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Topographic investigation from a low altitude unmanned aerial vehicle

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A B S T R A C T

Aerial imaging techniques used before the arrival of unmanned aerial vehicles had several limitations, including limited flight performance, low resolution in certain situations, and high cost. Artificial satellites can be used to collect very large images covering vast areas of the ground surface. Nonetheless, the acquisition is very slow and only possible in clear weather. In addition, there are situations where high-resolution images are difficult to obtain through a satellite because as the coverage increases, the level of detail of the obtained images decreases.

To obtain high-resolution aerial images of small areas, unmanned aerial systems allow the recording of images in great detail. This paper aims to perform optical 3D measurements using a combination of optical profilometry techniques and a remote-controlled air vehicle by a ground operator. The system is essentially a camera, a miniature projector, and a lightweight ultrasound sensor attached to an unmanned aerial vehicle (UAV). The technique discussed here can record smaller sites and generate topography with great detail to record topographical maps of small landscapes.

1. Introduction

Images obtained from satellites and aircraft have high quality; the data represent linear dimensions ranging from tens of meters to hundreds of kilometers. The acquisition and processing of digital satellite imagery provide a very large-scale mapping of the area of interest, in addition to increasing the sampling density with respect to that achievable by ground-based platforms [1,2]. Despite the obvious advantages to remote sensing from satellites and aircraft, there are certain drawbacks and limitations, mainly the high costs and the low repeatability in a short time. In addition, small regions less than 10 m cannot be measured accurately using artificial satellite remote sensing because the region is not clearly discernible, and complete and exhaustive information of the area being studied is not provided.

The earliest aerial photographs using balloons as platforms were taken in the 1860s. This technique was widely used to produce photographs for mapping small areas or monitoring changes in the boundaries of certain sites [3,4]. During the French Revolution, the French Army used balloons for reconnaissance missions.

Although the cost of implementing a remote sensing project via hot air balloon is much cheaper compared to conventional digital satellite imagery, the balloon system is limited by the wind velocity and should be operated only on calm days. Obtaining images of very small areas at low altitudes is relatively straightforward. Simple and inexpensive methods for obtaining low-altitude mapping that allow the quantization of the geometry of an object on a spatial scale that is difficult to match using other methods, such as satellite-based remote sensing or hot air balloons, are not widely known because less attention has been paid to this topic.

Combining aerial and terrestrial photogrammetry can be a good option for mapping small-scale areas using very light platforms such as unmanned aerial vehicles (UAVs). Airborne radar sensors have been used to build elevation maps. However, radar sensors cannot be mounted on small unmanned aerial vehicles.

At present, some researchers use flying robots equipped with lightweight sensors to more accurately conduct altitude measurements [5]. New applications have been introduced using UAVs for a variety of civil engineering tasks, such as detecting subsurface delimitations in concrete bridge decks or obtaining surface flow measurements [6–8].

A growing body of literature has demonstrated that the modern technology of small air devices has ushered in a new era for aerial photogrammetry and civilian applications [9–12]. Other important benefits of drone technology include the ability to operate them for professional crime scene investigations [13].

UAVs combined with amateur or digital cameras can provide a low-cost alternative for photogrammetric applications. Drones can also be used for high-resolution texture mapping. The combination of photogrammetric aerial and optical profilometry using drones enables a broad range of applications. There are many optical methods for extracting the geometric information of an object from an image [14–20]. Our work is based on the fringe projection method. The fringe pattern

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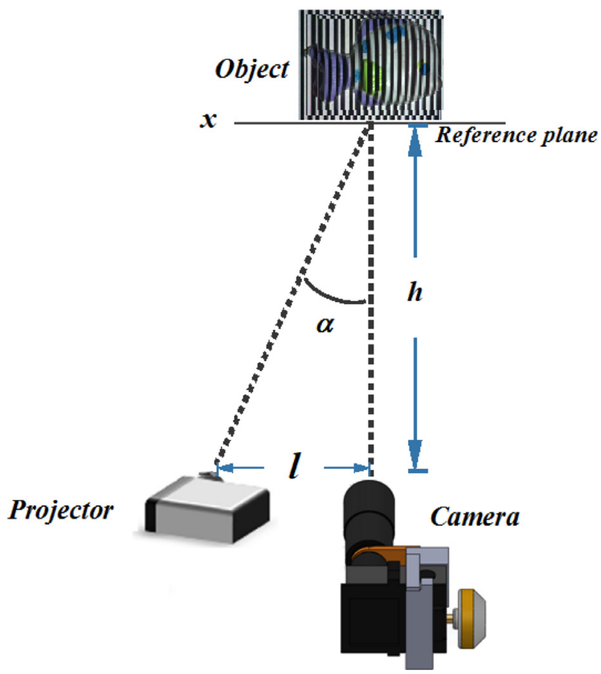

Fig. 1. Diagram of the fringe pattern acquisition system used in this study.

