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Remote Sensing in Humanitarian Logistics: An Integrative Approach

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Remote sensing is becoming increasingly important for the acquisition of information in humanitarian logistics. While different platforms (e.g. satellites, drones) with their own characteristics and advantages exist, the literature often refers to just one of them. This paper aims at integrating platforms, making full use of their specific advantages. The work is conceptual, comparing different remote sensing platforms according to their advantages and limitations as well as evaluating the potentials of their combination drawing on both academic and practitioner literature. Moreover, drone test flights (hexacopter) demonstrate the practical implementation of data acquisition, processing, as well as their integration. The results show that the combination of data gathered via different remote sensing platforms is highly beneficial for the management of humanitarian logistics in terms of quality, time, flexibility, and cost. Furthermore, the feasibility has been demonstrated by the drone experiment and the respective data processing and integration. To the best of our knowledge, this is the first work systematically examining the integration of data acquired via different remote sensing platforms considering their specific advantages and the area of application in the context of humanitarian logistics as well as demonstrating the feasibility through the use of an experimental drone flight. The results discussed represent the first step in the use of combined remote sensing data in humanitarian logistics; specific applications should be examined more in detail. Furthermore, challenges in the use of such data have to be overcome, such as their integration into the information management processes of humanitarian actors.

Keywords: Humanitarian Logistics; Humanitarian Operations; Remote Sensing; Drones

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1 Introduction

Natural and human-made disasters have unfortunately become almost commonplace. Even though some of these tragedies might be preventable, the occurrence of others cannot be influenced. Extensive multifaceted responses are coordinated by the international community, represented by numerous of humanitarian organizations or agencies, in order to alleviate the suffering of those affected. In this context, logistics plays a crucial role (Kovács and Spens, 2011). Information is increasingly recognized as a key factor of successful humanitarian operations (Altay & Pal, 2014; Kim et al., 2012), whereas, at the same time, information management is recognized as underresearched (Gupta et al., 2016). Concerning the rapid acquisition of profound data, remote sensing technologies are of rising importance. Different platforms are applicable, such as satellites, aircrafts, and drones, to gather remote sensing data. Previous work consider only one of these remote sensing platforms (Delmonteil and Rancourt, 2017; Tatham et al., 2017). As each platform inheres specific advantages and limitations, this paper aims to combine them. Therefore, the different remote sensing platforms will be examined and compared comprehensively in order to answer the following research questions: Which are the specific advantages and limitations of different remote sensing platforms in the context humanitarian logistics and are there potentials of combining data from these platforms? And how can such an integrative approach be realized practically by utilizing drones? The remainder of this work is organized as follows: After introducing humanitarian logistics and remote sensing in the second section, a systematic overview of the potential humanitarian uses of remote sensing technology is given by not distinguishing between the different platforms. In section three, the different platforms are compared according to their advantages and limitations and the potentials of integration are examined. Following, the experimental drone flight is described concerning the methodology, the technical realization, as well as the results in section four. Finally, the conclusion and an outlook are provided.

