Jonas Gruner*, Albrecht Bloße, Max Rockstroh, Thomas Neumuth, and Philipp Rostalski

Requirement Analysis for an Aerial Relay in Emergency Response Missions

https://doi.org/10.1515/cdbme-2020-3005

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.

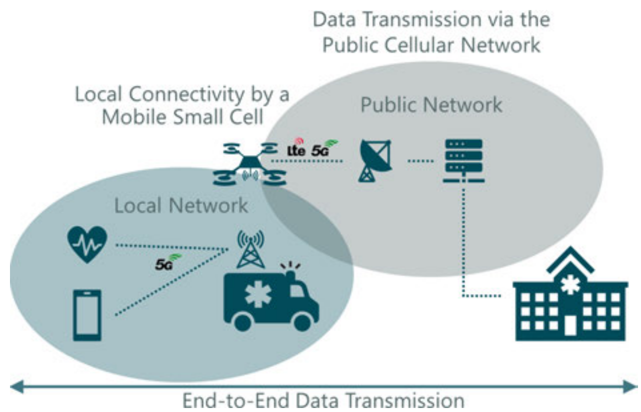

Fig. 1: Concept of the MOMENTUM project.

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-

***Corresponding author: Jonas Gruner,** Universität zu Lübeck – Institute for Electrical Engineering in Medicine, Ratzeburger Alle 160, 23562 Lübeck, Germany, e-mail: j.gruner@uni-luebeck.de
Albrecht Bloße, Max Rockstroh, Thomas Neumuth, Universität Leipzig - Innovation Center Computer Assisted Surgery, Leipzig, Germany
Philipp Rostalski, Universität zu Lübeck – Institute for Electrical Engineering in Medicine, Lübeck, Germany

ing to the aerial measurements, there is an optimum height at which the signal strength becomes maximum. At this height, a direct line of sight to the transmitter cell was accomplished. Therefore, this line of sight is beneficial for the stable data connection required in rescue missions. A UAV can serve as a mobile relay and establish a line of sight to the transmission tower. With appropriate sensor technology, one can determine the optimal flight altitude and position of a relay unit.

A UAV can also be useful as a flying base station [4]. As such, it can be used to carry a so-called small-cell to support the device-to-device connection of the medical equipment on-scene with a dedicated secure cellular network. The position of the aerial cell can be optimized to ensure maximum coverage. [5, 6].

2.2 Situation Awareness

The situation in cases of emergencies can be complicated and overstraining. At the optimized aerial relay position, the UAV may be used to generate an overview of incidents from above. Inspired by the rescue copter system developed with the Deutsche Flugsicherung [7], the UAV is scanning the surrounding area. The camera operator can give feedback about the number and position of possible patients. The perspective from above results in an advanced viewing angle, avoiding vision blocking by cars, trees, and rocks. Consequently, it helps to find patients in a shorter time and to figure out who is in need [8]. The UAV can also be equipped with with a thermal infrared camera, searching for patients even in night cases. Thermal cameras use a wavelength from 0.8 µm to 15 µm and can so see through smoke, rain, dust, fog and snow to get a clear image. Even under bright sunlight, the perception of patients can follow the procedure of detecting a warm spot, measuring size, solidity and eccentricity. Moreover, confirmation is gathered through a coloured image [9–11].

3 Requirements

The described use-cases pose design challenges as well as technical requirements to a UAV. Additional to the requirements of the UAV, the ground station on the ambulance requires a facility for take-off and landing and possibly a power connection for charging.

3.1 UAV Design

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.

3.2 Air-to-Ground Connection

The air-to-ground-connection (AGC) between the UAV and the base station is an integral part for both the connectivity and the situation awareness. The AGC needs to transmit the video data of a camera to the ground while connecting the on-board relay to the ambulance. It can be accomplished via a wireless connection or a cable solution. The advantage of a wireless connection is the omission of additional payload and the flexibility in positioning the UAV. On the other hand, a cable may support a secure and uninterrupted data transfer connection, while wireless AGC is subject to signal interference. A cable can also supply the UAV with power. For this purpose, it must allow a high power throughput at minimum cable weight. The length of the cable should enable the aircraft to fly above the average building height, or in the forest above the average tree height. The city of Berlin, for instance, reaches an average building height of 13.4 m [12]. Trees in Central Europe, however, grow to an average height of 30 m [13]. Since the aircraft does not necessarily fly vertically upwards and the cable should not be on tension, a generously rounded length requirement of 80 m is assumed.

