UAS Medical Delivery in Rural/Mountain Areas under UTM Surveillance

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Abstract
UAV logistics is efficient and prompt by improving its infrastructure and technology. In remote and rural areas, delivery becomes desperate after disaster, especially in mountainous territory. A medical delivery network can be constructed to rely on high mobility UAVs to execute missions. By using different characteristics of UAVs, a hub and spoke concept for UAV logistics network is proposed with preliminary study and test. A hexa-rotor UAV is tested in Alishan for medical delivery by introducing Self-Fly autonomous flight control mechanism under UTM surveillance. Adequate path planning is also studied in mountainous area for terrain avoidance. From the flight log data, the performance of UAV logistic delivery is analyzed to examine its flight safety and possible impact. The autonomous flight control supports UAV delivery in mountainous area. Due to Medicine Regulation, the tests just try to verify the system feasibility and function capability for further developments.

Keywords: UAS medical delivery, autonomous flight control, path planning, UTM surveillance, terrain avoidance.

1. Introduction

Aerial transportation and delivery for parcels and materials in unmanned aircraft system (UAS) environment has become a trend to the future. UAS medical logistics to remote/rural areas has been paid much attention by government and hospitals. It is livelihood, humanity and charity. The surface transportation in remote/rural areas inside mountains is relatively weak and fragile. Remote areas and mountainous areas are in urgent demand of medical supply and chronic medicine delivery.

On unmanned aerial vehicle (UAV) development and applications, CB Insight Research Brief collected “38 ways drones will impact Society”. It presented the most focused issues on using UAVs to improve the known livelihood solution methods [1]. UAV is definitely the most valuable and efficient way to reach beyond human’s natural ability. According to Nasdaq OMX’s News, UAV delivery market will hit US$ 7,388.2 Million by 2027. Up to date, there are many projects on-going for proof of concept (POC) and proof of business (POB) for delivery all over the world [2]. Some excellent jobs have been done in the past few years.

In fast and efficient delivery, UAV logistics has verified with its high mobility and prompt response in use. It magnifies the importance in medicine delivery, especially for the health and medical system. UAVs are also used to extend the supply chain in medical services [3]. Zipline established a UAV medical supply chain in Ghana [4] to distribute to four logistic center around the country and conducted regular delivery for medical supplies, emergency blood and chronic medicines with supports of 2000 medical and health care personnel.

UAV delivery as well as Urban Air Mobility (UAM) were pointed out as two future demands of the unmanned system [5] with surveys. It expands UAV mobility into the third dimension of low-level airspace, out of a privilege reserved to the military. UAVs combine three key principles of technology modernity - data processing, autonomy and boundless mobility. UAV are known by general motivation to make process much faster and more flexible, while improving precision and cost-effective. Potential safety and security for privacy are major challenging issues by 2019.

Before 2004, without adequate regulations, UAV’s were governed by the following guidelines [6]: UAV Operations shall not increase the risk to other airspace users or third parties. The Joint Aviation Authorities (JAA) used an “Equivalent Risk” for UAV operations to monitor the safety of UAVs and their accidents for the past 20
years. Due to the lack of UAV event/accident data, manned aircraft event/accident data has been referred to study the risk level for UAVs. In order to determine the risk of UAV operations, some safety factors are proposed using the linear model, such as the physical factors of weight, velocity, kinetic energy (KE) and frontal impact area, the ground population and the effect of shelter and the number of casualties [6]. Frequent UAV activities imply that UAS traffic management (UTM) for surveillance and control in low-altitude airspace would be required. Under such UAS safety concept, a dependent surveillance UTM is developed with close reference to air traffic management (ATM) in air transportation [7].

A quad-rotor parcel delivery was demonstrated to carry package to fly over river. Mobile phone 4G system was adopted for video tracking along the flight path. Image processing for target recognition was applied to precisely drop the package. By GPS guidance to target neighborhood, the 4G image capture the target QR code and guide the UAV to approach to precision release [8].

As UAS logistics will become mature for use to the public, the FAA shall approve UAV to fly into daily life in the US from recreational flying to commercial uses under the number one priority of safety [9]. UAS Integration Pilot Program (IPP) focused on testing and evaluating the integration of civil and public UAV operations into the National Airspace System (NAS). As participant in these programs move to prove their concepts, they must follow the FAA’s existing Part 135 Certification Process. UPS Flight Forward conducted its first UAV package delivery with its Part 135 certification to fly medical supplies in Raleigh, North Carolina on September 27, 2019.