1.1 Humanitarian Logistics

Although logistics has always been involved in relief operations, its appearance in practice and academic literature was very limited before the beginning of the 21st century (Kovács and Spens, 2011). This recognition seems overdue since logistics plays a particularly important role in humanitarian operations, as it influences their effectiveness significantly and determines the speed, the coverage, and the costs of humanitarian organizations (Baumgarten, 2011). Although commercial and humanitarian logistics are closely related, there are significant differences which characterize the humanitarian relief work environment and pose specific challenges. Nevertheless, humanitarian logistics definitions resemble those of logistics in general. Thomas and Kopczak (2005) specify humanitarian logistics as 'the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people'. In contrast to commercial logistics, attention here is placed on the reduction of people's suffering. Humanitarian logistics includes a wide range of activities and processes such as preparedness, procurement, transport, warehousing, and training (Schwarz, 2012). In order to visualize relief chain management and humanitarian logistics tasks and to contribute a standardization of terms, definitions, and activities, Blecken (2009) developed a reference task model. He describes the two dimensions of hierarchical and structural decomposition (Figure 1). Within the dimension of the structural decomposition it is distinguished between assessment, procurement, warehousing and transport activities. Assessment is required to identify the affected people or the community needs; procurement tasks ensure the availability of all required material resources. Warehousing tasks are related to the storage and the transshipment of supplies; transportation includes all distribution activities. Finally, vertical and horizontal cross-section functions accompany these tasks. In disaster management, there is often a distinction between different phases. While diverse approaches exist, the cyclic classification into the phases mitigation, preparedness, response, and recovery has become commonplace (OCHA, 2013). The first two phases relate to the pre-disaster and the others to the post-disaster phase. The activities cannot be modeled strictly in sequence, as they might vary, repeat, or overlap according to the disaster scenario.

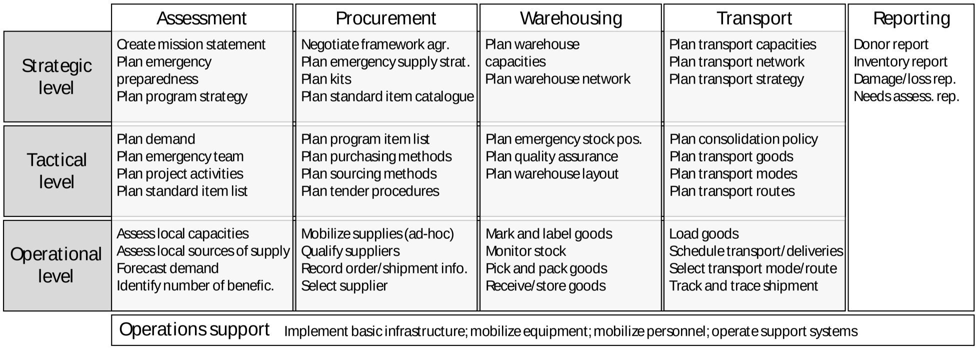

Figure 1: Humanitarian logistics framework with task samples (Blecken, 2009)

1.2 Remote Sensing

Remote sensing involves the contactless and areal extensive exploration of the earth´s surface (Heipke, 2017). Chen et al. (2016) define this as ”the science and technology of capturing, processing and analyzing imagery […] of the earth […], from sensors in space, in the air and on the ground”. Further terms are commonly utilized: Photogrammetry, which describes the part of remote sensing focusing mainly on analysis (Toth and Jutzi, 2017), and earth observation, often used interchangeably with remote sensing, but in a more comprehensive way (McInerney and Kempeneers, 2015).

A key component of remote sensing systems are the sensors. They are determined by their spatial, temporal, and spectral resolution. Passive sensors record the visible environment - such as photo cameras - and can represent different spectral bandwidths. Active sensors - mainly LiDAR (Light Detection and Ranging) and Radar (Radio Detection and Ranging) - are less determined by visual contact, as they send electromagnetic waves, which they receive in turn. Hence, they are applicable in cloudy environments or even at night (Toth and Jutzi, 2017). Remote sensing sensors are installed on so called platforms, which can be divided into satellite-based, airborne, and drones. Furthermore, there also exist terrestrial (mobile and static) platforms (Toth and Jutzi, 2017). Satellites are very common in remote sensing. Today, approximately 50 countries operate earth observation satellites, which can differ in their constellation, sensor type, resolution, strip width, their altitude, and their orbit. Airborne platforms have been deployed for quite some time, exclusively in remote sensing. Most common are aircrafts and helicopters. Drones represent a relatively new form of platform. Here, there are a number of terms which can be identified: Often used are also the terms unmanned aircraft systems (UAS), remotely piloted aircraft system (RPAS) and unmanned aerial vehicle (UAV) (Heipke, 2017). The range of drones is very diverse, including micro very light weight (under 1 kg) drones, having only a short range and altitude, up to drones with the size and capabilities of conventional aircraft. Hence, there is no commonly accepted classification as of yet. Griffin (2014) distinguishes four types of drones: Fixed wing, rotary wing, multi-rotary wing, and airships. In summary, a wide range of technological solutions exists which can be applied in humanitarian context.

