LIGHTER-THAN-AIR (LTA) UNMANNED AERIAL SYSTEM (UAS) CARRIER CONCEPT FOR SURVAIILANCE AND DISASTER MANAGEMENT

(Lighter-Than-Air (LTA) Unmanned Aerial System (UAS)
Konsep Pembawa untuk Pengawasan Dan Pengelolaan Bencana)

Ahmad Salahuddin Mohd Harithuddin¹, Mohd Fazri Sedan¹, Syaril Azrad Md Ali¹, Shattri Mansor², Hamid Reza Jifroudi², Siti Noradzam Adam², Zailani Khuzaimah²
Department of Aerospace Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia¹
Geospatial Information Science Research Centre, Faculty of Engineering,
Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia²
E-mail: shattri@upm.edu.my

ABSTRACT

Unmanned aerial systems (UAS) has many advantages in the fields of surveil lance and disaster management compared to space-borne observation, manned missions and in situ methods. The reasons include cost effectiveness, operational safety, and mission efficiency. This has in turn underlined the importance of UAS technology and highlighted a growing need in a more robust and efficient unmanned aerial vehicles to serve specific needs in surveillance and disaster management. This paper first gives an overview on the framework for surveillance particularly in applications of border control and disaster management and lists several phases of surveillance and service descriptions. Based on this overview and surveillance phases descriptions, we show the areas and services in which UAS can have significant advantage over traditional methods.

Keywords: UAS, surveillance, disaster management

INTRODUCTION

Surveillance and disaster management have been mentioned as important fields of application of unmanned aerial systems (UAS). Traditionally, space-borne technology like satellites, manned aircraft and in situ methods are relied on. However, with the development and ever-growing accessibility of UAS latest technology to the public, we see more and more potential applications being realized in real world problems. To gauge the effectiveness of the new UAS technology in these fields however we need to have an overview on what are the main features of a surveillance or a disaster response mission. surveillance and disaster management missions share several important characteristics,
including collecting vast amount of imagery data, identifying specific features, tracking changes, and keeping and exchanging information between different systems among others. Systematically, there are five basic steps for effective surveillance in disaster management: 1) to collect multitemporal imagery; 2) spatially co-register multitemporal images; 3) perform change detection to identify features of interest; 4) collect geographic coordinate information; and 5) transmit the locations of change of features of interest.

Depending on the area (maritime or land), surveillance activities can be grouped in distinct progressive phases based on three levels: strategic, operational, and tactical. Strategic level pertains to the planning of sequences of operations, the resources needed for the operations, and the collection and analysis of information needed to make that planning. The planning timescale for a strategic level surveillance typically takes months to years. Any change of plans will take weeks to be executed. Operational level, on the other hand, refers to the planning and running of operations, which is defined as a sequence of actions in a pre-planned framework of assets, personnel and time. Planning time is typically a magnitude shorter than strategic level (weeks to months). Any late decision of change of plan can be executed in a matter of days. The most immediate phase of surveillance is the tactical level. This level relates to the execution of elements of an operation, choosing the elementary actions and reactions in almost real time. Decisions in the tactical level are made immediately usually without any long planning ahead. A summary of these surveillance phases and service description are shown in Table 1.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Strategic Level</th>
<th>Operational Level</th>
<th>Tactical Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical timescale for planning</td>
<td>Months to years</td>
<td>Weeks to months</td>
<td>Hours to days</td>
</tr>
<tr>
<td>change plans</td>
<td>Planning of sequences of operations</td>
<td>Pertaining to the planning and running of</td>
<td>Pertaining to executing the elements of an operation</td>
</tr>
<tr>
<td></td>
<td>Still refers to the planning and running of operations</td>
<td>operations</td>
<td></td>
</tr>
<tr>
<td>Shortest timescale to change</td>
<td>Weeks.</td>
<td>Days</td>
<td>Seconds (immediate)</td>
</tr>
<tr>
<td>plans</td>
<td>E.g. decision to start collecting information from a certain area</td>
<td>E.g. decision to call off a planned operation</td>
<td>E.g. decision to apprehend persons or save people in immediate danger</td>
</tr>
<tr>
<td>Maximum allowed delay of</td>
<td>A month.</td>
<td>Days</td>
<td>Fraction of an hour</td>
</tr>
<tr>
<td>information</td>
<td>E.g. statistics of arrivals and analysis of methods used by illegal immigrants</td>
<td>E.g. information in the appearance of new tracks</td>
<td>E.g. information about last sighting of group of people, or locations of unknown boats</td>
</tr>
<tr>
<td>Radius of interest</td>
<td>Semi-global</td>
<td>Region/basin</td>
<td>&lt; 10 km²</td>
</tr>
</tbody>
</table>

