation accuracy of the maps.

The images are post-processed with the flight log to extract the location at the time of exposure. As the GNSS receiver operates at 10Hz and the average drones speed is 4.4ms^{-1}, there is 0.44m gap between two position readings. In order to obtain an accurate estimate of the position of the image exposure, built-in Extended Kalman Filter (EKF) of the Ardupilot firmware is used. The geotagged images are photogrammetrically processed into

Figure 5: Study Area

orthomap and DSM using the Pix4D software, resulting a high-resolution orthomap and DSM.

Table 5: Flight Parameters

Area	0.05km^2
Overlap	75%
Flying height	100m
Total flying time	10 mins
Camera	Sony DSC-RX100 MIII
Average GSD	2.65cm
Number of images	52
RTK fix rate	100%

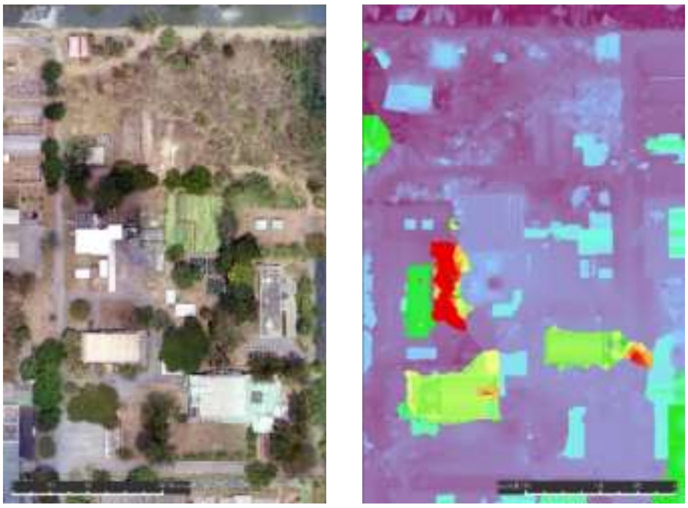

Figure 6: Final Orthomap (left) and DSM(right) of the Study Area

4.2 Accuracy Analysis

The mapping accuracy is assessed by comparing the map coordinates with the actual ground coordinates established by Independent Check Point Network. The analysis shows that the custom-made drone can make 2D maps to an accuracy of 11cm and 3D accuracy of 13cm in the given scenario without the aid of ground control.

The analysis was further extended to assess the effect of introducing GCPs to the process. When GCPs were used in the photogrammetric process, the accuracy increased up to 5cm in 2D and 6cm in 3D. It was observed that increasing more GCPs after introducing 3 GCPs, the accuracy does not significantly increase.

Table 6: Accuracy Comparison and Variation with the Number of GCPs

	Number of GCPs	0	1	2	3	4	5
Custom Built RTK Drone	2D Accuracy (cm)	**11.0**	11.5	5.2	4.7	5.2	5.1
	3D Accuracy (cm)	**12.5**	14.7	8.5	7.2	5.8	6.0
Phantom 4 Pro	2D Accuracy (cm)	113.8	365.4	3.0	2.9	2.9	1.7
	3D Accuracy (cm)	2844.7	438.0	42.9	5.8	4.3	3.4

The performance of the custom-built drone is evaluated by comparing it with phantom 4 pro which is a commercially available consumer-grade drone commonly used in mapping. As the Phantom 4 does not use high precision positioning system, the accuracy was low as 3m when no ground control points were used. Most of the contribution to the observed error comes from the height. When 3 GCPs were introduced, the accuracy increases to 5 cm.

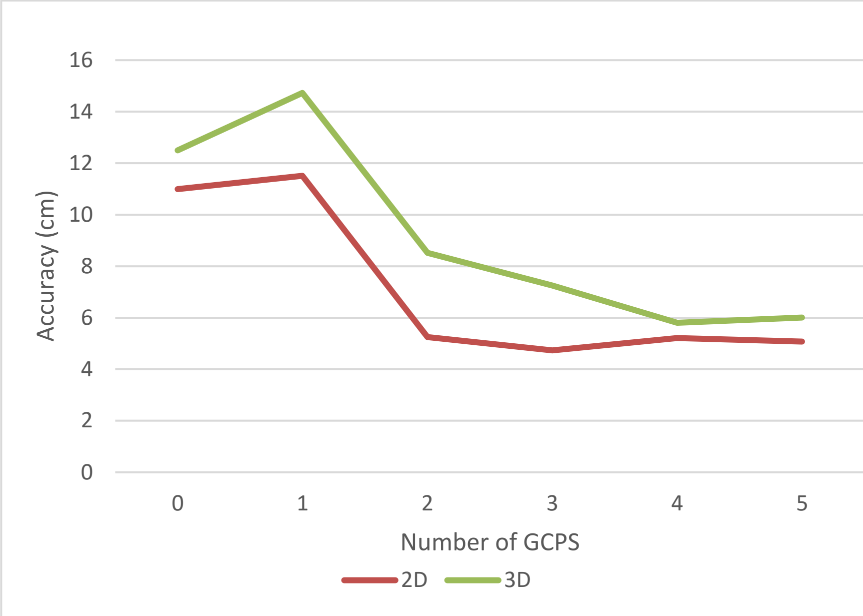

Figure 7: Accuracy variation of the RTK drone

4.3 Future Improvements

The prototype drone can perform high accurate mapping without ground control, but there is room for improvement as it does not gain the same accuracy as compared when ground control is used.

RTK GNSS Receiver with High Solution Rate: Swiftnav Piksi only provides a 10Hz RTK solution rate. The positioning accuracy can be increased by using an RTK receiver compatible with a higher solution rate.

Camera Feedback: There can be a small lag between the flight controller commands the camera to take the image, and the camera actually takes the image. This lag is minimized in this study using indirect way which was to set the camera's focus to infinity in manual mode. It is possible to obtain a more precise camera triggering position by giving feedback to the flight controller using a hot shoe compatible camera.

Fixed Wing Drone: The drone built in the study is a prototype to test the RTK functionality. One main limitation of this drone is 15 minutes of low flying time due to the payload and the high-power consumption of the six motors. The same hardware configuration can be used in a fixed-wing drone instead of a multicopper with ArduPlane firmware to increase which will ultimately increase the mapping time.

5 CONCLUSION

The RTK drone is capable of producing maps to global accuracy of 13cm in the selected scenario, but when a ground control is introduced, the accuracy increased by a factor of two. When compared with commercially available RTK drones, the accuracy of the custom made RTK drone is significantly less as drones such as Sensefly eBee X can produce maps to 1.5cm. The custom made RTK drone outperforms the Phantom 4, in a considerable margin in terms of the accuracy. When compared with the drones available in the market, the custom RTK drone has better price to accuracy value as the built cost is under 3000 USD. This prototype RTK drone provides unique functionality to obtain RTK corrections directly with the onboard internet connectivity. It is a considerable advantage when Continues Observation Reference Network (CORS) is available at the location of survey. The availability of CORS network eliminates the necessity establishing base station to provide RTK corrections. Location data observed by several high accuracy GNSS receivers are processed at a central server, and corrections can be broadcast to RTK receiver in the drone directly to obtain high accurate positioning. This approach is highly efficient and cost-effective. The onboard internet connectivity provides low latency positioning solutions as well as there is no effect on the RTK correction dataflow due to loss of radio signal from the ground control station. The custom-built RTK drone is an affordable drone which can provide a considerable level of accuracy in mapping. The custom made Ironman RTK drone can be successfully used in the applications where it matches with the accuracy requirements as the accuracy is always governed by the application.

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