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Infrared drones in the construction industry: designing a protocol for building thermography procedures

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Abstract

While a number of domains readily employ Unmanned Aerial Vehicles with infrared cameras (IR-UAVs), the IR and UAV research directions still need to be bridged in the construction domain. Our research aims to develop a protocol for IR-UAV flights to survey building thermography. Through a series of test flights and a literature study, the protocol was developed. The protocol was verified during a final test flight surveying PV-panels and the thermal shell of a building. By outlining the system, designing a protocol, and reflecting on our experiences, we contribute to the discussion to use IR-UAVs in the construction domain.

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Keywords: unmanned aerial vehicle, drone, thermography, infrared inspection, protocol, zero energy building

1. Introduction

Recent advances in infrared (IR) thermal sensing and Unmanned Aerial Vehicles (UAVs) technologies makes them disruptive for existing businesses. Multiple industries, such as the agriculture and mining industry, already realized potential benefits of such solutions. However, the construction industry appears to be less aware of the possible advantages of combining UAVs and IR technologies.

By itself, the application of thermography on buildings is already a well-known practice, as thermography enables us to distinguish surfaces with different temperatures. Temperature data from handheld IR cameras can, for instance, pinpoint flaws in the thermal shell of buildings or electric problems in the meter cup board. IR cameras located on

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planes can be used for large-scale airborne temperature mapping to document temperature signatures on the scale of whole suburbs at once. Compared to the former approach, the latter is more encompassing, but it is also more expensive and less controllable. Yet, the logic how to use a combination of IR and UAV technologies as an IR survey solution is not clear. Developing a protocol how to perform thermography surveys is therefore needed.

Our paper provides analysis that offer input for this task. We operate under assumption that external conditions (including weather) allow to perform the survey. Methodologically, we performed a sequence of generic research steps, which are reported in the following sections. The next section outlines the theoretical background. Section 3 reports on applying system thinking to the system in which a drone is an integral part and presents the protocol. Section 4 reports on the flight performed according to the protocol. Finally, in Section 5 and 6 we analyse data, draw conclusions, and suggest future research.

2. Background literature study

Even though thermography and drones are well-known topics, they are not commonly considered together. Inferring benefits related to these two topics motivates combining their functionalities to obtain joined benefits.

The applications of *thermography* in civil engineering include the identification of heat losses [1] or water leakages [2] in buildings. For instance, cooling down thermography can help in identifying subsurface structural deficiencies. With the help of an IR-camera, Clark et al. [3] were able to identify delamination in a concrete bridge structure in the UK. Furthermore, it was possible to investigate the internal structure of a masonry bridge. Experimental evidence can suggest that some sub-surface cracks are not detectable to the naked eye and thermographic analysis can better represent the baselines of the damages produced by an earthquake [4]. As a consequence, Bisegna et al. [5] developed and tested a method to use IR-thermography to spot weak points in ancient wall structures. In this way, the thermography serves a range of applications from identifying heat losses up to the non-destructive testing of structures.

Noticeably, IR surveying is a complex process, as there are three modes in which the energy is transferred to the inspected object or is generated from it [6]: 1) reflection, in which energy is delivered to an object from the same side from which data are recorded; 2) transmission, in which energy is delivered to one side of an object while observing from the opposite side and; 3) internal, in which thermal energy is generated or converted internally while data are collected from either side of the object. Therefore, it is not an easy task to make sure that material-related parameters (like emissivity, color, temperature difference, and thermal reflection) do not unintentionally influence thermographic testing, as noted by Barreira and De Freitas [7].

Moving to the second topic, there is a range of *drones* that can be described, for example, in connection to the altitude they fly at or the endurance of their flight [8]. Liu et al. [9] studied the potential of UAVs to facilitate applications in the field of civil engineering. They concluded that the advantage of UAVs in comparison to traditional data acquisition methods is the timely, versatility and flexibility to collect detailed imagery data in a wide geospatial extent. In a relatively rare example of applying IR-UAVs, Lega et al. [10] demonstrated contamination monitoring in the surface waters. Regarding PV-systems or so called ‘solar parks’, IR-UAVs can help to identify malfunctioning cells or broken electric circuits that show anomalous thermal behaviour [11].