2 Humanitarian Uses of Remote Sensing

The area of application for remote sensing in humanitarian operations is manifold and will be outlined systematically in this section. As stated above, there exists a variety of different platforms for remote sensing. It should be mentioned that all these platforms are also characterized by multiple uses, as they can be utilized in areas other than remote sensing as well. Satellites, for example, enable the functionality of positioning technologies, such as portable GPS devices or vehicle tracking systems. Further, telecommunication satellites often provide the only reliable form of communication in certain disaster situations (Delmonteil and Rancourt, 2017). Aircrafts and helicopters are mainly used for tasks other than remote sensing, primarily for transportation and evacuation services in disasters scenes. The application of drones is relatively new in humanitarian operations. In addition to their application in remote sensing, they can be used for communication support as well as (small) package delivery (Soesilo and Sandvik, 2016). All these other applications are of course of high importance for humanitarian operations and particularly in humanitarian logistics. However, as this article concentrates on remote sensing, in the following possible humanitarian uses of this specific technology will be examined.

A uniform systematization of remote sensing applications in humanitarian operations does not yet exist. Terms such as assessment, mapping, or monitoring are used inconsistently and often without any definition. For the following description of humanitarian uses, the relevant terminology will be outlined briefly. One of the most common applications of remote sensing can be seen in the field of assessments. Aerial images and the resulting maps are used to evaluate the (potential) extent of disasters and to determine the scope of the required help. Assessments are regularly performed in the context of humanitarian operations. Risk and vulnerability assessments pertain to the pre-disaster phase and aim to detect the exposure to hazards and to determine the vulnerability of people regarding the identified risks (Bündnis Entwicklung Hilft, 2017). Needs assessments are mainly performed after the onset of disasters and have an enormous importance in international relief operations. They should make clear whether an intervention is needed and how to best being performed. Further, needs assessments can be useful for the determination of demand regarding relief commodities. However, the main aim of assessments is to understand the situation and to identify the problems, their sources, as well as their consequences (ICRC and IFRC, 2008). Via data acquired and processed by remote sensing, adjustments can be made to these assessment processes. In the context of this work, the term assessment will be understood as an umbrella term for all activities related to these tasks. In order to specify assessments more in detail, the term mapping will be used if the concerning activities relate to remotely acquired and accordingly processed map material. The detection of changes by comparing data over a period of time will correspond to the term monitoring. Finally, the use of remote sensing material for management and illustration purposes will relate to the term visualization. As remote sensing techniques can be applied across all disaster management phases, a respective differentiation is helpful.

2.1 Assessment

Concerning the published works, assessments are the largest and also most diverse area of application for remote sensing in humanitarian operations. In their simplest form, remotely acquired images or videos can be used to get an overview of disaster scenes and to estimate the extent of a disaster (Tatham et al., 2017). Immediately after the onset of a disaster, remote sensing can be applied particularly in search and rescue activities. Special sensors are often required for these operations. However, for deeper analysis, further processing steps are necessary, such as creating maps or time series material.

2.1.1 Mapping

Cartographic representation and the related processing of this material can be utilized in manifold ways across the different phases of disaster management. In the pre-disaster phase, the main objective is to detect hazards, determine risks, and finally to develop disaster response plans. Hence, remote sensing supports both the mitigation and preparedness phase. Flood management can be supported by remotely acquired map material in order to detect potential breaches in dike systems or to identify flooding areas (Sharma et al., 2017). Sambah and Miura (2014) propose a tsunami vulnerability assessment by utilizing satellite images and processed digital elevation models (DEM). Further, for forest fire susceptibility and risk mapping, remote sensing has been proposed (Pradhan et al., 2007).