Mature UAV performance includes complete infrastructure, flight risk assessment, flight data access, autonomous flight control, and etc., in order to improve the safety and efficiency of UAV logistics delivery. In remote/rural areas, UAS delivery requires a precision path planning in logistics. It concerns not only the delivery itself but also impact to socio-safety. Lin and Shao [10] presented failure mode study on fixed wing and rotor wing UAVs. The crash probability density (CPD) was proposed to estimate the crash impact area from different flight performance. CPD circles the high probability area and connects as a corridor for specific path planning. This corridor bypasses the populated zones to avoid hazardous to the public. This creates a feasible methodology to construct UAV flight corridors for delivery services. Since UAV reliability index of Mean Time between Failure (MTBF) is still too far to meet air transport level of $10^{-6}$~$10^{-7}$, a new safety assessment for possible injury and fatality from UAV crashes is defined by Expected Level of Safety (ELS) [10]. The ELS analyzes fixed wing and rotor wing UAVs to get a safety margin for reference. Path planning for rural UAV medical delivery can become a minor concern with ELS to ground impact. Path planning from take-off base via waypoints to target requires pre-scheduled flyable paths with adequate separation among UAVs and terrains.

Up to date, the civil aviation industry including air transport carriers for passengers and cargos, generation aviation (GA), the booming UAVs and future UAM vehicles, plus military aircraft, share the airspace equally to fly. Since modern technologies have made all possible to support UAV flying into the National Airspace System (NAS), the UAV operations become a significant part to threat aviation safety. UAV surveillance in UTM shall be as important as manned aircraft in ATM.

In CNS/ATM development in 2010, the dependent surveillance using automatic dependent surveillance – broadcast (ADS-B) has been recommended as a significant part of flight information from the conventional independent surveillance by Radar [11]. Since ADS-B makes use of GPS technology, determines the precise aircraft location information and streams to other aircraft and ATM system. Resulting from its efficiency and accuracy, the FAA has set the goal to have ADS-B in full operational by the year 2020. US airlines are on the track to chase this goal, although the general aviation industry is struggling to meet the deadline date. In recent study, an ADS-B Like technology is introduced for UAVs in UTM with similarity to ATM.

Data communications augments ATM controllers to send command instructions and clearances to pilot rather than sole voice communication. System wide information
management (SWIM) is the network backbone structure to carry NextGen digital information [12]. SWIM will enable cost-effective, real-time data exchange and sharing among users of the NAS. The UTM system shall coordinate into such system [7].

The modern ADS-B enhances surveillance radar in augmentation to use GPS in satellite positioning instead of ground radio scanning. The use of ADS-B being faced certain threats due to signal jamming and spoofing that need some manner of protection. Strategies and planning shall be prepared to improve the defects in ADS-B.

The Self-Fly autonomous system is additionally introduced into the flight test. Self-Fly autonomous flight control system is built with S-bus protocol on top of Pixhawk flight control system to execute the embedded commands from mission planner and path plan commands from pilot [13]. Complete software route activates full autonomous. In mission planner assignment, due to terrain changes, level flights are setting to maintain enough clearance during climb and descend. A few waypoints are created to manipulate UAV flight performance over terrains. During flight tests, downwash wind turbulence presents most dangerous situation to autopilot control.

A preliminary infrastructure is proposed in this research to focus on planning and operation on medical logistics and material delivery in mountainous areas by UAS among Villages in Alishan territory in Taiwan. In the mountainous environment of Alishan, the GIS system is used to explore the terrain profile and formulate an automatic flight path planning for UAVs according to the 3D terrain avoidance. Flight demonstrations use a hexa-rotor UAV to fly in Alishan and study flight parameters of altitude, speed, communication coverage, meteorological condition, surveillance signal reliability, battery sustainability, payload affordability, landing procedure and operation awareness. The analysis explores the safety margin of logistics flights.

