Unmanned Aerial Systems and Healthcare: Possibilities and Challenges

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Abstract—**Unmanned Aerial Systems (UAS) have an enormous number of possible commercial and personal uses ranging from the basic delivery of packages to environmental monitoring and disaster relief support. Their possible use in emergency situations from the delivery of an automated external defibrillator to cardiac arrest victims, to 'search and rescue' operations, provides an indication of how useful the technology can be. Before the widespread adoption of UAS within the public and commercial sectors is achieved a number of challenges need to be overcome, especially those pertaining to public risk in the areas of safety, privacy and security. This contribution initially examines the proposed and active usage of UAS within healthcare, not only for emergency medical services and drug/blood delivery but also 'search and rescue' operations. The challenges to UAV usage for healthcare related services, as well as the current evolving state of UAS operational regulations are then discussed.**

Keywords- UAS; UAV; Drone; Healthcare; Medicine; Search and Rescue; AED; Safety; Risk Map; SORA.

I. INTRODUCTION

Unmanned aerial systems (UAS) also referred to as unmanned aerial vehicles (UAV's) or drones are steadily becoming a recognizable facet of everyday life. Though initially used mainly for military purposes the personal and commercial use of UAS is growing with an ever increasing range of applications being proposed, tested and commercialised. Examples include logistics such as delivering supplies and equipment; data collection relating to agriculture, land surveying; environmental monitoring and emission control; for communication; and aerial photography [1, 2, 3, 4, 5].

Many current UAS initiatives relate to environmental sustainability with, for example, the US Department of Agriculture currently financing a UAS water sampling project [6], of natural and public waterways, to determine the effect of nitrate runoff from intensive farming - a major cause of water acidification and toxicity. UAS are also routinely employed to assess large scale environmental events such as volcanic activity [7] while micro-UAS are currently being used in China to monitor air pollution on a large scale [8]. There are obvious advantages in using UAS within developing countries with underdeveloped infrastructures where UAS can provide a viable alternative for the transport of small payloads, especially in rural regions, where the roads might be of poor quality. Stoney Brook University's Global Health Institute is currently deploying UAS out of their ValBio Research Station in southeastern Madagascar [9] to (a) speed up the diagnosis of tuberculosis by the UAS transport of blood and stool samples from remote villages to ValBio for analysis and (b) to deliver vaccines to the remote villages once positive diagnoses' has been made.

In addition to the growing enthusiasm of healthcare organisations [3, 9] with regard to the possibilities of UAS use, it has also been suggested that emerging commercial and public use of UAS within cities will contribute to the development of 'smart cities' [10] - the UAS-based relay of, for example, real-time information relating to traffic flow, air-borne and water pollution, criminal activity and the overall condition of the city's infrastructure can make a significant contribution. Gallacher [5] has indicated that future UAS applications, with remote sensing capability, will operate at higher altitudes perhaps creating a permanent platform above cities, thereby providing a range of data communication services.

This contribution initially examines the proposed and active usage of UAS within healthcare, not only for emergency medical services and drug/blood delivery but also 'search and rescue' operations where people may be injured or exposed to a degree of harm. The challenges to UAS usage for healthcare related services, as well as the current evolving state of UAS operational regulations are then discussed.

II. UNMANNED AERIAL SYSTEMS

In the United States the Federal Aviation Administration (FAA) defines consumer and commercial UAS as those that weigh less < 1.0 lb (0.45kg) [11] with approximately a maximum 500 m altitude and 2km range from the base operator. Larger Military and government UAS tend to have at least a 5km altitude and 150km range, though this type of UAS has also been successfully used to provide aid for natural and urban disasters [12]. Hover and fixed wing designs represent the two main type of UAS. The small

UAS (sUAS) used commercially and by consumers are usually a ground operator controlled quadcopter or hexacopter, with hover capability, and the ability to carry a small payload. Figure 1 shows the sUAS used for a feasibility study into its use for search and rescue operations in mountainous areas [4]. This quadcopter is a DJI Phantom 3 Pro - a best-selling commercial sUAS with one of the longer flight times, ≈ 25 minutes, and with a camera, positioned underneath the main body that provides quality images, 1080p. Most of the feasibility studies carried out with these types of UAS has a fairly limited range with the operator having line of sight (LOS) throughput operations..