In post-disaster scenarios, remote sensing is mostly applied in the response phase immediately after the disaster's onset. Rapid post-disaster assessments are applicable in the management of the aftermaths of various disaster types, such as earthquakes, floods, storms, and fire as well as in the case of man-made disasters

(Griffin, 2014). Automated building damage assessments using remotely acquired data are proposed by different authors, e.g. Dinesh el al. (2013) for a tsunami case or Kakooei and Baleghi (2017) for earthquake and hurricane cases. Concerning logistics activities, the assessment of infrastructure can be beneficial, e.g. for route planning. Wang, J. et al. (2015) propose a road damage assessment by using high resolution remote sensing images. Also the identification of best locations for facilities can be supported by mapping activities. A further application is the estimation of displaced populations (Wang, S. et al., 2015). In the recovery phase, post-disaster restoration and reconstruction assessments are suggested (Adams and Friedland, 2011).

2.1.2 Monitoring

While the above mentioned mapping applications of remote sensing relate to the situation analysis at one specific time, monitoring activities are performed continuously over a longer period, comparing different stages. In the pre-disaster phase, a typical application can be found in food security management, monitoring agriculture assets and warning in the case of critical developments (Enenkel et al., 2015). Generally, warning is a highly beneficial field of application for remote sensing (Strunz et al., 2017); it might be particularly suitable for some specific disaster types with a certain lead time or specific indicators, such as tsunamis, hurricanes, or floods. In the post-disaster phase, dynamic disaster events are critical for monitoring activities. Multitemporal satellite images can be used for the watershed and flood monitoring (Rau et al., 2007). In relation to a longer time horizon, Guo et al. (2010) propose a method for monitoring the damage reduction and reconstruction after the Wenchuan earthquake via satellite imagery.

2.2 Visualization

In contrast to the above stated areas of applications, remote sensing material can also be used in order to support general management processes. On this occasion, the visual presentation of cartographic material is used for the development of emergency plans or for communication aspects (Voigt et al., 2007). Providing near time information after the onset of a disaster supports the collaboration efforts of the different humanitarian organizations (Strunz et al., 2017). These activities can be performed in both pre-disaster and post-disaster phase.

3 Comparison of Platforms

Following the systematic description of the manifold uses of remote sensing in humanitarian operations and logistics, this section aims to compare the different platforms and describe advantages and disadvantages in order to subsequently discuss the potentials of their integration.

3.1 Advantages and Limitations

The comparison of the different remote sensing platforms is to be executed keeping various aspects in mind. A complete list of these criteria can be found in Table 1. Even though the spatial resolution of satellite images has increased in recent years, their maximum is with 30 cm (for some specific satellite sensors) still lower than those of airborne and drone platforms, whose resolution can be up to 1 cm; also the spatial accuracy of geo-positions in the acquired data is higher for the latter (Toth and Jutzi, 2017). Furthermore, airborne and drone platforms provide the opportunity to acquire oblique images for more specific processing and analysis methods. Moreover, drones can be applied for ad hoc, quick response assessments with live broadcasts in a 360° angle and their susceptibility to cloudy weather situations is lower (Kakooei and Baleghi, 2017; Toth and Jutzi, 2017). The higher spatial resolution and accuracy of airborne and drone platforms result from the fact that their flying altitude is significantly lower, particularly those of small drones. As one would expect, the observed space and the resulting surface coverage is substantially lower as well (Toth and Jutzi, 2017). Here, satellites make use of their inherent advantages. Contrarily, satellites are restricted by their predefined orbit and speed, which consequently limits their repetition rate and their preparation time compared to other platforms. The periodic flight path of satellites might be a disadvantage regarding their flexibility; however, it enables the availability of pre-disaster images, which is beneficial for comparison reasons and necessary for specific map analysis methods. Advantages of drones arise from their high flexibility; they are rapidly deployable and their application can be adjusted to the operations' requirements easily (Kakooei and Baleghi, 2017). Boccardo et al. (2015) note that drones are only rapidly deployed if they are already on site. Otherwise, the transportation to the disaster scene can restrict their short preparation time. Furthermore, the complexity of use as well as the operational risk is lower for drones than for the other platforms, whereas skilled personnel is generally required for remote sensing applications. However, whereas the deployment of satellite technology and airborne platforms has been established in the humanitarian context, the use of drones implies several legal and ethical issues. Most countries do not have any legal framework for the use of drones and also questions regarding privacy issues have not yet been answered. Moreover, the utilization of drones particularly in conflict-based disasters is seen as problematic (Tatham et al., 2017). Finally, the costs of the different remote sensing platforms vary significantly. Regarding the cost aspect, drones are the most favorable platform (Toth and Jutzi, 2017). Considering all these advantages and limitations, the potential of integrating several platforms is discussed briefly.