In this research, the medical logistic in mountain area tries to fit into different path planning from hub to spoke village distribution. In path planning, forward stretch into deep mountains or radially spray out from base medical station can be considered. Full autonomous UAV flight control is designed and embedded into hexa-rotors with mission planner assignments. UAV flight test is monitored under UTM environment. Solar mobile ground transceiver stations (GTS) are firstly used in this test to enhance UTM dependent surveillance during flight tests. Weather forecast and meteorological watch is also important for flight safety, since severe cloud and wind changes abruptly. Emergency plans based on standard flight procedures should be prepare and exercised. In this paper, several flight tests are shown with the medical logistics in mountainous areas.

2. Remote UAS Medical Delivery

2.1 Delivery Hub and Spoke Concept

The central area of Taiwan is mountainous territory. There are people and villages distributed in the remote site. The national health policy covers people’s medical care into deep forest. Although the integrity of medical system is well constructed and deployed, there are difficulties and shortages to carry out medical cares to those areas due to:

(1) Rugged road by ground transportation into remote mountains,
(2) Limited medical professionals to commission,
(3) Medicine laws to limit medical interrogation, diagnosis and treatment,
(4) Strict regulations to deliver medicine to patients.

Before the medical regulations can be released, medical logistics to mountainous area should be studied in advance.

Since UAVs are characterized by their performance and operation, high mobility multi-rotors can offer short distance, light weight supply delivery locally; while the fixed wings with long endurance high payload are used from hospital into mountain. A hub-spoke (H&S) concept of remote/mountainous delivery is studied and constructed using different UAV deployments as shown in Table 1. The supporting hospital delivers medical supplies to the remote hub stations. To the last mile, full autonomous multi-rotors are selected to fly from a Medical Station (known as remote hub) in the mountain area to another Health Station (known as spoke) to delivery medicines using multi-rotors. It should be
directly to patients if future regulation permits by some certain process, such as wireless Remote ID and object release.

Figure 1 shows the hub and spoke configuration in Chia-Yi Christian Hospital to Alishan. In the Alishan mountainous area there are villages grouped into three major sections. From Chia-Yi Christian Hospital Hub to Alishan Heliport Hub is about 40 km in air distance. From Alishan Heliport Hub to each section will be less than 10 km. This mountainous area can be supported from Alishan Heliport Hub. Major medical supplies can be delivered from hospital to heliport daily using dual mode (Vertical + Horizontal Take-Off and Landing, VTOL+HTOL) Stork UAV. Since the dual mode Stork can take-off and landing from the roof platform, it is most suitable to fit such applications. The proposed UAV fleet in our study for hub and spoke medical delivery is shown on Table 1.

![Figure 1: Concept of Chia-Yi Christian Hospital to Alishan Heliport.](image)

### Table 1: The proposed UAV fleet for medical logistics to mountainous area.

<table>
<thead>
<tr>
<th>Cat./Spec.</th>
<th>Name</th>
<th>Seraph</th>
<th>Octopi</th>
<th>Stork</th>
<th>Cardinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>VTOL</td>
<td>VTOL</td>
<td>VTOL+HTOL</td>
<td>HTOL</td>
<td></td>
</tr>
<tr>
<td>MTOW</td>
<td>12kgw</td>
<td>15kgw</td>
<td>50kgw</td>
<td>50kgw</td>
<td></td>
</tr>
<tr>
<td>Endure</td>
<td>&lt;40min</td>
<td>&lt;50min</td>
<td>&gt;120min</td>
<td>&gt;120min</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>&lt;8m/sec</td>
<td>&lt;12m/sec</td>
<td>&gt;30m/s</td>
<td>&gt;40m/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>28.8km/sec</td>
<td>43km/hr</td>
<td>108km/hr</td>
<td>140km/hr</td>
<td></td>
</tr>
<tr>
<td>Stall</td>
<td>NA</td>
<td>NA</td>
<td>20m/sec</td>
<td>20m/sec</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>&lt;10km</td>
<td>&lt;12km</td>
<td>&lt;100km</td>
<td>&lt;150km</td>
<td></td>
</tr>
<tr>
<td>Altitude</td>
<td>&lt;400feet</td>
<td>&lt;400feet</td>
<td>&lt;4000feet</td>
<td>&lt;6000feet</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>&lt;8m/sec (F5)</td>
<td>&lt;12m/sec(F7)</td>
<td>&lt;12m/sec(F7)</td>
<td>&lt;16m/sec(F8)</td>
<td></td>
</tr>
<tr>
<td>Comm.</td>
<td>Data + Video</td>
<td>Data + Video</td>
<td>Data + Video</td>
<td>Data + Video</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>Air Photography, PV Surveillance, Short range patrol, Logistic delivery</td>
<td>Air Photography, Ecological Surveillance, Long range Patrol, Logistic delivery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service</td>
<td>Distribute Hub to Spoke missions</td>
<td>Hub to Hub missions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Delivery Flight Scenario