Altogether, while a number of UAVs and IR procedures are already available for their use, IR-UAVs make only initial steps in the construction domain. It is therefore important to account how to employ IR-UAVs in the future. It is possible that applications can be found on the intersection of IR and UAV use cases described in this section. A protocol how to fly IR-UAVs safely, effectively, and efficiently can help designing procedures to use such drones.

3. Designing a protocol

To construct a protocol for IR-UAVs, we scheduled a number of field activities. The main focus of these activities was to become familiar with specifics how a drone equipped with a camera should be controlled. For this, we observed how skilled pilots operated their drones and visited several UAV manufacturers. In particular, a video production company, skilled in shooting movies using an UAV, performed a flight in a residential area (see Fig. 1). The utilized UAV system, a DJI Phantom 2 with a Go Pro 4 camera, is a solution affordable to a large audience. Besides, two manufacturers kindly demonstrated the use of their professional drones: at an abandoned airport and at an industrial area. These initial flights, performed in the beginning of this research project, provided multiple insights in the behaviour of a drone and a number of important elements to devise drone surveys were noted.

Figure 1 shows what forms of dynamic interaction can be observed, when flying a camera equipped drone. As

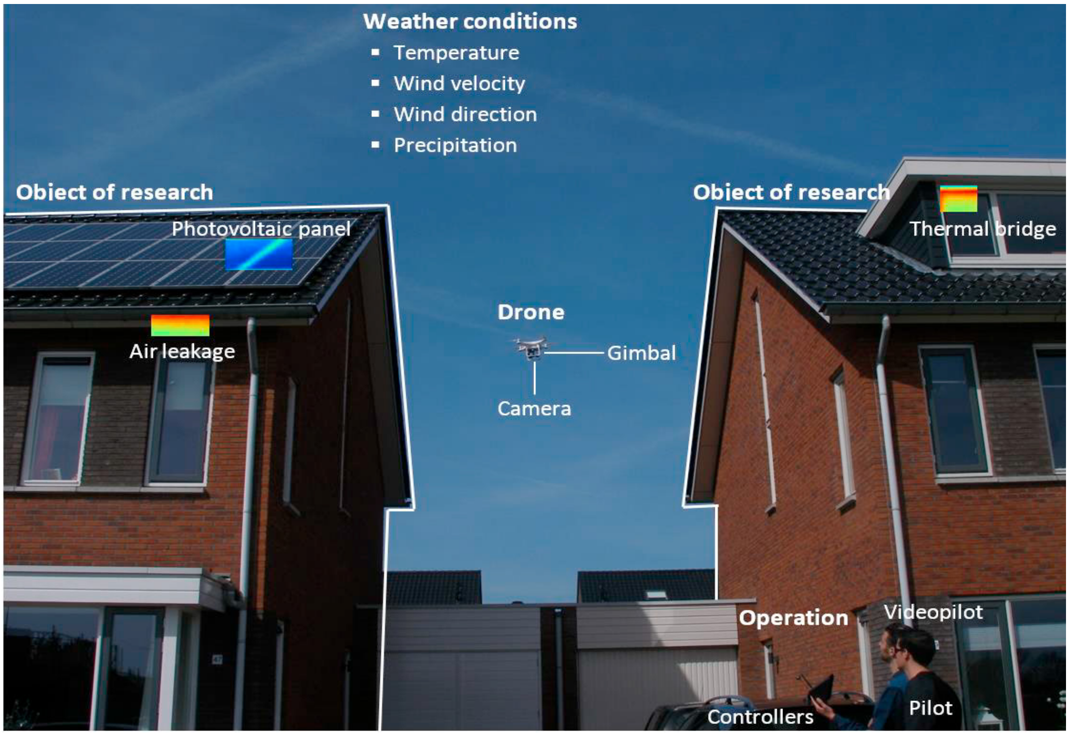


Fig. 1. System configuration of an outdoor building inspection by drone.

entities we can distinguish 1) the surrounding *weather* conditions, 2) *objects of research*, in this case the facades of semi-detached houses and a PV-system, 3) the *UAV*, in this situation a drone with a camera and gimbal, a pivoted support for a camera, and 4) the *operation* subsystem. The latter includes a pilot controlling the drone and a video pilot controlling the gimbal and the camera**.** Clearly, the context parameters of this system include not only weather conditions and are located not only in the physical realm, but do form a basis for our protocol shown in Tabel 1.