Table 1: Platform comparison (Kakooei and Baleghi, 2017; Toth and Jutzi, 2017)

	Satellite	Airborne	Drone
Spatial resolution	0.3-300 m	0.5-0.25 m	0.01-0.05 m
Spatial accuracy	1-3 m	0.05-0.1 m	0.01-0.25 m
Angle of view	Vertical	Vertical/oblique	360°
Weather susceptibility	High	Medium	Medium
Space of observation	Global	Regional	Local
Surface coverage	High (>10 km)	Medium (1 km)	Low (0.1 km)
Repetition rate	Day(s)	Hours	Minutes
Preparation time	1-2 days	Several hours	Within an hour
Pre-disaster image	Available	Probable	No
Maneuverability	No/limited	Medium	High
Usability	Difficult	Complex	Easy
Operational risk	Medium	High	Low
Operat. conditions	Established	Well established	Immature
Costs	High	Medium	Low

3.2 Potentials of Integration

Concerning the differences between the platforms for remote sensing, it has been shown that the disadvantages of the one platform are often the advantages of the other one. Hence, it seems plausible to consider the integration or combination of remote sensing data acquired via different platforms. In academic literature, a systematic discussion about such an integration for the humanitarian context does not yet exist. To the best of our knowledge, only Kakooei and Baleghi (2017) demonstrated the integration for the specific application of building damage assessments. However, the opportunities of an integrated approach are greater.

The benefits of integration can be systemized according to quality, time, flexibility, and cost aspects. In terms of quality the application of drones might be more reasonable due to their higher resolution. However, according to the performed task, it might be more important to get an overview of a specific region. For example, the condition of the road network and the related infrastructure could be assessed via drone, whereas the rest of the environment is gathered via satellite. In addition, oblique images from airborne and drone platforms can result in enhanced damage scale estimations but in turn they are limited in its spatial extension. On this occasion, the time aspect is critical as well. Considering the above stated uses of remote sensing in humanitarian operations, satellites could be mainly deployed for monitoring and to generate baseline material in the pre-disaster phase which can be used for comparison. The post-disaster data might be gathered via airborne or drone platforms as they inhere a higher repetition rate and a lower preparation time. On the one hand, this might be applicable for the assessment of critical logistical infrastructure, such as airports, ports, or warehouses. On the other hand, enhanced assessments can be useful for rapid demand determination. This flexibility is also a benefit of an integrated consideration of multiple platforms. Drones and airborne platforms are rapidly deployable after the disaster's onset and easier in use than satellites. They can therefore support the immediate response phase whereas the latter one are favorable in the longer term. Finally, cost aspects can be considered as well. Using the most reasonable platform for each task, can reduce the cost of remote sensing activities significantly.