The proposed hub and spoke remote/mountainous area medical logistics introduces four different types of UAVs. Since the fixed wing UAVs have better performance than the rotor wings, fixed wings in Table 1 will offer Hub to Hub operation, while the multi rotors are used
from mountainous hub to spokes. In this study, the Chia-Yi Christian Hospital will be the Hub to offer medical supplies to the mountainous hub at Alishan Resort Heliport.

For medical logistics, the test site is located at Alishan in Chia-Yi County in the middle part of Taiwan, as shown in Figure 2. Alishan is a famous recreation resort deep into mountain area. There are 10 villages with average population of 150. Most of the residence is Taiwan Natives. The National Health Department tries most efforts to offer enough health and medical support to those villagers. However, due to the rural situation, ground transportation is desperate especially after stormy weathers. The proposed idea tries to use UAV to deliver chronical medicines to the senior villagers. Hub and spoke concept is designed where hub has sufficient medical personnel with facility, and spokes are those far alone in the deep mountain. Based on H&S, the Chia-Yi Christian Hospital becomes the main hub to supply all demands.

In Figure 2, the test actual flight route is a little deviate from the direct route to bypass a mountain. The flight performance introduces the Self Fly system [16], which is a newly developed autonomous system on top of Pixhawk to feed in flight commands referring to path planning.

This test is conducted in cooperation with Chia-Yi Christian Hospital. Mountain sites are selected at two elementary schools. The flight test had made a week weather watch and decided to go with clearance.

The test site to take-off from Xi-Ding Elementary School, 23.25'51.56" N, 120.39'36.53", at altitude 1245 meter mean sea level (MSL) to Shan-Mei Elementary School, 23.22'57.35" N, 120.40'06.38" N, at 520 meter MSL. The direct air distance is 5350 meters, but it actually flies a little longer by a 3D detour over a mountain. The test flights are passing through undeveloped area of virgin forest.

Both test flights take about 12 minutes to destination, while ground transportation needs 35~40 minutes. Due to the down wash wind from mountain, the UAV flew with turbulent instability during landing.

Figure 3 is the hexa rotor UAV to conduct the flights. The performance of hexa rotor is very stable in performance. The battery budget uses 17600mAh LiPo and consumes 55% for one trip. This implies the flight performance can be either for longer endurance or against stronger wind. High altitude at 1200~1400 meter MSL delivery can be suitable using our hexa rotor UAV.
with arm pitch 850mm at maximum take-off weight (MTOW) of 9kg. The flight tests carried out 1 kg payload.

2.3 UTM Surveillance

For the medical logistics, the flight safety is the most concern issue. The risk of UAV crash to cause bio and material pollution will be strongly prohibited. Flight safety should be sustainable to high standard. On November 4, 2021, the team of UAV Center for UTM Project also supported the UAV mountain flight test. In this flight test, complete dependent surveillance for delivery UAV is verified on UTM.

Taiwan has been fully covered with UTM infrastructure [7]. The flight test has been monitored by UTM with on-board unit (OBU). Since the Alishan area is mountainous, two additional mobile GTS’s are installed at both ends of the flight tests as shown in Figure 4. The mobile GTS is design with solar panel to offer electric power to LoRa Gateways. The UTM performs a complete surveillance along the flight tests. Its track is shown on UTM monitor from UTM Center at CICU, Tainan [7]. Since GTS relays flight data to nearby 4G mobile base transceiver station (BTS) into Internet service by Chung-Hua Telecom, the UTM surveillance coverage is confident with their supports. During the logistic flights, UAV is completed monitored by the dependent surveillance mechanism of our UTM system.

UTM controller at CICU center maintain clear flight watch.