The company Elistair (Champagne-Au-Mont-D'or, FR) offers a potential commercial solution for a cable system that meets the requirements in terms of weight and data transmission [14]. The weight of the cable with about 2.5 kg at a length of 80 m includes an air module as a replacement for half of the initial batteries. The system is limited by the maximum 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, 11585 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 lager 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.

Author Statement

Research funding: The work was funded by the German Federal Ministry of Education and Research under grant no. 16KIS1027. Conflict of interest: Authors state no conflict of interest.

References

[1] Zhang L, Zhao H, Hou S, Zhao Z, Xu H, Wu X, et al. A Survey on 5G Millimeter Wave Communications for UAV-Assisted Wireless Networks. IEEE Access 2019;7:117460–504.

[2] Al-Falahy N, Alani OY. Technologies for 5G Networks: Challenges and Opportunities. IT Professional 2017;19(1):12–20.

[3] Sundqvist L. Cellular controlled drone experiment: Evaluation of network requirements. 2015.

[4] Mozaffari M, Saad W, Bennis M, Debbah M. Drone Small Cells in the Clouds: Design, Deployment and Performance Analysis. 2015 IEEE Global Communications Conference (GLOBECOM). IEEE; 2014:1–6.

[5] Bor-Yaliniz RI, El-Keyi A, Yanikomeroglu H. Efficient 3-D placement of an aerial base station in next generation cellular networks. 2016 IEEE International Conference on Communications (ICC). IEEE; 2016:1–5.

[6] Kalantari E, Yanikomeroglu H, Yongacoglu A. On the Number and 3D Placement of Drone Base Stations in Wireless Cellular Networks. 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall). IEEE; 2016:1–6.

[7] Virtual Disaster: Tilmans J, 2019. (Accessed: March 19, 2020, at https://www.fsd.rwth-aachen.de/go/id/donwu/lidx/1)

[8] Sibley AK, Jain T, Nicholson B, et al. MP01: Use of an unmanned aerial vehicle to provide situational awareness in a simulated mass casualty incident. CJEM 2018;20(S1):S40.

[9] 10 Thermal Vision Cameras For Drones And How Thermal Imaging Works. Corrigan F, 2019. (Accessed: March 19, 2020, at https://www.dronezon.com/learn-about-drones-quadcopters/9-heat-vision-cameras-for-drones-and-how-thermal-imaging-works/)

[10] Drury JL, Riek L, Rackliffe N. A decomposition of UAV-related situation awareness. Proceedings of the 2006 ACM Conference on Human-Robot Interaction;2006(May):88–94.

[11] Zaheer Aziz M, Mertsching B. Survivor search with autonomous UGVs using multimodal overt attention. 8th IEEE International Workshop on Safety Security and Rescue Robotics. IEEE, 2010:1-6

[12] Tröger E, Eberle D. Dichte Atmosphäre. Basel / Berlin / Boston: Birkhäuser; 2015.

[13] Bäume. Tübingen-Bebenhausen: Forst Baden-Württenberg. (Accessed: March 19, 2020, at https://www.forstbw.de/wald-im-land/lebensraum/pflanzen/baeume)

[14] SAFE-T Product Presentation. Champagne-Au-Mont-D'or: Elistair; 2016.

[15] Quan Q. Modeling and Evaluation of Propulsion System. In: Introduction to multicopter design and control. Singapore: Springer Singapore; 2017:78–95.

[16] Al-Madani, B, Svirskis, M, Narvydas, G, Maskeliūnas, R, Damaševičius, R. Design of Fully Automatic Drone Parachute System with Temperature Compensation Mechanism for Civilian and Military Applications. Journal of Advanced Transportation 2018:2964583.

[17] Nagata I, Abe T, Nakata Y, Tamiya N. Factors related to prolonged on-scene time during ambulance transportation for critical emergency patients in a big city in Japan: a population-based observational study. BMJ Open 2016;6(1):e009599.

[18] IoTBit 4G Datasheet v1.6. Bristol: Altitude Tech; 2019.

[19] Raspberry Pi FAQ. Raspberry Pi Foundation. 2016, (Accessed April 01, 2020, at https://www.raspberrypi.org/documentation/faqs/)

[20] Sercomm SCE4255 - LTE Indoor Base Station Datasheet. Shenzhen: Sercomm; 2016.

[21] Zenmuse XT2 Quick Start Guide 1.2. Shenzhen: DJI; 2018.

[22] Aerial Situational Awareness for Every Firefighter. Zurich: PERSPECTIVE ROBOTICS AG, 2019, (Accessed April 02, 2020, at https://cordis.europa.eu/project/id/856120)