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 Requirement Analysis for an Aerial Relay in Emergency Response Missions

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Abstract: First aid of patients at the scene of an emergency requires an adequate flow of information. The publicly funded research project MOMENTUM aims at seamlessly connecting the point of care to the hospital. An unmanned aerial vehicle serving as a network relay may help in cases of limited or no mobile wireless connection, e.g. due to topographical circumstances. The aerial system may also provide situational awareness in cases of mass casualty incidents. For these two defined use-cases, safety and stability considerations are discussed, and required flight times and payloads are defined. The relay can be connected to the ground via a cable or wireless connection. It is concluded that the use-cases can be realized best when using a multicopter — either combined with a cable for independent flight times and reliable data communication or a wireless solution to mitigate the risk from the increased payload while limiting flight time. For the first option, the payload of the aircraft should be adjusted to ensure the power consumption in hover matches the power limitation of the cable.

Keywords: Emergency Medicine, First Responder, Aerial Relay, Unmanned Aerial Vehicle (UAV), 5G, Drones

1 Introduction

The MOMENTUM project, funded by the German Federal Ministry of Education and Research under grant no. 16KIS1027, aims to connect emergency care from the place of an accident to the hospital without losing track of the patient’s situation and health data on the way to the medical trauma room and supporting telemedical assistance from the experts in the hospitals. It is planned that the assistant will have access to all crucial data from the ambulance, such as heart rate, respiration, cognitive state and the ABCDE survey. The gathered data may help to organize the right number of needed surgeons for the medical trauma room and speed up the door to CT/MRT time. Eventually, this could decrease mortality, especially in medical haemorrhagic stroke cases. The required wireless connection from the point of care to the hospital can become unstable due to poor network coverage or blockage effects. An unmanned aerial vehicle (UAV) starting from the ambulance may be used to relay the data stream by finding a suitable place for improved signal reception to enable reliable data transmission. The connectivity concept of the MOMENTUM project is summarized in Fig. 1. This paper discusses possible use-cases and their consequent requirements for a UAV in emergency rescue scenarios.

2 Use-Cases

2.1 Connectivity

Signal improvements may help to implement telemedical assistance at the point of care as well as aid the transmission of high volume data such as ultrasound images and other video streams. This, on the other hand, would make emergency teams highly dependent on a reliable connection to a public cellular network. Special requirements, including low latency and high data throughput, need to be achieved. The connection can, however, be impaired by several means. First and foremost, an increased distance to the nearest cellular network tower also increases the path loss due to absorption effects [1]. Furthermore, the signals are sensitive to strong absorption by solid structures such as buildings in urban environments or trees and hills in rural areas [2]. The blockage effect has already been demonstrated in 2015 by Sundqvist [3]. Accord-

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To discuss the necessary hardware for the use-cases in section 2, the general aircraft architecture for the UAV needs to be defined. As a possible UAV for both use-cases, fixed-wing aircraft seem inappropriate. They require a runway which cannot always be implemented in mobile use. Also, hovering at an optimal signal reception or filming position is ambiguous. The aircraft must move continuously to stay in the air. With a balloon-based solution, both vertical take-off and hover flight are possible. In urban environments, however, the balloon limits the possibilities of movement. A so-called multicopter offers a compact, manoeuvrable solution to this problem. With the appropriate programming, it can take off autonomously, find an optimal position for the desired use-case and stay there in hover. The main limitation is the flight time, which is usually less than half an hour for battery-powered systems. This problem may be circumvented by a power supply via a cable, as described in section 3.2. Alternatively, hybrid solutions like the combination of an electric motor with a combustion engine or a combination of a fixed-wing aircraft with a multicopter are possible. For the further elaboration, multicopters are chosen as UAV platform due to their versatile scalability and the resulting flexibility in choosing an air-to-ground-connection.
allowed continuous power. This may hinder the use of more powerful motors that allow an increased payload.

### 3.3 Technical Requirements of the UAV

In addition to safety and stability considerations, the requirements for the UAV are divided into two main parts, the necessary flight time and the payload. In the case of a multicopter, these parameters can be influenced by, among other things, the choice of the battery, the motors, and the propellers. In the following paragraphs, the considerations made for the parameters are based on the propulsion model for multicopters by Quan [15].

