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CURe MODERN - Franco-German Infrastructure Inspection with Unmanned Air Systems

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Abstract

This paper presents the investigations made at Fraunhofer IZFP within the *INTERREG IV A Greater Region* project *CURe MODERN* where different rotary wing micro UAS have been used together with ground-based robotic systems to scan infrastructures including bridges and monuments at high resolutions for damage assessment and monitoring purposes. The aerial pictures taken at high speed and frequency have then been stitched together to obtain full 2D and 3D building surface reconstructions at a resolution allowing damages and cracking to be observed still in the millimeter range. With these ultra hi-res building reconstruction models a specific data base could be created for each object in order to provide extensive information for long term evaluation and life cycle management.

1 Introduction

The Saarland-Lorraine-Western Palatinate region is distinguished by a centuries-old common history in which this region was not always separated by territorial borders. Already the Romans have left monuments of great historical and cultural relevance which characterize the regional infrastructure up to the present day. In order to continue to preserve this significant cultural heritage as well as to maximize the life cycle of modern engineering structures, the condition of these infrastructures should be continuously inspected and monitored. In the context of the *INTERREG IV A Greater Region* project *CURe MODERN - Initiative Modern Building Inspection, Urban and Regional Planning* funded by the European Union, a network of specialized partners from the regions of Saarland, Lorraine and Western Palatinate was set up, which will contribute to the cross-border exchange of experience in the field of non-destructive testing in civil engineering and urban and regional planning. This network facilitates cross-border provision of non-destructive testing systems and new methods of urban and regional planning, which can be used in the framework of appropriate services for the condition assessment of infrastructures, the inspection of roads concerning their asphalt construction as well as the inspection of architectural monuments of reinforced and pre-stressed concrete. Basis for a solid and complete inspection of such objects is a comprehensive data base, which in real case is either poorly or even not existent. This applies in particular for the field of inspection of infrastructures difficult to access which are distinguished by their exceptional location, size or architecture. One method to counter to this problem is by using unmanned air system (UAS) used as a flying sensor system to collect the required data with simultaneous reduction in manpower and material costs. The potential applications for such unmanned aircraft in the non-destructive testing (NDT) focus on the tasks state detection, damage analysis and condition monitoring. As a part of the condition assessment, the infrastructure inspection can be done by numerous NDT methods, as for example visual inspection, thermography, radar or laser for geometric properties. At the Fraunhofer Institute for Nondestructive Testing (IZFP), the use of UAS for visual building inspection and remote damage detection is investigated since 2009. For this purpose, the IZFP runs multirotor helicopter platforms, which are equipped with various sensors for stabilization and navigation close to buildings. Depending on the infrastructure to be inspected and the defined tasks, the UAS can carry different digital optical and thermal cameras for high definition image or video capture.

2 The CURe MODERN Project

The *CURe MODERN* project is a research project cofinanced by the European regional development fund within the INTERREG IV A Greater Region programme. The major project aims are the identification of common structural engineering or urban planning issues as well as the evaluation of potential common approaches and implementations. This comes along with the establishment of a cross-border network of specialized partners from the regions of Saarland, Lorraine and Western Palatinate. It is also the aim to provide tools for a better overview of the condition of infrastructures and cultural and historical monuments by evaluating opportunities to build a cross-border database which could directly be used by state agencies, treasurers and municipal councils. This database should be filled with data captured by terrestrial laser scanning, ground robot scans, as well as aerial survey with UAS. This data then can be used for the construction of high detailed, zoomable 3D reconstruction models of the infrastructures for a later consolidation and analysis regarding detection of structural change, aging, and the current condition of the object.

2.1 Project Partners

The partners in the *CURe MODERN* project are research and academical institutions as well as governmental agencies in both countries. With the Fraunhofer IZFP on the one hand, the other academic partner is the Department of CAD & Planning Methods in Urban Planning and Architecture of the University of Kaiserslautern (TU KL). On governmental side, there are the French Eastern Engineering Center (CETE) with the focus on sustainable local planning and development, and the Saarland Regional Road Authority (LfS). Besides these listed institutions, there are a few more strategic partners from both countries also with a special focus on the transnational work to be done in this European project.