**UAV for Filling the Gap**

The focus of this paper is on unmanned aerial vehicles (UAV) as a vital component of a UAS in ensuring mission effectiveness. UAV has demonstrated itself as a unique solution that offers high spatial resolution for regional coverage and flexible observational timing. UAVs have significant advantages over space-borne solution (satellites) or manned airborne solution (patrolling using aircraft and helicopters). It is a technology that is lower in cost and more accessible to public where its basic components available as commercial off-the-shelf products. Comparing to the huge cost of launching payload into orbit and the rising cost of aviation fuel, UAVs can be a big plus in surveillance missions. Its flexibility means a UAV can be launched quickly, affordably and repeatedly. While satellites are incomparable in terms of its effectiveness for global coverage, UAV is shown to be very useful for regional coverage. Its operation is closer to ground which provides higher spatial resolution.
Its ease-of-launch in most terrain shows that the system can be robust enough to be used in most emergency response cases.

**Lighter-Than-Air Unmanned Aerial System**

A lighter-than-air (LTA) system refers to an aerial platform or vehicle that achieves flight due to its buoyancy in air. Such aerostatic flight can be achieved by enclosing a volume of lifting gas, such as helium, in a lightweight envelope to which other structures and components are attached. Airships, or blimps, are the most obvious example of a lighter-than-air system. In the past decades, there has been a revival of interest towards LTA systems due to advances in materials technology and the push for green aviation. **Figure 1** shows the four regimes of earth science measurement attributes which are the Airship, Fixed-wing aircraft and LEO satellites. In contrast to LEO satellite and Fixed-Wing Aircraft, suborbital or “near-space” platform such as Airship obtained higher spatial resolution, capture diurnal behavior and provide more persistent local and regional observation (Gil Braid, 2014).

![Figure 1](image.png)

**Figure 1.** Four regimes of Earth science measurement attributes, airship, Fixed-wing aircraft and LEO Satellite.

There are two types of Lighter-Than-Air Vehicle or Airship which are the conventional airship and Hybrid airship design. Conventional Airship type is the most common airship design that was used today, it’s comprised of three type of structure which is the Rigid Airship structure which the envelope is supported by an internal structure as shown in **Figure 2**. The rigid airship can be built much larger than non-rigid and semi-rigid airship due to its capability of the rigid airship to reduce the twist in the hull due to aerodynamic force and moment (Stockbridge, 2012). Semi-rigid airship is sort of a blimp that maintains its aerodynamic shape from inner lifting gas pressure, but it has a partial rigid frame which guides and distributes load and gives structural integrity. Instead of using a framework structure this type of airship also use suspension cable to maintain its shape (Colozza & Dolce, 2005). The last type of conventional airship design is the non-rigid airship or blimp. A blimp is technically a pressure airship that does not have a rigid skeleton supporting its hull as shown in **Figure 1**. Usually, for the non-rigid airship, they only utilize two ballonets which located at the front and black of the airship (Khoury, G. A., 2012). The advantages of using ballonets are its can provide the pitch balance and altitude change of the airship by manipulation of buoyancy of the airship.
The hybrid airship is a type of airship which utilize lighter-than-air principle together with heavier-than-air technology such as fixed wing and rotary wing means that the hybrid airship does not depend fully on the lifting gas to create lift. 10% of its lift is generated from aerodynamic force (Earon, 2007). Nowadays, the hybrid airship were divided into two which are Dynastat and Rotastat as shown in Figure 3 (Li, Y., & Nahon, 2007). Both hybrid combination improve the advantages of current aircraft today for example, the Dynastat improve the disadvantage of long takeoff and landing field of airplane. Moreover, Rotastat combination help to reduce the weight of conventional helicopter and power requirement.

The LTA concept has the potentials to extend the mission capabilities of unmanned aerial system. The four identified advantages of an LTA-UAV – long-endurance, high altitude operability, quiet flight, and design scalability – opens up more application opportunities for UAV. An aircraft that is lighter-than-air offers a distinct advantage over multirotor if being able to stay airborne for a longer time without refueling or recharging. The widespread use of high-altitude balloons for scientific observation has sparked ideas on the operability of airships in high altitudes up to 40 km altitude. An LTA vehicle can provide persistent and high-resolution observations in the atmospheric region between 10 – 20 km altitudes. The quiet flight can also be advantageous for SURVAILLANCE purposes such as border SURVAILLANCE and environmental monitoring. An LTA size can be easily scaled up to offer more lifting capability for carrying cargos and heavy equipment.