The UAV surveillance data is broadcasted from LoRa OBU, as shown in Figure 5, to receive by the mobile solar panel GTS and relay into Internet. The total flight test is 12 minutes, from take-off to landing, the UAV is under UTM surveillance, but still flight data loss along the flight path, due to mountain obstruction.

Figure 4: Solar powered mobile GTS on tests.

But this loss did not affect the total flight surveillance as shown in Figure 6. Finally, the UAV landed safely in Shan-Mei Elementary School.

Figure 5: The on board unit (OBU) of UTM.

Figure 6: UTM surveillance display the Alishan flight tests with Remote ID 53640027 (user 1) at 1318 m MSL.

3. Flight Data Analysis

In this study, the UAV broadcasted the flight data to UTM in 90 Bytes:

| Heading(5); ID(12); Lat(9); Long(10); Alt(4); 6 DoF(p, q, r, α, β, γ)(36); V(6); A(6); Tail(2). |

The UTM server collects all flight data and stores in the server memory for further restoration and analysis. The introduction of UTM into the test flights is successful to fully monitor on the UAVs in flight surveillance. The log data on UTM and on flight control system offers further analysis on flight tests.

The flight path of this test is from Xi-Ding Elementary School at 1243 meter MSL to Shan-Mei Elementary School at 510 meter MSL. The total flight distance is 5.5 kilometers, and UAV endurance is about 40 minutes with payload of 1kg. Flight data are shown in Table 2.

The weather watch is sunny clear at 22°C wind 4 m/sec at 10:30 am with visibility 5 km for the first take-off. The second flight takes off at 20°C at 11:30 am. Just after 2 minutes, the cloud covered abruptly into strong wind up to 8 m/sec and visibility drops to 1 km. It was too late to call back, the Captain commanded to go ahead to escape from the bad weather. The actual flight route detour to bypass a nearby mountain and maintain about 1320 meter MSL in horizontal flight. This prevents unexpected mountain obstruction in the flight route. Until approach to the destination
the UAV descends to landing. The vertical profile of flight test is shown in Figure 7.

One of the pre-flight operations is to survey the geographical environment between the origin and destination points of UAV flight. The Geographic Information System (GIS) is used for terrain analysis on the mountainous area, and then the path planning is mapped as shown in Figure 1 and Figure 2.

In flight test data analysis, the flight test is mainly based on the parameters of Log Data for the Mission Planner flight control software. The UTM system can also conduct real-time monitoring based on the quantitative parameters broadcast by OBU, as shown in Table 3. During the UAV flights, the residual voltage gradually decreases in consumption. Previous studies have pointed out that within a certain range, the residual voltage has a linear relationship with the remaining capacity of the battery [14]. However, in the last stage of flight, voltage drops abruptly to result in a rapid loss of thrust in the multi-rotor UAV [14]. In this study, the residual voltage is regarded as the main parameter that the battery can provide the normal airworthiness of the UAV.

The main objective in this analysis tries to watch the cross relationship of all parameters via UTM system, as Table 3, and to assert whether any of them affects the LiPo voltage during the flight.

In this analysis, the flight parameter values, referring to Table 3, are received from the UTM system. They are used as the independent variable group of \( x_{1} \sim x_{9} \), and the residual voltage is used as the dependent variable (\( y \)).

In order to understand the degree of interaction between variables in UTM system, the multiple regression models is introduced to analyze the relationship between the variables. Equation (1) is formulated to express this relationship [14].

\[
y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \epsilon
\]

where \( y \) is residual voltage (Measured Voltage) which is the criterion for determining the endurance and \( x_{1} \sim x_{9} \) are 9 flight parameters related to UTM system, as shown in Table 3, and \( \beta_0, \beta_1, \cdots, \beta_9 \) are the parameters, and plus the error term \( \epsilon \). [14]

The assumption for multiple regression model indicates that the mean or expect value of \( \epsilon \) is zero. Based on this assumption, the mean or expect value of \( y \) is denoted by

\[
E(\gamma) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \epsilon
\]

This is called multiple regression equation, as Equation (2).

\[
E(y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \epsilon
\]

Equation (2) illustrates how the mean value of \( y \) (as the measured LiPo Voltage) is related to \( x_{1} \sim x_{9} \) parameters under the UTM system. Is there a correlation between the UTM flight parameters(\( x \)) from UAV and the