2.2 Inspection Methods

As mentioned before, the main attention of the project is on the introduction and application of new automated non-destructive testing systems, which are implemented in appropriate services for condition assessment of infrastructures, for the study of roads in the asphalt construction and of building monuments of reinforced concrete and prestressed concrete. These testing systems are exclusively ground and aerial robots, everyone with a special sensor equipment for specific inspection purposes:

- OSSCAR: semi-autonomous on-site scanner for the detection of reinforcement and tendons in engineering structures made of steel and prestressed concrete, bridges and engineering structures
- BetoScan: an autonomous ground robot system for condition assessment of flat reinforced concrete surfaces on bridges and in particular for the investigation of road surfaces in asphalt construction [6]
- SIMON: structural inspection multicopter UAS for the condition detection and damage assessment of infrastructures which are difficult to access

In this paper, the UAS platforms operated in the *CURe MODERN* project should be highlighted as well as their use for transnational inspection missions. The multicopter concepts used in this project are an eight-rotor octocopter configuration as well as two different sized four-rotor quadrocopter configurations. One reason for choosing an octocopter configuration - which is the mainly used platform - is the advantage that even in case of a failure of one or even several electric motors flight control is still preserved, which is essential concerning safety issues while thinking about flying in urban areas. The two smaller quadrocopters are more suitable for the use in narrow or indoor environments, but are necessary even for outdoor use in the project due to legal limitations in France.

The octocopter in Figure 1 has a size of about 1.2 meters in diameter and a maximum take-off weight of less than 5 kilograms, so it does not exceed German legal weight limitations even with maximum payload. The platform is equipped with various sensors such as 3-axis gyroscopes, 3-axis accelerometers and a barometric altitude sensor, which are used by a microprocessor-controlled flight control system for attitude stabilization. Together with the sensors of the flight control system and magnetic sensors for 3D orientation, navigation could be done by GPS, but this function is permanently disabled due to reasons mentioned in Chapter 3.

The quadrocopters with overall sizes of 58cm and 36cm (Figure 2) both have a maximum weight of less than 1kg, so they fit French legal weight class requirements further explained in Chapter 4. Both platforms are equipped with the same sensor hardware as the octocopter except the barometric pressure sensor.

Figure 1: Octocopter UAS

Figure 2: Miniaturized quadrocopter UAS

3 Airborne Infrastructure Inspection with UAS

For infrastructure inspection by UAS several NDT methods are generally applicable, but currently mainly optical methods are used for this purpose. This is based on the fact that in most cases there is not even image data available for a first rapid preliminary damage assessment, so that the need for a purely visual documentation is greatest here. According to this fact and the current flight platforms, building inspections are usually conducted with visual high-resolution cameras. These cameras are commercial digital cameras with usable resolutions up to 18 megapixel with focal lengths between 5.0 and 70 millimeters. For a better post processing, the focal length does not vary during the capturing of the inspection data. Only for areas of special interest where high detailed photos are needed, the focal length is set to a higher value.

The infrastructure inspection by UAS is generally divided into two process steps: data acquisition by aerial survey, and digital post-processing.

The main focus of using UAS for infrastructure inspection is clearly on the data acquisition. To generally fly around an object, a preliminary flight track planning is needed, which is usually done by using a common software based on GPS waypoint navigation. However for inspecting a building, GPS navigation becomes insufficient due to its very low accuracy especially while flying close to the objects caused by shadowing effects of the tall structures. Moreover standard GPS does not allow accurate flight altitude control which is an essential factor under flight planning aspects. A combination of anti-collision and navigation sensors has therefore to be developed allowing an autonomous flight program (under pilot control) to become feasible in the long term. Hence manual flight control is currently still the only option to perform when flying close to a building. The digital camera installed underneath the UAS is controlled by an automatic photo-firing sequence, which can be set to fixed frequency. The flight distance to the inspected infrastructures usually is in the range of 2 to 3 meters. The shutter speed often ranges from 1/500 up to 1/2000s due to the small distance to the objects and also sunlight reflections of the building facades. For the in-flight detection of damages, a low resolution real-time video link can be used for manual camera orientation and detailed inspection of exposed damaged areas. The captured image data is stored on the camera and is read out after landing. Each flight generates a large amount of data, e.g. in a 15 minutes flight normally more than 1200 photos, but as a result of not fully filtered out vibrations from the platform or external influences such as wind gusts a relatively high incidence of unusable image data is produced. But due to a very high overlap of the area captured on consecutive images, which varies depending on the hover speed parallel to the building facade, inapplicable records can be eliminated.

