3D Photogrammetric Thermographic Imaging for Building Performance

A Prototype

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***Abstract*— The present paper delineates the evaluation of a modification to existing protocols of creating three-dimensional models via unmanned aerial vehicle image acquisition using photogrammetry to examine building thermal performance. This experimental prototype incorporates current techniques of drone image acquisition, photogrammetry, and radiometrically accurate infrared imaging to propose a streamlined method of evaluating building performance and thereby inform decisions on sustainability.**

***Keywords—*** *UAV, drone, photogrammetry, thermal, thermography, IR, structure-from-motion, model, infrared, Unmanned aerial vehicle.*

# I. INTRODUCTION

Population growth, resource depletion, climate change, and technological advancements have begun to move the public general consensus toward consideration and the advancement of conservation. “Sustainability is based on a simple and log-recognized factual premise: Everything that humans require for their survival and well-being depends, directly or indirectly, on the natural environment” [1]. The U.S. Environmental Protection Agency has four thrust areas for improving sustainability: (a) energy efficiency, (b) green infrastructure, (c) sustainable materials management, and (d) sustainable purchasing and products [2]. Resource efficiency is becoming a desirable trait for architects in proposing new designs or renovating existing structures. To ensure transparency and legitimacy of these sustainable propositions, several organizations have been founded to certify the quality of building efficiency (e.g., Energy Star, Leadership in Energy and Environmental Design, Green Globes and, Living Building Challenge). The present research focuses on green infrastructure and improving the rate of assessing energy loss for potential renovations.

For this paper, a quadcopter, a four-propeller based helicopter, is considered a type of unmanned aerial vehicle (UAV) and when automated classified as a drone. The purpose of this paper was to evaluate the use of an autonomous quadcopter, outfitted with a radiometrically calibrated thermal camera, to photogrammetrically construct a three-dimensional (3D) heat transmission model of a sample building.

# II. RELATED WORK

## A. Photogrammetry

Photogrammetry is the use of multiple photographs to extrapolate distances between corresponding points and reconstruct the photographed environment in three-dimensions. Photogrammetry has been identified as a reliable source of creating three-dimensional geometry of structures. In recent research (2016), the use of ‘found’ photographs from the world wide web were used to reconstruct a famous fountain [3].

Criss, et al. [4] theorized the use of photogrammetry to extrapolate coordinates with UAVs, using an example of the General Atomics MQ-1 Predator. This theory of using UAVs to collect photos for analysis has been identified as an accurate means of deriving dimensional coordinates and creating three-dimensional geometric models [5-8].

## B. Thermography

Thermography has two primary camera types radiometric and non-radiometric. Radiometric cameras are used to measure quantitative temperatures across a whole image, whereas non-radiometric provides a qualitative difference of the image [9].

Bison, et al. [10] conducted a thermographic evaluation of a refrigeration trucks storage space. Using a pan/tilt head and software to automatically stitch the images into a panoramic thermographic representation of the interior, Bison and colleagues evaluated the transmission of heat through the insulated walls. Ferrarini, et al. [11] prototyped a robot with a pan/tilt mounted infrared (IR) camera to create an expedited method of collecting quantitative thermographic readings.

# III. BACKGROUND

## A. UAVs

During the 1990s and the 2000s, UAVs were prohibitively expensive and, in the United States, were the strict domain of the military. Hobby grade UAVs during this time were comprised of airplanes and traditional helicopters. It was in the years of 2008 and 2009 that there was a surge of interest in the quadcopter due to the appearance of hobby grade products at hobbyist prices [12]. The rise in hobbyist purchases, increased production of quadcopters and over a few years reduced the retail price of commercial drones.

The history of UAVs, drones, and quadcopters is important for illustrating why research utilizing such products is limited to the last decade.

# IV. METHOD

## A. Equipment

A DJI Phantom 2 Vision+ drone was used during this project, equipped with an original equipment manufacturer digital camera to capture visible energy. A FLIR Dev Kit breakout board with Lepton LWIR Imager connected to a Raspberry Pi 2 Model B microcontroller were used to capture the IR energy of a target structure. Video footage was stored on a micro SD card and then transferred to a computer for post processing.

Video footage was processed via the free software project FFmpeg and key images extracted using a Python script at a rate of 0.25, 0.5, & 1 image per second. After discretizing the video into a set of stills images they were subsequently imported into a photogrammetry software for processing into a 3D model.

## B. Project Timeline

Prototyping was divided into milestones as a check and balance system to keep the project on task and reduce any potential for error or bias in the data collection phase. Prototyping milestones were based on standard software development lifecycle (SDLC) project milestones. Development of the prototype was confined to a sixty day timeframe.