<table>
<thead>
<tr>
<th>Items</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD Height &amp; difference</td>
<td>O: Xi-Ding 1243 m</td>
</tr>
<tr>
<td></td>
<td>D: Shan-Mei 510m</td>
</tr>
<tr>
<td></td>
<td>about 733 m</td>
</tr>
<tr>
<td>UAV Flight at Velocity</td>
<td>Air distance 6 km flight 12 mins at 5~6 m/sec</td>
</tr>
<tr>
<td>Car travel</td>
<td>12.6 km, 45 min at 30km/hr</td>
</tr>
<tr>
<td>Test flights</td>
<td>2</td>
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<tr>
<td>Payload</td>
<td>1 kg</td>
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<table>
<thead>
<tr>
<th>Abb..</th>
<th>Parameter</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volt</td>
<td>LiPo voltage</td>
<td>( y )</td>
</tr>
<tr>
<td></td>
<td>Dependent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Independent</td>
</tr>
<tr>
<td></td>
<td>Current</td>
<td>( x_1 )</td>
</tr>
<tr>
<td></td>
<td>Roll</td>
<td>( x_2 )</td>
</tr>
<tr>
<td></td>
<td>Pitch</td>
<td>( x_3 )</td>
</tr>
<tr>
<td></td>
<td>Yaw</td>
<td>( x_4 )</td>
</tr>
<tr>
<td></td>
<td>Lat</td>
<td>( x_5 )</td>
</tr>
<tr>
<td></td>
<td>Lng</td>
<td>( x_6 )</td>
</tr>
<tr>
<td></td>
<td>Alt</td>
<td>( x_7 )</td>
</tr>
<tr>
<td></td>
<td>Spd</td>
<td>( x_8 )</td>
</tr>
<tr>
<td></td>
<td>Vz</td>
<td>( x_9 )</td>
</tr>
</tbody>
</table>

Figure 7: Vertical profile of test flights.

Table 2: Flight conditions of UAV mountainous logistics test.

Table 3: Quantitative parameters broadcast by UAV
residual voltage ($y$) of the UAV? The null hypothesis ($H_0$) and the alternative hypothesis ($H_a$) using the significance test of the multiple regression model are as follows [14]:
\[
H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = \beta_9 = 0
\]
\[
H_a: \text{at least one parameter is nonzero.}
\]
Where $H_0$ = hypothesis, $H_a$ = alternative hypothesis, $\beta_1 \sim \beta_9$ = the parameters of the multiple regression model, and estimate value for slope.

In this analysis, if at least one of the parameters for $\beta_1 \sim \beta_9$ is not 0, the null hypothesis is rejected, that is, the $y$ variable (residual voltage) has a relationship with $x_1 \cdots x_9$ (from UTM flight parameters). In order to understand the relationship between the UTM parameters, Pearson Correlation Analysis, Analysis of Variance (ANOVA), Significance Test, Collinearity Diagnosis and Residual Statistics are introduced to analyze the data of the secondary UAV flight test [14].

There are 6,897 and 6,562 data for each parameter from two flight tests. Referring to Table 3 for descriptive statistics, there are 10 UTM parameters in Flight Test 1 and Flight Test 2. The wind speed in these two tests are 4m/s and 6m/s, relatively. The wind speed change can be judged by the standard deviation increase of several parameters, including the data of Volt, Roll, Pitch and Yaw parameters.

The explanatory power of the multiple regression model is taken from the adjusted $R^2$ of 0.959 (95.9%), and the model explanatory power is excellent. In Table 4, the adjusted $R^2$ value in Flight Test 1 and Flight Test 2 are 0.959 (95.9%) and 0.955 (95.5%). The results show that the model has more than 95% explanatory power.