However, limitations of LTA UAVs as a need also to be addressed. Maneuverability of a buoyant platform is expectedly poor compared to a fixed-wing or rotor-based UAV. An LTA UAV flight is also very susceptible to wind and gusts due to its large surface area (Bueno, 2002), which, if untethered or unmoored, makes station-keeping very difficult. Aerostatic platforms are also typically large, and even more so for cargo-carrying airships.
METHODOLOGY

![Flow chart of design selection for LTA Vehicle concept for surveillance and disaster management]

The design methodology that used in this work begins with the problem statement that LTA vehicle for surveillance and disaster management as shown in Figure 4. Some research background conducted to review the existing technology and design of LTA Vehicle. From the study, some requirements selected as the reference of the design solution then the final design solution is developed, prototyped and tested.

RESULT AND DISCUSSION

Development of Lighter-Than-Air Unmanned Aerial Vehicle for Surveillance

The Putra Space Hybrid Airship UAV (PSHAU) is a novel quad-rotor airship which development started in 2015 in Universiti Putra Malaysia. This hybrid airship utilized the Rotastat Hybrid Airship and finless design. The PSHAU hull has a triangular shaped airship (Figure 5). The airship is roughly 5.0 m long and it has a maximum diameter of 2.1 m thus, its fineness ratio which is the ratio of its length to its maximum diameter is about 2.38. This polyvinyl chloride hull airship was developed to overcome the performance limitations of conventional airship design and its poor ground handling by utilizing quadrotor-like four vector thrusters and finless design. The second-generation prototype is produced in 2018 with improved manufacturing of its hull. The technical specifications of the newest prototype are given in Table 2.

![Two developed prototypes for a Lighter-than-Air Unmanned Aerial Vehicle (LTA-UAV), PSHAU-1 (left) and PSHAU-2 (right).]

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Length and Diameter</td>
<td>5.0 m and 2.1 m</td>
</tr>
<tr>
<td>Weight</td>
<td>Weightless (Buoyant)</td>
</tr>
</tbody>
</table>
It is equipped with a Global Positioning System (GPS), and an Inertial Measurement Unit (IMU) that make this versatile vehicle to perform autonomous missions especially for surveillance mission. The goal of this development is to design and fly a fully autonomous airship with minimal intervention on the part of the human operator to be used in missions that require persistent surveillance capability such as border control and disaster management.

**Hardware Integration**

All actuator in PSHAU system is manipulated by the Pulse Width Modulation (PWM) output using the constructed attitude control system to control the amount of thrust and tilt angle of the thruster. Meanwhile, the attitude control output of the motor thrust is calculated directly by the Pixhawk 2.0 using custom PSHAU firmware. Moreover, Radio Controller (RC) receiver and transmitter also used to enable the airship received manual input from operator to the flight controller as to demonstrate the PSHAU flight stability. The implementation of more external sensor in PSHAU required a microcontroller board that enable use of external sensor such as current sensor, First Person View (FPV) Camera and voltage sensor, thus Arduino Mega board used to enable usage of external sensor. RFD 900+ modem is used as the communication telemetry due to its transceiver capability enable the user to control or change parameters of the airship using mission ground station. **Figure 6** illustrate the full hardware integration of PSHAU avionic system.

![Figure 6. Hardware configuration for PSHAU-2. Red line represents power line, dashed black line represent wireless connection and solid black line represent wired connection.](image)
Thruster Configuration and Motions

The default thruster configuration of PSHAU-2 as shown in Figure 7. The thruster of PSHAU used the X-frame configuration the same as used in Quadcopter frame. The thruster configuration also facing opposite to each other where motor 1 and 3 facing the nose of the airship and motor 2 and 4 facing the tail of the airship. This enable the PSHAU to perform backward motion and more controllable, plus this configuration serve as the breaking mechanism in forward motion and counter moment during yawing (Sedan, 2018). Note that motor 1 and 2 rotate in CCW direction while motor 3 and 4 rotate in CCW direction.

![Figure 7. PSHAU top view (left) and side view (right)](image)

The thruster of PSHAU consist of motor and servo that enable the thruster to tilt at 0° to 180°. The advantage of this tilt mechanism is, its enable the airship to perform vertical takeoff and landing (VTOL) which is very important to extend the capabilities of the airship especially in disaster management aspect. The entire assembly of the thruster is shown in Figure 8, that attached on the airship by Velcro pad on the legs of the tripod base as well as three nylon string whose tension is adjustable individually as the skin tension reduced.