A number of regulations (e.g. law to keep distance from airports) govern the use of drones. In this paper we refer to them as *regulations*. Drone usage and flight procedures should also be respected. Besides, as drones are often transported disassembled, time and space need to be accounted for their *assembly* and *disassembly*. A *secondary landing spot* should be identified in case of emergency. One needs to be familiar with the coordinates of the location of the UAV. The *drone flight dynamics* by means of speed in any direction, angle of turn, etc. should also be accounted for. Batteries and maximum control distances are other concerns related to the flight area. It is also possible that some objects (e.g. trees or antennas) exist at the survey place. An accident can happen if the drone, as the most mobile part of the outlined system, has an impact with such an *ancillary* object. Not only a drone can be damaged, but it can even cause consequent human injuries. Essentially, a protocol is a structural way to account for interactions between the four components listed that forms the basis of the procedure for designing an IR-UAV survey.

Through a literature study, several suggestions how to perform IR inspections were identified. Firstly, one needs to consider the effect of solar irradiation on the object of research. When one wants to check for thermal bridging in a façade, preferably an inspection needs to be conducted before sunrise. When inspecting PV-systems, one needs to wait for a later, sunnier moment. Secondly, the distance between the object of research and the thermal camera should be noted and taken into account when interpreting thermal images. Prashr and Jones [12] used a Fluke Ti32 with a resolution of 320x240 pixels to make thermal images of multiple plots of turf grass. Although a thermal image of some plots showed a temperature gradient of 40.7 °C for the nearest plot to 36.2 °C for the furthest, the same temperatures were found when placing the camera at the opposite end of the grass land. This temperature variation was an effect of viewing distance [12]. Thirdly, the inspection of a PV-system might require positioning of the camera at a particular (non-perpendicular) angle. To avoid reflections of the IR equipped drone and its operator, a developer and manufacturer of infrared technologies recommends to apply a viewing angle of 5 to 60°, where 0° is perpendicular to the PV-panels. When making thermal images of buildings, the same caution for reflection, also for the sky and surrounding buildings, needs to be paid to windows and metal surfaces [13]. Lastly, camera characteristics might be accounted for as well, namely those of the field of view of the lens and the resolution of the camera. FLIR explains when a helicopter is used to inspect PV-systems a resolution of at least 320x240 pixels should be used, and a resolution of 640x480 pixels is even recommended [13]. These elements can be summarized as suggestions to take thermal images with a camera with proper *specifications*. The camera might operate at a proper *distance* and at a right *angle*. It can be centred in front of an object and from a small distance. However, when a camera is centred in front of a window, it is likely that reflection occurs. Altogether, these suggestions, partially derived from literature, and combined with the experience gained in three demonstration flights resulted in the protocol shown in Table 1.

Table 1. Developed protocol to fly IR-UAVs around objects of interest.