(a) **(b)**

Figure 1. Basic UAS comprising (a) A video camera carrying quadcopter and (b) Operator console with screen to view real-time camera output [4].

The military tends to use fixed-wing, propeller driven UAS though these types of long-range, heavier payload bearing and faster systems are also being increasingly used for non-military purposes. Their usage normally requires non-line of sight (NLOS) operation from a dedicated operations centre that can both track and command the UAS. Figure 2 shows a non-military fixed wing UAS with bright markings, a strobe light for recognition as well as a 'detect and avoid' system [13].

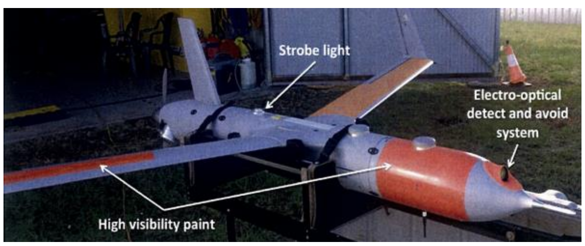


Figure 2. INSITU Fixed wing propeller driven UAS, [13]

Currently the flight times relating to sUAS hover designs remain limited while faster fixed wing UAS, have much longer flight times though usually have to take-off via a slingshot mechanism. Hybrid UAS designs which combine hover capability, for take-off and landing as seen in sUAS designs, with fixed wing inflight operation have also begun to appear. The UAS developed by Vayu Inc., for the previously described sample retrieval and vaccine delivery operations in Madagascar [9], see Figure 3, as well as the Latitude Engineering HQ-40 UAS, see Figure 5(a), have these capabilities [10]. In both of these figures the fixed wings and hover blades, of the hybrid UAS, for take-off and landing can be clearly seen. The current flight times of sUAS need to be increased beyond 25 minutes so as to increase their range and usefulness in both the urban and rural environments. The development and use of more innovative, and power efficient, battery technology and/or integrating energy harvesting while keep the sUAS size and weight within reasonable limits would extend the range of hover type systems though hybrid designs would seem to be most practical approach at the present time.

Figure 3. Vayu Inc.'s hybrid UAS in a remote village [10].

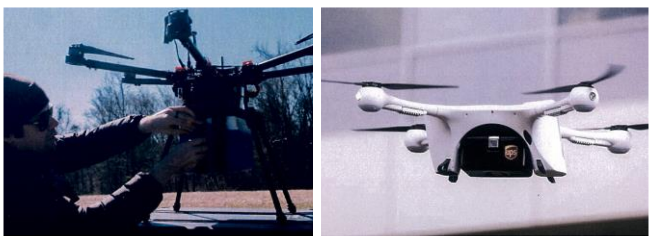
Ultimately, despite the vast possibilities of UAS use, within the urban environment, regulatory constraints relating to NLOS operations (that is the operational risks pertaining to mid-air collision or impact with buildings, terrain or people, see Figure 8) will ultimately determine the uptake, range and success of commercial UAS operations. Both the EU and the FAA are examining and developing legislation relating to operations risk assessment [14, 15] and NLOS UAS operation within urban areas [16]. UAS use must also be weighed against the financial and other costs associated with these risks and also against ground-based alternatives [5] - Haidari et al., [17] comparing UAS costs against those for a traditional multi-tiered land transport system in the transport of vaccines.

III. UAS Application Possibilities

In healthcare the possible advantages of using a UAS to transport medicine(s), especially for emergencies, was immediately recognized. Many of the studies carried out so far, with regard to UAS utilization, have been feasibility studies though medical UAS delivery trials, carried out in North Carolina by Matternet, have now resulted in UPS using Matternet UAS to deliver lab and blood samples between WakeMed hospitals, clinics and doctors offices in Raleigh and Wake County within the state, see Figure 4(b). This initiative is part of the U.S. governments, 'UAS Integration Pilot Programme' [16, 18].