4 Experimental Remote Sensing by Drone

In order to demonstrate the practical application of the integration of remote sensing data, experimental drone flights have been performed and the acquired data processed. The aim is to shown how the data acquired by drone can be processed. Therefore, a 3D model will be computed in order to generate orthoimages as well as elevation models, which in turn can be integrated into a Geographic Information System (GIS). These systems are capable of combining data from different remote sensing platforms. The technical realization of these tasks includes the three main working steps of data acquisition, processing, as well as their integration and will be demonstrated more in detail in the following. Finally, results are presented and compared and a judgment in terms of the applicability of the proposed integration will be given.

4.1 Technical Realization

The technical realization includes the following three main steps: First of all, the data has to be acquired, followed by the steps of data processing and the integration into a GIS.

4.1.1 Data Acquisition

For data acquisition, a commercially available hexacoper (Airborne Robotics XR6, diameter : 950 mm, max. payload: 1.2 kg, max. speed: 15 m/s, max. flight time: 15 min) was used. The Sony NEX-7 Alpha camera was utilized with a fixed focal-length of 19 mm, providing pictures with a resolution of 24 megapixels. With its 25-area contrast autofocus and the quick shutter lag, this camera is particularly suitable for remote sensing. For flight planning, the software MissionPlanner (1.3.49) was applied. By compiling waypoints, this plan can be transmitted to the flight-control device of the drone, specifying its precise flight route. For the experimental flights, a test area was chosen, which meets specific requirements. At a minimum, this area should include one street with one intersection, as well as accompanying infrastructure (e.g. power cables) and vegetation within a small range of about two hectares (this limitation is set by the technical range of the drone). Optimally, the area further includes different forms of vegetation and different types of streets as well as buildings. Such an area, meeting almost all

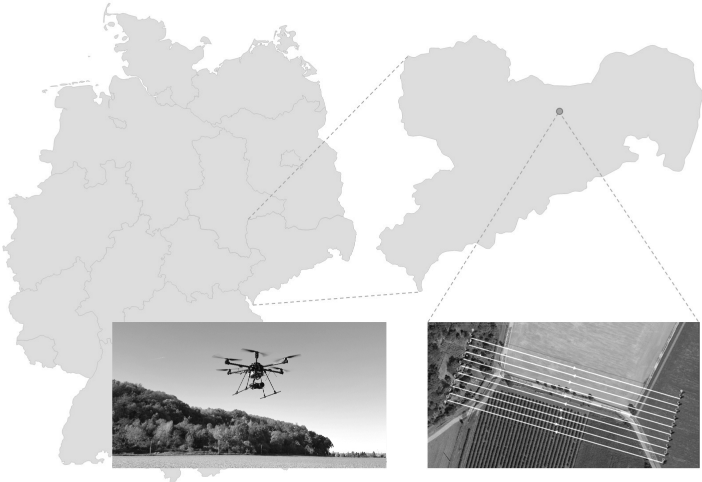

Figure 2: Test flight area and drone (own figure)

these requirements, was found in the district of Meißen (Germany) north of the municipality of Sörnewitz. Figure 2 illustrates the location of the flight area and the flight plan as well as the used drone. The drone flights were performed on a sunny day in October 2017. Two flights at different altitudes were conducted: The first flight at an altitude of 40 m (total flight duration: 12:00 min) and the second flight at an altitude of 80 m (total flight duration: 7:10 min).