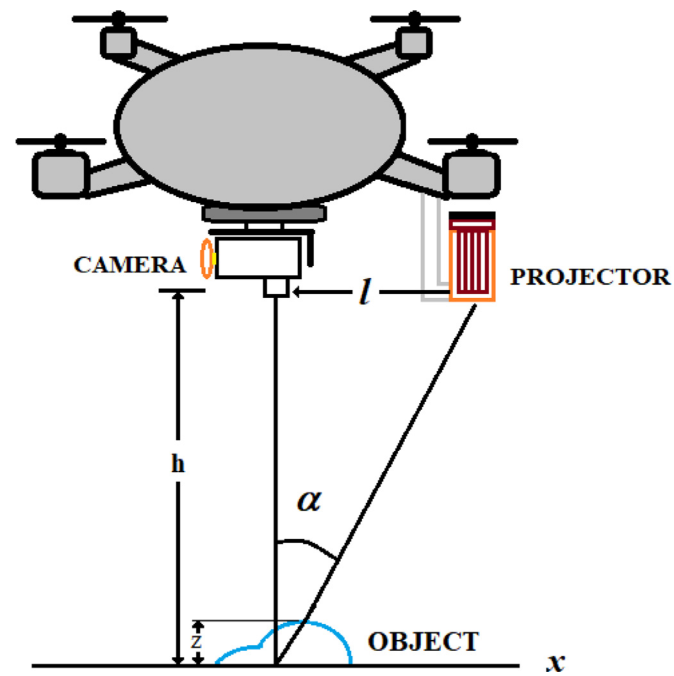

Fig. 2. Schematic drawing of the setup.

projection technique is considered an incoherent technique and has become one of the most widely used for reconstructing 3D object surfaces. Structured light fringe projection systems for 3D surface measurement have reached an adequate maturity level in controlled environments. This has motivated us to implement this outdoor-operated UAV technique for acquiring detailed information on elevations in small-scale areas when flying at low altitudes.

Drone technologies with a wide array of portable sensors, including optical sensors for image acquisition and appropriate phase unwrapping algorithms for fringe projection profilometry, are powerful tools capable of performing automated 3D reconstructions of surveyed objects from one or a set of images, facilitating the production of physical replicas. The combination of optical profilometry techniques and unmanned aerial vehicles is an alternative to produce 3D topography; additionally, the surveyed objects can be scanned from different viewing angles through a single lens. The potential of this alternative to produce 3D geometric models is self-evident.

It is important to note that indoor and outdoor environments present different challenges for 3D reconstruction. The current study analyzes the possibility of transferring this technique from one situation to others.

In this research, the combination of a CCD camera, a small projector, and a drone were used to acquire detailed information on elevations in small-scale areas from low altitudes.

To conduct 3D digitalization, we designed a small projector that is light, efficient, and inexpensive. It can be loaded onto a drone without any complications and controlled simultaneously. Many varieties of projecting light patterns have been proposed, such as liquid-crystal displays (LCD) [21], spatial light modulators (SLM) [22], and digital micromirror devices (DMD) [23]. A traditional projector requires a power supply to function properly. This is a limitation in a drone, so it is necessary to design a projector with low weight and low energy consumption according to the drone's capabilities.

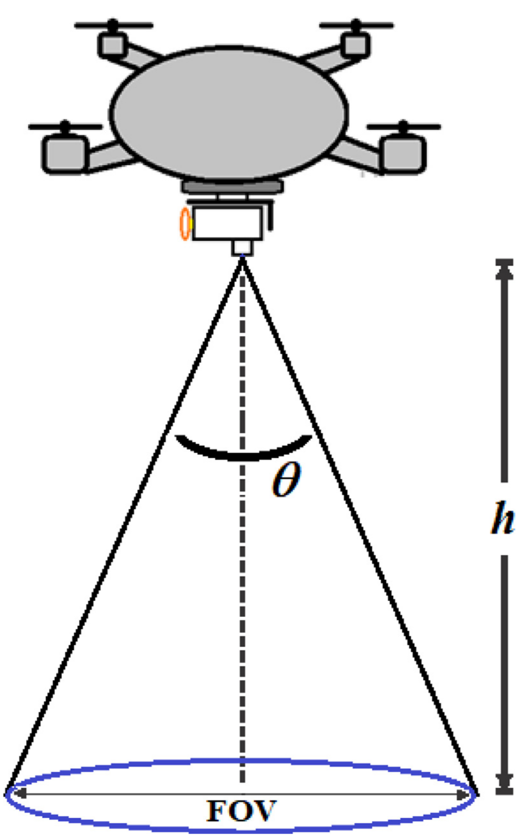

Fig. 3. The coverage radius on the ground depends on the flight altitude.

2. Fringe projection technique

There are many different ways to obtain 3D measurements. The most widely used method is the fringe projection technique, which is considered one of the simplest to implement with good results in shape recovering. Using a projected image of structured light with a known spatial frequency, it is possible to obtain 3D data via triangulation.

Due to the depth variations of the test object, the fringe pattern is deformed, which is observed and recorded by a camera, and then a phase map is calculated. The phase information modulated in the deformed fringe pattern corresponds to the depth of the measured object. The ob-