![Figure 8. Thruster assembly](image)

By understanding the tilt mechanism of the thruster, the PSHAU motion can be developed and divided into five motions which is translational motion (Horizontal and Vertical) and rotational motion (Pitch, Roll and Yaw). All this motion can be achieved by changing individual thruster thrust by varying PWM value that sent to Electronic Speed Controller (ESC) as well as the change of vector thrust direction. Figure 9 illustrate the free body diagram of translational motion of the airship where \( T_H \) is the Horizontal thrust and \( T_V \) is the Vertical thrust. For forward motion, only motor 1 and 3 contributed in driving the airship forward and motor 2 and 4 set to minimum PWM value. Whereas, for vertical
motion all thruster will produce the same amount of thrust and vector thrust direction will define the upward and downward motion of the airship.

![Diagram of airship motion](image)

**Figure 9.** Forward motion (Top) and Upward motion (Bottom) free body diagram.

The free body diagram of rotational motion of airship attitude is shown in **Figure 10**. By understanding the direction of propeller spin, the motor thrust can be manipulated to produce positive and negative yaw motion. It is assumed that the clockwise direction is always positive where the yaw error is positive. For positive yaw motion thrust produced by motor 1 and 2 higher than motor 3 and 4 and vice versa for negative yaw. The thruster tilted to specific angle based on the throttle value given from operator. The tilt angle is limited to +90 degree to -90 degree. The airship is pitching up when motor 1 and 3 tilted upward and motor 2 and 4 tilted downward and vice versa. In rolling, it is assumed that when the HAU is rolling to clockwise direction it has positive roll error while otherwise negative roll error.

The airship rolled clockwise when motor 1 and 4 tilted upward and motor 3 and 2 tilted downward. Each motor for roll motion will have the same thrust. From the motion of PSHAU that described previously, a method called motor mixing and servo mixing used to calculate the PWM of each thruster both motor and servo. Motor mixing is a method of mixing each of the pure attitude motion thrust and then summing it up all together to form a mathematical expression for the thrust required for each motor and servo mixing is a method mixing the pure motion thrust and then summing it up to calculate the tilt angle required for each servo.

![Diagram of yawing, pitching, and rolling](image)

**Figure 10.** Free body diagram of yawing (left), pitching (middle) and rolling (left) motion.
**PSHAU Attitude Control System**

Mainly, PSHAU attitude control system work by reading input from operator which is the stick input. Then, by direct proportional, the input is read as desired angle for PSHAU attitude control system. Next, current PSHAU attitude angle and desired attitude is compared to calculate the attitude angle error. Next, the attitude angle error is given a proportional gain for respective flight mode which is the stabilize mode used in this project for manual control. The attitude angular rate from the angular velocity transformation matrix is fed into the PID controller in the inner loop of the attitude control system.

![Figure 11. Simplified PSHAU Attitude Control System (AB. Malek, 2015)](image)

Finally, the PID controller will result the output of the desired torque which can be translated into PWM value using constructed motor mixing matrix. Then, the PWM value send to the ESC to provide thrust and in turn create torque with respect to the desired attitude given. The output of the desired torque also used in servo mixing which later translated into tilt angle. The simplified PSHAU attitude control block diagram is shown in Figure 11.

**CONCLUSION**

Our study looks at the needs of SURVAILLANCE and disaster management and proposes a hybrid lighter-than-air vehicle concept. A newer prototype designed to be a persistent aerial surveillance platform has been developed and currently are undergoing field and flight tests. Our study makes the following recommendations for work on the aerial platform for surveillance and disaster management. Design of a robust unmanned aerial vehicle for extreme weather usage suitable for disaster management purposes. Such vehicle must be able to withstand string-wind and heavy rain situations. Develop high-endurance aerial vehicle that can achieve sustained flight for days or weeks at a time. Important characteristics are “persistent” and “station-keeping”. Utilize the “near-space” altitude (20-40 km altitude) for high-altitude persistent observation for surveillance and disaster management.

**ACKNOWLEDGEMENT**

This research work is funded by Universiti Putra Malaysia IPM Putra Grant 2016. We thank UPM Space Systems Laboratory research and technical staff for assistance with the building and development of the PSHAU hybrid airship prototypes.

**SELECTED REFERENCES**