4.1.2 Processing

A first evaluation of the acquired data already took place on site in order to decide whether enough images were produced and if their quality was sufficient. During the flights an adequate number images for the given tasks were taken; only a small number had to be removed due to fuzziness. First of all, the taken pictures had to be geo-referenced, which was done by utilizing the GPS data of the drone. Therefore, a camera position tool was used. This step can be omitted if the camera

Figure 3: Thick point cloud generated by Agisoft Photoscan (screenshot)

already contains a GPS function (which was not the case for the utilized camera). For the 3D model generation, the software Agisoft PhotoScan (1.3.4) was applied. Agisoft is able to use the taken 2D images in order to generate a geo-referenced point cloud (Figure 3). This step is essential for generating orthoimages and DEMs, which in turn are needed to embed the data into a GIS. Orthoimages are straight, distortion-free and scaled illustrations of the earth's surface, whereas DEMs contain the respective elevation information. For their generation, the 2D images have to be aligned to create a thin point cloud in a first step, followed by the creation of the thick point cloud and the polygon mesh.

4.1.3 Integration

For the final step, the integration into a GIS, the software QGIS (2.18.13) was used. It is one of the most common open source GISs and enables the recording, manipulation, management, and presentation of spatial data. The system's capabilities go far beyond the demonstrated aspects here. However, in our case the GIS was used for the integration of the previously generated orthoimage, the refining of the respective geo-references, and the representation of the DEM. A GIS enables the combination of different remote sensing data, such as satellite or airborne

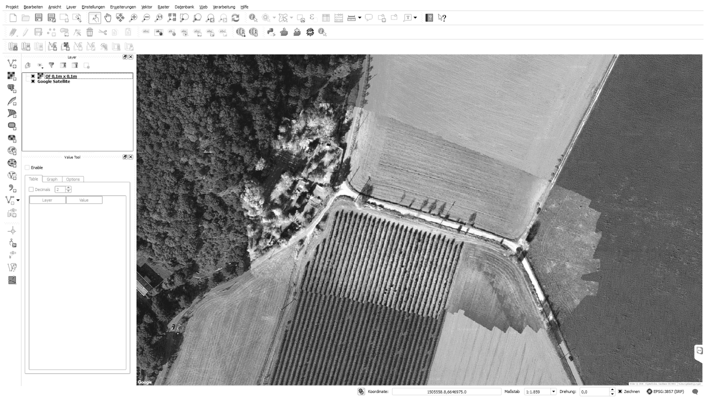

Figure 4: QGIS with Google layer and orthoimage, 0.1 x 0.1m (screenshot)

images, as well as geographical maps. In this case, a referenced, freely available Google Maps layer (airborne images) and the orthoimage were imported. The result of the integration within QGIS with our own layer in the foreground can be seen in Figure 4. As the geo-references of the drone's positioning system are not sufficient in all cases, a refining can be performed. Therefore, the two layers can be aligned according to distinctive points.

4.2 Results

As a result of the two drone test flights and the subsequent processing of the acquired remote sensing data, orthoimages and DEMs with a resolution of up 1 cm2/Px could be generated. The quality of geo-referencing can also be stated as high-grade, as their deviation is less than 20 cm (absolute) and the total computing time was between 107 and 165 min. All data could be processed by the GIS without any difficulties and obvious errors. The high level of detail is shown in Figure 5 which presents the resulting orthoimage. The resolution of the overview orthoimage corresponds approximately with the quality of the airborne image of the freely available Google Maps layer. The enlarged image details make clear one of the main advantages of drones compared to other remote sensing platforms. It is demonstrated that even cracks in the asphalt or mud holes as well as power cables can be detected.