After the aerial survey, the second process step is the digital post-processing of the collected image data. In fact there is a variety of experimental and commercial software solutions available to reassemble the individual images nowadays, e.g. for applications such as airborne terrestrial mapping [7] or panoramic photography [9], [3]. These stitching or mosaicking methods are based on pattern recognition techniques which analyze similar image content structures, called matching points, in two or more images and link them together based on these points. A panorama software analyzes the input data under the assumption that images recorded are made only by pivoting without changing the camera's position, but since the aerial survey with UAS generates images each made from a slightly different position, the above algorithms are not suitable for this application. In contrast, the software for the mapping of landscapes or similar 2D objects can handle images from different locations but is based on a precise geo-referencing procedure, which is possible due to noticeable GPS location changes together with inertial systems of high accuracy [5]. Other current software developed from close range photogrammetry, which can also work with little or no initial knowledge of exterior orientation, either focuses on 3D stitching or results in distortion while reconstructing detailed planar objects. During several investigations, different stitching and mosaicking programs have been analyzed to test their practicability for the reconstruction of building facades. But currently no software can provide a precise stitching of the aerial image sets. Facing the fact that no commercial software is currently suitable for fully automated stitching, stitching work has to be done mainly by hand so far. This is mainly realized by using photoshop programs, with which every single image or image set has to be distorted and resized until it is adapted and integrated in a collage.

4 Legal Aspects

The aforementioned notes relating to the safety aspects may be taken up again: In the field of the unmanned aircraft exist different UAS classifications categorized according to size limits, weight limits

or specific applications. These general categories include planes, helicopters, as well as any other type of unmanned aircraft. While regarding aerial infrastructure inspection, especially due to the high building density in urban areas coming along with the associated traffic, the risks to persons and damage to infrastructure must be reduced to an minimum. Accordingly, the redundancy within in the individual systems as well as the overall system is of high importance since it represents the reliability of important functions and therefor the flight safety for every operation. Safety aspects, such as the aforementioned controlled retrieval even in case of a partial engine failure, therefor are an important part of UAS applications, especially when deployed in urban areas.
Since the usage of UAS is currently still strongly limited by legal security restrictions, the current research focus is on the development of the automation of the systems, with particular attention to the aspect of a safe navigation. Of course the long-term goal should be that in the future such a UAS application only has to be monitored by a trained person, while the actual inspection flight navigation is completely autonomous. But since the technology as well as the governmental restrictions do not yet allow such operation, the national regulations still limit the potential of the aerial systems in a way that the current focus has to be on system safety and redundancy.

In Germany, regarding insurance aspects, the use of unmanned aircraft systems outside of specific flying sites is limited to a maximum takeoff weight of 5kg which applies accordingly also for the UAS used for the building inspection. Since a flight permission must be obtained even for such small aerial platforms for nearly every UAS activity, the competent regional authority often includes institutions such as regulatory agencies and governmental road companies in the approval process who decide on the actual scope of inspection according to local conditions. This is especially true for buildings which are located close to highways or high traffic areas in general.