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### 1) Alpha Milestone: This stage of the prototype development was dedicated to honing skills needed to properly maneuver the drone for video acquisition. Once skills elevated past basic levels, video footage was collected of multiple sample targets (e.g., sedan, SUV, and basketball hoop), key frames selected and separated into still images to be later passed into the photogrammetric software. Additionally, photos of a sample target (e.g., a porcelain bust) were taken with a Canon EOS Rebel XS DSLR camera to develop the understanding of how to use Agisoft PhotoScan. Once understood, the limits of PhotoScan were tested, along with testing the photogrammetric function with the key images from the aforementioned drone video.

Alpha stage results indicated the need for a software solution to automate navigation of the drone, rather than user controlled, as it proved difficult to maintain vector to the target. A Python script was developed using FFMPEG to decode and parse out key images from the resultant drone video, key images were subsequently sent to be analyzed by PhotoScan.

Prior to working on drone derived images, a preliminary photo set was used to develop the necessary techniques to work with a photogrammetry software, PhotoScan (Agisoft). The preliminary photo set consisted of 33 photos at 8 Megapixels from a DSLR camera of a procaine bust. The resultant model was of decent quality, consisted of a three hundred and sixty-degree triaxial model that reasonably resembles the original. The developed protocol for creating a 3D model in PhotoScan was: import images into a chunk, process the chunk to align the images, build dense cloud, build mesh, and build texture.

Subsequently, the key images from the drone video were passed into PhotoScan which resulted in unusable 3D models. Examination of the original images uncovered a distortion caused by a field-of-view lens on the drone’s camera. Having corrected this, another video was collected, key images parsed and re-entered into PhotoScan. Resultant models continued to show distortion or insufficient structural integrity.

### 2) Beta Milestone: The Beta Milestone was initially planned for the configuration of IR hardware, IR pilot data collected, and rendering conducted. If the pilot data were confirmed usable the final part of this milestone would be the testing of IR photo sets in in the modeling pipeline.

This however, is not how the Beta Milestone occurred. To overcome the malformations of 3D models in PhotoScan other photogrammetry software were tested (e.g., AutoDesk ReMake and 3DF Zephyr Pro). The most reliable output was generated from AutoDesk ReMake, by using their cloud based rendering option. The cloud option was utilized because any time we attempted to render the model locally ReMake would give an error and refuse.

In addition to rendering difficulties, there were issues with the IR hardware. The design of the FLIR Lepton breakout board was to allow for development and prototyping with the IR camera. However, this has been part of the problem preparing the IR camera for the Beta Milestone, as the camera would not remain seated in the breakout board preventing the stable acquisition of video footage. This issue with the breakout board was attributed the movements and motion of the drone in flight. This raises a concern with the usability of this IR module for this prototype.

### 3) Gold Milestone: The intention of the Gold Milestone was to conduct the prototypical process of the proposed system and the culmination of the software pipeline to provide the thermographic 3D model. However, complications with the drone hardware and the amount of time required to become proficient in the use of multiple photogrammetric software prevented the completion of the Gold Milestone.

# V. RESULTS

At the completion of of the Beta Milestone a single RGB data set was found to be usable and the collection of IR data just beginning. Multiple complications prevented the completion of the prototype within the defined timeframe. These difficulties included: (a) the underestimation of required time to process a still image data set in photogrammetric software, (b) the steep learning curve and quantity of time required to become proficient in each photogrammetry software package, and (c) attempting to correct for the FOV lens on the drone to later discover it was not required, and (d) the IR camera failing to stay mounted in the development board.

# VI. RECOMMENDATIONS

## A. Drone

One aspect that slowed the development of this prototype was finding software that would allow for geospatial flight planning for the drone. Since drones are still a niche product many of the manufacturers do not produce software to issue flight plans to the drone rather they function like remote control operations. In addition, flight time is reduced by the addition of the IR camera and any additional weight applied to the drone. It is therefore recommended that a drone with flight planning software and an interchangeable camera module be utilized to mitigate the aforementioned problems.

## B. Software

Agisoft PhotoScan provides an intuitive user interface but requires powerful computing hardware to processes the data sets on a local system. There is a feature to utilize the hardware of networked computers, however, this feature is complicated and not intuitive to initialize.

Autodesk ReMake offers both online and local processing of data sets, however, limitations prevented it from being a viable resource at the start of the project, as the latest version, at that time, was not compatible with the operating system installed on many of the computers available. Half way through the project Autodesk released an update that allowed for ReMake to be usable for online processing.

3DF Zephyr Pro is the more complex of the three software packages used. It is difficult to learn, not intuitive, and appears to take longer to process data sets then PhotoScan. Zephyr Pro may have tools to expedite the processing of data sets but requires an advanced level of skill to know how to utilize them.

# VII. CONCLUSION

The prototype shows promise as a method of building performance analysis through thermographic photogrammetry. This is evident by the rapid 3D model created by using the onboard drone camera. Developing the method of IR capturing to retexture a 3D model generated by simultaneous RGB capture to create a 3D thermographic model is the logical continuation of this prototype. The recommendations indicated above should be considered, purchase of equipment should be done as early as possible, and training in photogrammetric software completed prior to formal data collection.

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