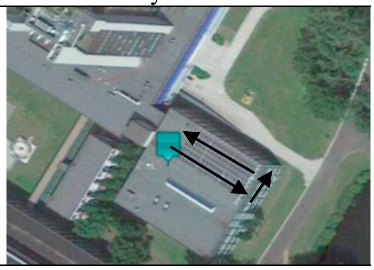
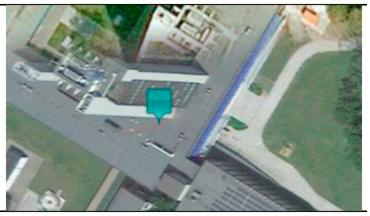
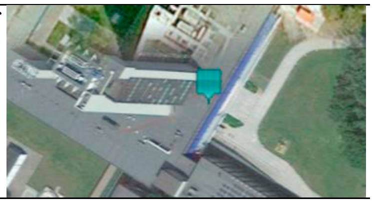
1. Plan the initial set-up phase
a. Become acquainted with the *object of research* (e.g. PV-system or the thermal shell of a high rise building)
b. Become acquainted with the national, regional and local *regulations* related to flying UAVs
c. Find a location close to the object of research to *assemble* the UAV so enough space is available
d. Check the *weather* forecasts and the local weather conditions
e. Find a location safe to the pilot, video pilot and any audience to control the UAV (*operation subsystem*)
f. Conduct a short test flight to ensure the *UAV* is operational
2. Outline a safe and secure flight area (as a 3D flight space)
a. To adequately cover the zone of interest around the *object of research*
b. That provides an unobstructed view between the *UAV* and the pilot (*operation subsystem*)
c. That contains no *ancillary* objects that can be impacted with the UAV
d. Consider safety landing locations (*secondary landing spot*) in case the final landing zones cannot be reached
3. Account for requirements to momentarily photos and continuous video collection
a. Decide what camera(-s) and lens(-es) have the proper *specifications* for studying the object of research
b. Consider appropriate camera *angles* to capture elements of interest in the *object of research*
c. Determine *distances* between the camera(-s) and elements of interest in the object of research
d. Account for the rotation, horizontal and vertical speed of the UAV in flight (*drone flight dynamics*)
4. For each element of interest within the object of research
a. Construct a flight path that takes into account *drone flight dynamics* or in other words the speed
b. Connect flight paths moving the UAV around *ancillary objects*, while ensuring a proper *camera distance/angle*
c. Check the length of the (total) flight path(-s) in relation to the capacity of the *battery* of the UAV

4. Field experiment

In a field experiment to test the protocol, we focused on two *objects of research*: a PV-system on top of a flat-roofed two storey building, Oost-Horst, and the thermal shell of a high-rise building, Horst-Toren. Both objects (partially shown in figures in Table 2) are located at the campus of the University of Twente, where local regulations for UAVs apply. A short list of questions needed to be answered in advance of the test-flight in order to comply with these regulations. During a first round of test flights a pilot controlled two professional drones, a HeightTech Inspector S and a HeightTech HT-8 C180, to collect thermographic footage. Unfortunately, due to the lack of contra weight for the camera, it was impossible to balance the drone's gimbal. Despite the inability to collect IR data, the pilot was with a wind velocity up to 46.8 km/h able to demonstrate that the octocopter is capable to operate in 6 Beaufort.

Afterwards, on 29th of February 2016 our flight procedures based on the protocol were tested. To make sure enough space was available to assemble the drone, to keep the drone in sight during flight and to keep audience at a distance, the take-off took place from a lined area at a grass field at the back of the high-rise building. Flight paths (see Table 2) were set by using drawings of the buildings, maps from Google Earth, co-ordinates from GPScoordinaten.nl and heights from Actueel Hoogtebestand Nederland (AHN). Adding the height of the PV-system to the building height and taking into account a distance of 5.0 m to be able to make clear pictures to inspect all 120 panels, the drone flew at 16.3 m. Furthermore, the panels have a fixed tilt angle of 20° to which the drone should not fly perpendicularly. Using the flight procedures, the pilot guided a HT-8 C180 equipped with a conventional and an Optris PI400 Lightweight infrared camera across the PV-system and along two facades of the high-rise building.

Table 2. Flight procedures used in the final test flight with HT-8 C180 at the campus of the University of Twente.