A. Blood and Medicine Transportation

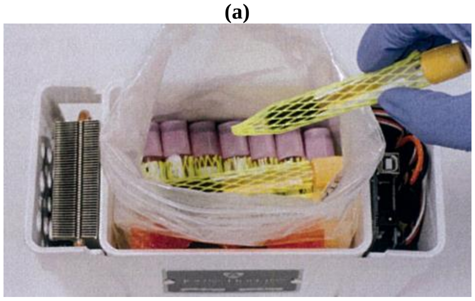
Thiels et al., [19] discussed the use of UAS for the transport of medical supplies and blood to hospitals in 2015 while the current use of UAS for both patient sample retrieval and vaccine delivery in Madagascar and North Carolina has already been indicated. UAS-based blood/medicine delivery feasibility studies were also carried out over the period 2014-16 by Amukele *et al.,* from the Johns Hopkins School of Medicine in Baltimore [3, 20]. The first examined the feasibility of transporting blood products, via UAS over short distances, in both rural and urban Maryland, while the second study examined the feasibility of long distance, speedy transport of temperature sensitive drugs. Because of the different requirements of these two studies the type of UAS used was fundamentally different – the first using a S900 hexacopter for blood package delivery within the city of Baltimore, see Figure 4(a). For each test run, the sUAS was flown a distance of approximately 13 to 20 kilometers while 100 meters above ground. In their long distance delivery study Amukele et al., [20] used a much larger and sophisticated aerial system, a Latitude Engineering HQ-40, with a hybrid take-off/flying configuration; see Figure 5(a). The temperature controlled container can be seen in Figure 5(a)) (placed in front of that UAS) and (b). During testing 84 samples were collected in pairs - one sample from each pair being loaded on the UAS, which flew them 161 miles. The samples then being driven 62 miles to the Mayo Clinic in Scottsdale, Arizona [20].



(a) (b)

Figure 4. Urban Trasportation of Blood Proucts using a Hexaxopter.(a) the S900 Hexaxopter being set up for flight [13] (b) UPS delivery of medical supplies in North Carolinafor WakeMed in 2019 [18].

(a)



(b)

Figure 5. Long Distance Delivery of Drugs using a Hybrid UAS. (a) UAS with storage compartment and Temperature controlled drug container. (b) Inside the temperature controlled drug container [20].

B. Automated External Defibrillator (AED) Delivery

Out-of-hospital cardiac arrest affects nearly 360,000 individuals in the United States [21] and about 300,000 in Europe each year with survival rates being low [22]. The time to treatment of a cardiac arrest victim, with a defibrillator, is the most important survival factor - each minute without CPR treatment decreases the chance of survival of the victim by 10% [24]. The quick delivery of an AED device to the location of the reported heart attack so that a bystander can attempt resuscitation of the victim as quickly as possible, would seem to be a major justification for using UAS technology. The first dedicated AED UAS prototype was developed by Alec Momont in 2014, while a Master's student at the Technical University of Delft (TU Delft) in the Netherlands [25] - the UAS being able to fly up to speeds of 100 km/hr while carrying the AED.

There is ongoing research that examines not only the possible integration of UAS delivered AED's with currently existing emergency medical services (EMS) locations but also to optimize the location of additional EMS with UAS AED capability – the ultimate aim being to minimize AED delivery time to potential cardiac arrest victims [26, 27, 28].

The Centre for Resuscitation Science at the Karolinska Institute in Sweden started investigating the possible use of UAS delivered AED's to treat cardiac arrest victims in Stockholm County in 2013 [28]. A geographical information system (GIS) based model was used to predict 20 optimal locations of UAS EMS services with time savings in urban areas estimated to 1.5 minutes, with the UAS arriving before traditional EMS in 32% of cases. For the rural cases the UAS was estimated to arrive before ground-based EMS in 93% of cases, with a mean time saving of 19 minutes.