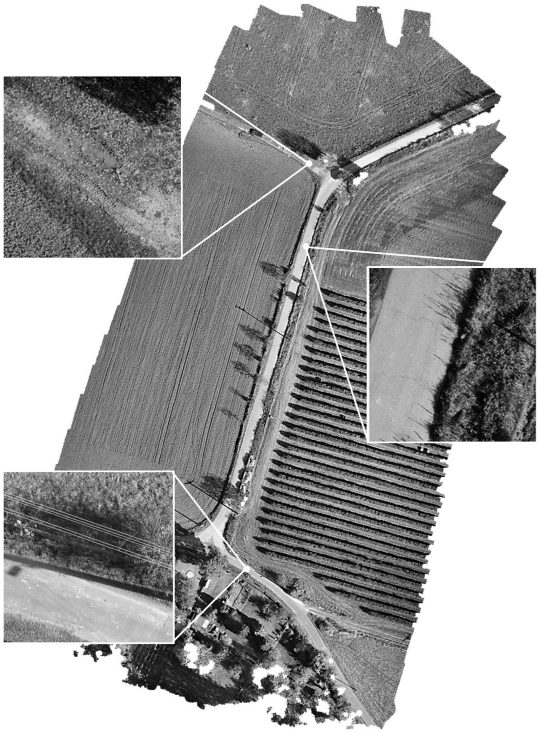

Figure 5: Orthoimage (40 m, 1 cm^2/Px) (own figure)

5 Conclusion

Remote sensing platforms inhere their specific advantages and limitations as shown in section 3. Hence, it can be assumed that an integrated approach in terms of combining data from different platforms will be beneficial for remote sensing activities in humanitarian context. The practical applicability of such an integration has been demonstrated in section 4. In the following, possible application of an integrated view in humanitarian logistics will be discussed. Moreover, a summary and an outlook for further research will be given.

5.1 Discussion

The above stated integrated approach in remote sensing can be supportive for different humanitarian logistics tasks. First of all, procurement and distribution processes are highly affected by sound information beneficiaries' needs. Knowing which and where these needs exist is crucial for logistical activities. Here, improved procedures comparing pre-disaster (generated by satellite) and post-disaster data (airborne or drone) could be applied for damage and needs assessments. Furthermore, the utilization of remote sensing for mapping task should be highlighted. In humanitarian operations, the integrated view could be beneficial in the distribution context. Infrastructure assessments are of high importance and they should be balanced regarding high surface coverage and high level of detail. Hence, satellite data could be used for general overview assessments, extended by drone data for detailed infrastructure assessment. According to different types of disasters, the possible applications are manifold, for example concerning the accessibility of certain areas by roads blocked by landslides, water or fire. The strength of satellite images in getting an overview and drones in providing detailed data can be mutual supportive. Further application areas can be found in warehousing concerning the facility location. Similar aspects as mentioned above can be beneficial. The initial assessment of best locations for transit points or warehouses could be done by satellite, whereas the detailed analysis will be supported by drone images. Finally, the visualization aspect can be mentioned. Decision makers in humanitarian logistics need to be provided with detailed information from the site. As drones are not capable to provide images from all areas, particularly in disasters with a high coverage, the supplement with according satellite images is appropriate. This approach should not be limited solely to the different remote sensing platforms, but should also consider data from different humanitarian actors.

5.2 Summary and Outlook

This work shows that the combination of different remote sensing platforms is highly beneficial in the context of humanitarian operations and logistics. Therefore, the possible areas for application have been categorized and outlined regarding certain assessment tasks, including mapping and monitoring activities as well as visualization tasks. Following, the advantages and limitations of the platforms were highlighted. It was shown that the platforms are mutually supportive. Hence, an integration of remote sensing data from different sources can be highly beneficial as support for humanitarian logistics activities such as procurement, distribution and warehousing in terms of quality, time, flexibility, and cost. In the last section, the practical implementation of such an integrative approach was demonstrated. Therefore, drone test flights were conducted and the gathered material processed and integrated.

The area of application for remote sensing in humanitarian operations and particularly for logistics activities is manifold. Further research is necessary to systematically identify the potentials of remote sensing, regardless of their platform, and according to the disaster management phases, on the one hand, and the different disaster types, on the other. Moreover, the requirements regarding these areas of applications have to be identified. This relates mainly to the necessary resolution and the time horizon concerning the gathered data. Finally, the integration into the information management processes of humanitarian organizations and the sharing of information amongst the various actors should be evaluated. Investigating these questions could lead to more efficient and expedient humanitarian operations, not just in terms of logistical aspects.

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