#	Co-ordinates	Altitude	Description / Picture
1a	Starting point 52.23744; 6.86148	Ground level 30.9 m (NAP)	To make sure enough space is available to assemble the drone, to keep the drone in sight during flight and to keep audience at a distance, the take-off takes places at the back of a building at the campus of the University of Twente. 
1b	Increasing height 52.23744; 6.86148	16.3 m 47.2 m (NAP)	The altitude needs to be increased to such a point that the PV-system on top of the flat roof of the Oost-Horst can be inspected without hitting any antennas. The building is 10.3 m high. Adding 1.0 m for the PV-system and a distance of 5.0 m to the camera, the drone needs to fly at 16.3 m.
2a	Start PV check 52.23710; 6.86089	16.3 m 47.2 m (NAP)	On top of the Oost-Horst two sets of 60 PV-panels each have been installed. The infrared camera will be used to scan for any cells that malfunction. The panels have a fixed tilt angle of 20°, to which the drone should not fly perpendicularly. 
2b	1st PV section 52.23691, 6.86138	16.3 m 47.2 m (NAP)	The drone needs to move slowly to point 2b to picture the first three rows of 54 Canadian Solar panels in total.
2c	Lining up 52.23699, 6.86145	16.3 m 47.2 m (NAP)	The drone needs to be in position to scan the second group of panels.
2d	2nd PV section 52.23715, 6.86097	16.3 m 47.2 m (NAP)	The drone needs to move slowly to point 2d to picture the last four rows of 60 Kyocera panels and 6 Canadian Solar panels.
3a	Start facade check 52.23743, 6.86064	16.3 m 47.2 m (NAP)	After having scanned the PV-panels, an inspection of the thermal shell of the Horst-Toren will take place.
3b	Decreasing height 52.23743, 6.86064	13.3 m 44.2 m (NAP)	The building Horst-Ring is slightly lower than the Oost-Horst. To make sure the whole height of the façade can be scanned, the drone needs to be lowered. 
3c	1st facade section 52.23743, 6.86064	69.1 m 100.0 m (NAP)	The drone slowly needs to move upwards to 3c. The constructional height of the Horst-Toren is 52.35 m. Again it is needed to avoid a collision with systems on top of the roof. The drone needs to move to 69.1 m.
3d	Lining up 52.23749, 6.86094	69.1 m 100.0 m (NAP)	After having scanned a first section of the building skin. A second section will be scanned. Over the top of the high-rise building the drone needs to move to point 3d to get in line for a second scan. 
3e	2nd facade section 52.23749, 6.86094	13.3 m 44.2 m (NAP)	The drone slowly needs to move downwards to 3e scanning the thermal skin for deficiencies in thermal resistance.
4a	Home point 52.23744; 6.86148	13.3 m 44.2 m (NAP)	When the drone comes closer to the roof of the Horst-Ring, it sets off to its last but one destination.
4b	Decreasing height 52.23744; 6.86148	Ground level 30.9 m (NAP)	The drone returns to the starting point.

5. Lessons learned: reflections and analysis

By analyzing the system relevant to IR-UAV surveys, we developed a protocol, instantiated it, and performed the corresponding flight procedures to undertake PV-system and building surveys. We particularly payed attention to the distances between the drone and objects. The coordinates we derived from the databases mentioned, did not align with the coordinates in the software piloting the drone during the test flight. Based on interviews with drone pilots, it was expected that at least a distance of 5 m between drone and research objects would be regarded as being safe. This distance increased up to 10 m in the test flight. Furthermore, in the original flight procedures we had overestimated the number of panels that could be captured by the camera of the drone. The number of moves back and forward across the PV-system needed to increase from 2 to 8 and the velocity of the drone from point 2a to 2d was reduced from 1.5 m/s to 1.0 m/s. As all PV-panels fitted the video frame, that made the survey for malfunctioning cells possible. Comparable experiences we had in surveying the thermal shell of the high-rise building. Multiple vertical flight paths were needed to complete the building survey and the distance to the thermal shell was increased. The collected data appears to be satisfactory for future analysis, which is currently underway.

6. Conclusion

The construction domain typically considers IR and UAV technologies separately. Joined use of these technologies and the corresponding benefits are subjects to be explored. Based on our observations during several test flights and literature study, this paper outlines a protocol to design building thermography UAV procedures. The protocol was employed to survey a PV-system and the thermal shell of a building. Clearly, not all possible external variables were observed during the test. Additional variables might include temperature differences indoor to outdoor, the influence of wind during flight, and precipitation. Further tests are needed to investigate possibilities for developments of the protocol. All in all, we offer the protocol together with the analysis of a survey system, to the reader in an attempt to initiate discussions how IR-UAVs can be used in the construction domain and what factors might limit their potentials.

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