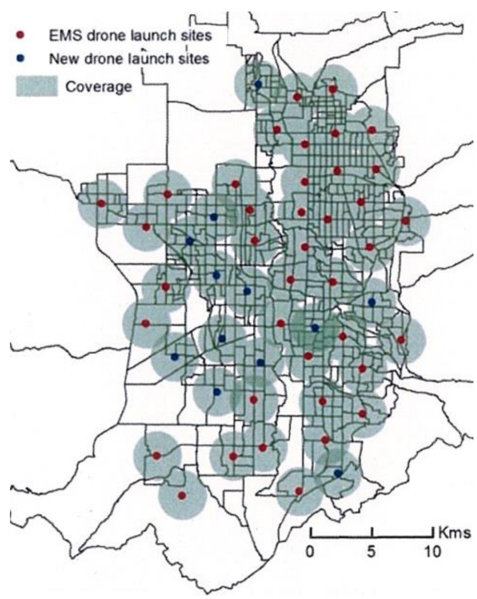


Figure 6. Salt Lake County, Utah. RED dots - existing EMS centers/UAS launch sites. BLUE dots - proposed new UAS launch sits to provide greater overall coverage of the SLC area. [26]

A similar study was also carried out in Salt Lake County in Utah in the United States [27]. GIS was again used to estimate the current EMS travel times and then these were compared to the estimated travel times of a network of AED enabled UAS. The study objective was to determine a configuration of UAS locations so that 90% of EMS cases could be reached within 1 minute. The most cost efficient solution to this ‘maximum coverage location problem’ was to use 39 existing EMS stations with 12 additional new locations for UAS launch sites - these 51 sites resulting in a total cost of $2,010,000 (2015 values). Figure 6 shows the most cost efficient solution with the current EMS sites (in red) as well as the required new UAS launch sites (in blue). The black lines in the figure indicate boundaries between individual census block groups within the county.

B. *Search and Rescue*

Beyond the transportation of blood/drugs and AED’s there are also many other emergency situations directly (or indirectly) related to the possible harm of a person where a UAS could provide a quick response.

- Disaster zones whereby air-borne surveillance of the conditions on the ground so as to facilitate recovery.
- Searching for people reported missing in dangerous environments.

A people search situation could cover a multitude of situations from hikers and climbers lost in mountainous areas, people in difficulties in the sea or even just searching for people in inclement weather conditions.

Two recent studies examined the feasibility of using UAS for search and rescue ‘in the wilderness’. [29] describes two UAS- based search and rescue cases while [4] investigated the feasibility, using the UAS shown in Figure 1, for searching for people lost in the mountainous areas. A scenario involving an unconscious victim on snow-covered ground was enacted 10 times using a 180 cm mannequin to represent the accident victim. Two rescue approaches were compared (a) the rescue team followed the classical line search technique (CLT) and (b) the use of a UAS for identification followed by retrieval by snowmobile. Median time to arrival at the mannequin was 57.3 min for classical line search technique (CLT), compared to 8.9 min for a UAS/snowmobile approach - a much wider area being covered by the UAS in a fraction of the time needed for CLT-based recovery [4].

Another feasibility study, carried out by Claesson et al. [30] investigated the practicalities and efficacy of using drones to identify people in swimming difficulties in coastal waters off Sweden. The use of a UAS in this way could ultimately provide a low cost approach to reducing the time before CPR is initiated [31] - well before the arrival of a search and rescue helicopter. The time to identify a 112 cm manikin in the sea using the UAS was the performance indicator used. Figure 7 shows a screen shot from a tablet using UAS transmitting live video.