<table>
<thead>
<tr>
<th>Model</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>R Square Change</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
<th>Durbin-Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>.979a</td>
<td>.959</td>
<td>.11831</td>
<td>.959</td>
<td>20161.174</td>
<td>8</td>
<td>6888</td>
<td>0.000</td>
<td>.067</td>
</tr>
<tr>
<td>Test 2</td>
<td>.977a</td>
<td>.955</td>
<td>.13050</td>
<td>.955</td>
<td>17272.614</td>
<td>8</td>
<td>6553</td>
<td>0.000</td>
<td>.087</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Vz, Roll, Spd, Yaw, Curr, Pitch, Alt, Lat
b. Dependent Variable: Volt

Table 5: ANOVA table

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<tbody>
<tr>
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<td>20161.174</td>
</tr>
<tr>
<td>Residual</td>
<td>96.409</td>
<td>6888</td>
<td>.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2353.933</td>
<td>6896</td>
<td>.014</td>
<td></td>
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</tr>
<tr>
<td>Test 2</td>
<td>Regression</td>
<td>2353.354</td>
<td>8</td>
<td>294.169</td>
<td>17272.614</td>
</tr>
<tr>
<td>Residual</td>
<td>111.604</td>
<td>6553</td>
<td>.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2464.958</td>
<td>6561</td>
<td>.017</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: Volt
b. Predictors: (Constant), Vz, Roll, Spd, Yaw, Curr, Pitch, Alt, Lat

In ANOVA table, Table 5, the $F$ values of the variance significance of these two tests are 20161.174 and 17272.614. The $p$-values for these two tests are the same as both 0.000 value, which means the significance level is less than $p$-value 0.05. The analysis outcome shows the parameters of $\beta_1 \sim \beta_9$ are not equal to 0, as referring to Table 5, thus rejecting the null hypothesis ($H_0$) that the $y$ variable (as residual voltage) has relationship with $x_1 \cdots x_9$ from UTM flight parameters.

In order to test whether the model has a multi-collinearity problem, this study uses the Variance Inflation Factor (VIF) to analyze
the flight data. If the VIF is greater than 10, it means that there is a linear coincidence problem between the parameters. In the flight tests, the Latitude (Lat) and Altitude (Alt) parameters have a linear overlap and the Longitudinal (Lng) parameter is excluded.

In Equation (3), the null hypothesis ($H_0$) and the alternative hypothesis ($H_a$) using the significant test of the multiple regression model, based on Standardized Coefficients Beta value, all parameter were non-zero, and we reject the null hypothesis [14]. According to the result of t-test for individual parameters, all parameters are significant in Model 1 (Test 1) and Model 2 (Test 2).

In order to know whether the sample observations of flight data conform to the bell-shaped distribution of the normal distribution, by referring to the histogram of the standardized residual values of the regression Model 1 and Model 2 in Figure 8, which roughly conforms to the trend of the normal distribution. The regression standardized residual values are mostly in three Standards within the range of Standard Deviations ($\sigma$), no obvious extreme values appear. It should refer to the normal probability distribution diagram of the sample standardized residues in Figure 9.

Based on the models explanatory power of flight were over 95%, there is a strong positive correlation between the predictive power of the model for the UTM parameters.

From the flight data analysis, the UAV in logistic delivery has presented with significant relationship of battery voltage to overall performance. LiPo voltage monitor is the important key parameter during flight. Both ground control computer via Mission Planner or UTM via OBU surveillance shall play important roles in flight operations. This ensures flight safety in logistic delivery.

4. Conclusion

The UAV logistic delivery flights in remote or mountainous area are demonstrated with beyond visual line of sight (BVLOS) operation through virgin forest in Alishan mountainous territory. Although UAV performance is the key part to successful flights, this paper just tries to demonstrate how flight planning with UTM surveillance can also offer strong support to assist the flight test, especially regular delivery should launch in the near future. In addition to technical data, how is the statistical analysis to support logistic delivery flight using UAV shall be explored.

According to the above flight data analysis, the UTM parameter analysis conclude the followings:

1. The UTM parameters of this study are all related, which once again prove that the 90 Byte surveillance data form OBU is important to ensure flight safety in BVLOS flights.

2. The explanatory power of the multiple regression model established with UTM parameters is as high as 95%. There presents a linear correlation between UTM parameters to flight performance.

3. All coefficients of UTM parameters are non-zero, and individual parameters show obvious goodness-of-fit in terms of the overall multiple regression model.

This paper tries to bring in demonstration of UAV logistic delivery in real world application. It can be feasible in realization with UAV technical integration with autonomous flight control as well as UTM infrastructure supports to ensure flight safety. UAV logistic flight can work in mountainous area to bring in prompt delivery for those
marginalized minor social groups. Medial material delivery, especially for chronical patients, shall be the exceptional parts under current medical regulations.

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References