In France, the regulations have been adapted to unmanned systems in April 2012. In contrast to Germany and the mentioned common weight limitations which are mainly based on insurance requirements, the French law mainly differentiates between platforms with a maximum take-off weight (MTOW) of less than 2kg and those with a MTOW between 2 and 25 kg. These weight limitations of special interest for small UAS for infrastructure inspection are part of new defined national categories classified by seven different weight classes (denoted by letters from A to G). The French classes for the two weight limits mentioned before are:

- Category C: MTOW <25kg, commercial use of the system (photo, video, IR, surveillance, ...)
- Category D: MTOW <2kg, commercial use

The other five categories apply for either bigger platforms or those for leisure activities. Besides these categories, the French law also defines three different types of piloting:

- flying within visual line of sight
- piloting without visual contact (>100m and with remote control based on video transmission)
- automatic flight based on predefined waypoint navigation

The regulations also concern about the operation area where the flights will take place. Here it differs between four flight zones:

- S1: flight within a horizontal distance of less than 100m, outside populated areas
- S2: flight within a circle of 1km at an altitude of <50m, outside populated areas

- S3: flight in urban areas or near people, within line of sight, horizontal distance <100m
- S4: activities which exceed the limitations of S2

Furthermore the UAS pilot has to hold the theoretical part of a private pilot license (PPL) for gliders or microlights, and has to present certain declarations regarding his pilot experience as well as the conformity of the aerial system. The regulations even dictate specific type of sensors installed in some UAS categories as well as failcrash and failsafe instruments.

5 Project Results

After the data acquisition and post-processing procedure it is the aim to obtain a full building facade reconstruction. The data results in form of ultra-high resolution 2D models can directly be used for digital remote inspection. In order to get such a solid database, huge amounts of image data have to be collected. Several UAS inspections at different locations in the transnational region and the collection of digital images of selected objects are the basis for the creation of such comprehensive 3D reconstruction models for condition detection.

Among the infrastructures chosen in the *CURe MODERN* project is for example the historic castle of Malbrouck shown in Figure 3. This castle, built between 1419 and 1934, has been completely renovated in the 1990s, but shows already damages in specific areas of the stone construction. Especially on the west side of the castle, which is heavily affected by the weather, there are problems with penetrating water. In order to detect cracks in the joints of the stones, high resolution images have been taken of these areas. Also a complete 3D model of the castle has been created out of old two-dimensional plans, ground as well as also aerial photos. This 3D model 4 is the basic texture for the later overall building model on which the high resolution facade reconstructions can be mapped in order to provide full remote inspection options.

Figure 3: Aerial photo of *Malbrouck Castle*

Figure 4: 3D model of *Malbrouck Castle* (TU KL)

Besides the castle, the same results have been achieved at several other objects such as highway bridges or taller office buildings. Due to the on-going work within the *CURe MODERN* project and the fact that it started in 2012, two results of preliminary projects can be seen in Figure 5 and 6, representative for the kind and quality of 3D reconstructions feasible out of UAS image data.

Figure 5: 3D building model based on high resolution UAS data

Figure 6: Fraunhofer IZFP

Such 3D models based on huge image data sets have a final size which is quite hard to handle for digital inspection. For example for the buildings shown above several thousand images were taken in-flight, while the final dimensions of the single 2D facades equal only the size of several hundred images due to high overlap. Nevertheless, the digital facade reconstructions can reach an overall resolution of some gigapixels. To make the inspection more user-friendly the model facades usually are separated into floors which by themselves are separated into parts of e.g. 10 window frames each. Based on this separated data, the inspection then can be done directly on these sections so that any part of the building can be enlarged for an exact analysis. In terms of damage inspection, tests have been done based on high resolution areas with an achieved ground resolution of less than 1mm allowing even small cracks to be characterized. Due to the high resolution of the image data, even a magnification of the real size of the building is possible, without having an impairment in quality of the inspection. This detailed inspection is particularly important for a precise damage assessment and of great interest especially concerning critical areas. But yet this degree of detail cannot be provided within a 3D model since the digital size would become way too large to work with, which explains the need of new database solutions. Such a solution could be the use of dynamic graphic models which first provide low resolution overviews while the high resolution data is only loaded for a specific area when zoomed in.

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