A submerged mannequin was placed in a shallow (<2 m) 100 × 100-m area at Tylösand beach, Sweden. The performance of a search party of 14 surf-lifeguards was compared to a UAS that transmitted video to a tablet device. Twenty searches were performed - 10 for each group. The median time to contact with the mannequin was 4:34 min for the search party (control) and 0:47 min for the UAS (intervention) respectively, though skin color, choice of bathing suit or wave conditions will all significantly impact the ability to locate a swimmer in difficulties.

Figure 7. Mannequin at 1.5 m depth recognized at 60 m altitude. Surf-lifeguard and lifebuoy positioned in the centre of the 100 × 100 m search area. [19]

IV. UAS Application and Use Challenges

There are a number of challenges to the utilization of UAS for the variety of healthcare related applications outlined in the ‘Possibilities’ section. Public opinion relating to the perception and acceptance of UAS operations within both rural and urban environments is one but most of the challenges are technical and regulatory relating to the safety risk of UAS operation, particularly over populated areas. The propellers of sUAS (<5 kg) can inflict serious injury, while larger and heavier UAS (5-25 kg) can potentially kill [32]. Many proposed urban UAS applications, within healthcare, that require NLOS operation, are currently impractical, from a regulatory standpoint though the landscape is changing with UAS risk assessment gaining some degree of maturity and pilot programmes being initiated to gain a better understanding of NLOS UAS urban operational risk [14, 16].

The primary hazards due to the operation of UAS are a midair collision with an inhabited aircraft or uncontrolled descent of an UAS over a populated area, see Figure 8.

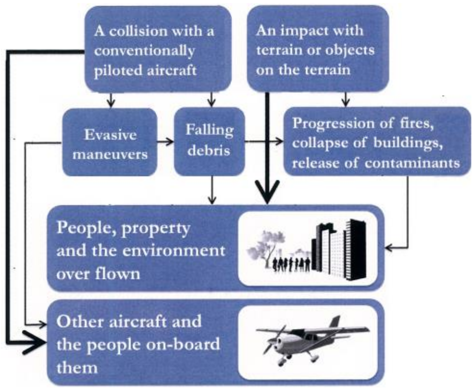


Figure 8. Primary Hazards relating to UAS operation over a Populated Area [38].

A possible midair collision has driven the regulations relating to the level of integration a UAS can have within national air space. A causal model that describes the sequence of states leading to a Mid-Air Collision can be found in [33, 12]. These states consider 'separation volumes' between the UAS and the other aircraft. 'Threshold volumes' are also defined with these serving as triggers for collision avoidance activities.

The risk to people and property on the ground forms the basis for standards and regulations relating to UAS airworthiness [34]. Recorded UAS mishap rates are up to two orders of magnitude greater than those exhibited by conventional manned aircraft [35] with the low reliability of current systems being a major contributing factor, though accident reports indicate that human factors, poor maintenance and operational procedures are also significant factors [36].

A lot of work, typically derived from the risk management of manned flight operations, has already been done on determining the risk of an unmanned aircraft flight. Models developed for ground impact risk take into account the population density under the flight path [37, 38] with uncontrolled UAS descent being of particular interest. [37] uses simulation-based analysis to specifically look at the distribution of possible impact positions while [39] presents a simple risk mapping model for a UAS approaching Edinburgh Royal Australian Air Force Base, see Figure 9. Methods for automatically finding a UAS landing area in an emergency descent are outlined in [40], while the ability of a fixed wing UAS to glide to a designated emergency landing area is examined in [41].

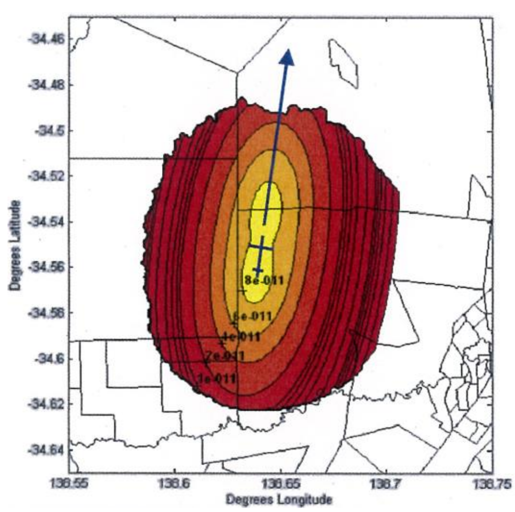


Figure 11. Individual risk contour for a UAS approaching Edinburgh Royal Australian Air Force Base. [40].