#### 3.3.1 Safety & Stability

The main priority at the point of care is the safety of patients and first responders. An aircraft on-scene must not on any account be a threat. The aircraft’s weight should, therefore, be kept at its necessary minimum, to mitigate the associated risk. Furthermore, the UAV must land safely, even if one of the engines is malfunctioning. In the case of a multicopter, this implies the use of at least six motors (hexacopter). An equal redundancy needs to be planned for the mission-critical telemetry sensors. In addition to redundancies, failsafe actions should be implemented. These may include a so-called return-to-home functionality on radio-link or other sensor failures, making the UVA land at its take-off location autonomously. A parachute may ensure a safe landing after mission-critical incidents [16].

Another important safety aspect is flight stability. Especially in urban areas, sudden wind gusts can occur. For a swift and wind stable flight, the aircraft should, therefore, not be operated at its propulsion limit. For this reason, less than 80% of the possible thrust created by the aircraft’s rotors should be required for maintaining hovering flight [15]. This leaves a margin for possible gusts or changes in air density. The thrust created by the rotors is dependent on the rotational speed of the motors, the propellers elevation angle, and the air density.

#### 3.3.2 Flight Time

The UAV should be able to fly throughout the time the ambulance team is at the emergency scene, the so-called on-scene time. In a large-scale study in Japan, 115,855 cases were found to have an interquartile interval of 13 to 23 minutes of on-scene time, with a median of 17 minutes [17]. Significant outliers were also observed. Various other studies confirm these findings. For the elaboration of possible concepts, a hover time of more than 17 minutes is chosen as a minimum requirement.

In case of a battery-powered UAV, the flight time is dependent on the available battery capacity and the current required for the motors and the onboard components [15]. The motors’ current differs depending on their load. Thus, it is also varying in different heights and weather conditions.

#### 3.3.3 Payload

The payload is the additional weight the aircraft can carry while having sufficient thrust to hover. The weight of the aircraft components, including the battery, are not considered as payload. The maximum theoretical payload depends on the total thrust of the rotors and the weight of the frame and the propulsion system.

The required payload highly depends on the use-case. The aerial relay for the aforementioned connectivity can, for instance, be implemented by two connected modems. One modem connects to the public cellular network, and another is part of a local network. An exemplary modem is the IoT Bit 4G by Altitude Tech (Bristol, GB), which is connected to a Raspberry Pi. The weights are 95.3 g and 45 g, respectively [18, 19]. The total payload of two modems can hence be estimated at 250 g. A possible small-cell on the aircraft would constitute about 2 kg of additional payload. This weight is estimated based on a SCE4255 Small Cell by Sercomm (Shenzhen, CN) [20]. Furthermore, the camera and gimbal for situational awareness can be chosen to weigh below 600 g, using, for example, a Zenmuse XT2 assembly by DJI (Shenzhen, CN) [21]. A cable-based AGC, as discussed in section 3.2, is considered with 2.5 kg of additional payload. Together the mentioned components total to a required payload of at least 5.35 kg when implementing the proposed use-cases. The weight of the frame and the propulsion system add another 2 kg to the required thrust of the motors.

### 4 Conclusion & Summary

The previous chapters have shown that a UAV can be beneficial in emergency missions by providing situational awareness and improved connectivity between the point of care and the clinic. The development of such a UAV shifts between the necessary requirements of safety and clear improvements at the point of care opposed to the additional effort using an aircraft. A UAV that suffices the requirements to implement all the described use-cases is hard to implement since some requirements object with each other. The weight of an aircraft
that carries all payloads described in section 3.3.3 creates an increased risk within an emergency mission. The high payload would require large rotors and therefore corresponding powerful motors. These motors, however, demand increased power consumption, supplied by larger batteries or through the cable. Larger batteries constitute another increase in the payload while a cable is limited by its maximum allowed power throughput.

From the findings two possible implementations are concluded to be feasible in the MOMENTUM project: One would include a UAV optimized for connectivity enhancements by including a small-cell as well as modems for a relay on board. A cable AGC enables nonstop flight during prolonged emergency missions, while, however, limiting the positioning flexibility. Furthermore, the aggravated risk due to the increased payload needs to be discussed further. Another option would be a relay UAV without small-cell and cable to mitigate the associated risk. In this case AGC is achieved by a point-to-point connection with a small-cell on the ground. This will, on the other hand, limit the flight time, but allows further position optimization, for situational awareness and enhanced connectivity.

As a future perspective, an integration of this relay functionality into an existing hardware solution, for example, the Fotokite Sigma by Perspective Robotics (Zurich, CH) [22], may also be possible.

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