A. *The Specific Risk Operations Assessment (SORA)*

The European Aviation Safety Agency recently published proposals for legislation on unmanned aircraft in European airspace [14, 15]. The JARUS (Joint Authorities for Rulemaking on Unmanned Systems) proposal for three categories of unmanned aircraft has been adopted, namely; Open, Specific, and Certified [42]. The 'Open' category relates to very low risk operations while 'Certified' relates to the highest risk operations with flight crew licensing, airworthiness as well as operator certification being required. 'Specific' and 'Certified' category-based risk assessments must address both air risk and ground risk with the new legislation indicating that the specific operations risk assessment (SORA) methodology, developed by JARUS, must be used for both.

The SORA begins with risk modeling, followed by risk assessment, and then culminating with recommendations on mitigation measures to be used for safety risk management. Figure 10 shows the different tasks across these activities and the associated data flow [43].

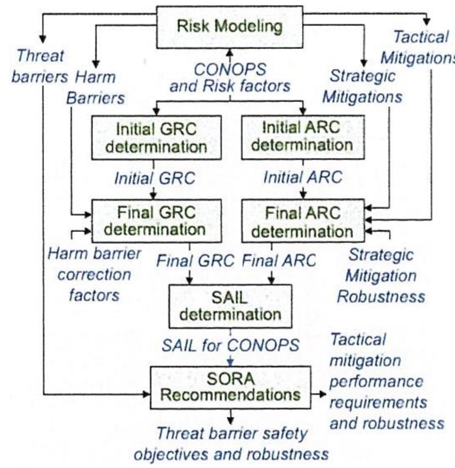


Figure 10. SORA starts with risk modeling to provide GRC and ARC determinations which produce recommendations on risk mitigation. [43].

The SORA is based on a 'barrier' model of safety. This can be represented using bow-tie diagrams which provide a flexible and transparent risk-based approach to both examine and trade off technical airworthiness, UAS performance and capabilities as well as operating rules, restrictions, and procedures. Denney, Pai and Johnson [43] indicate that this approach effectively provides a basis for an operational UAS safety case where implemented safety measures are chosen to be proportional to the assessed risk.

This legislation and the choice of SORA for carrying out risk assessments is a massive step forward on the road to integrating safe UAS operation within public airspace and hence a step forward to perhaps realizing some of the Healthcare related UAS possibilities.

V. Discussion and Conclusions

The acceptance of UAS operations and by inference their use for healthcare related applications, goes beyond risk assessment and the development of an operational safety justification. Understanding stakeholder concerns, the motivation for them and how they influence their decisions in relation to safety, is key to achieving the broader acceptance of UAS operations. Clothier *et al.* [44] use the situation faced by horseless carriages in the 1800s as an analogy to the situation being faced today by UAS.

Currently, operational mitigation strategies (*e.g.*, restrictions on the flight of UAS over populous areas) are central to obtaining operational approvals. Mitigation technologies, like sense-and-avoid (See Figure 2) and automated emergency landing systems, are currently under development and show much promise. These mitigation technologies will reduce the need for restrictions on UAS operations and will be vitally important to the uptake of UAS in a greater number of civil applications. Only a small fraction of the ongoing healthcare related UAS studies have been reported here – for example Matternet has carried out over 300 commercial medical supply carrying UAS operations in Switzerland. The use of SORA within the EU and the US pilot programmes - that are mainly directed towards facilitating NLOS UAS operation in urban environments - suggest a bright future for UAS use not only within healthcare but in many other areas.

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