Empirical Assessment of an Autonomous Lighter Than Air (ALTA) Imaging/Sensing Platform for Environmental Monitoring

By

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Abstract

Low-altitude aerial photogrammetry using Lighter Than Air (LTA) platforms is attractive alternative to that using Heavier Than Air (HTA) platforms like Unmanned Aerial Vehicles (UAVs) or any small aircraft in aerial imagery collection. Autonomous Lighter Than Air (ALTA) platform is a balloon-borne Lighter Than Air (LTA) platform to capture aerial imagery for low-altitude aerial photogrammetry. It's also a low-cost oblique and vertical aerial imagery collection system. Based on the characteristics of ALTA platform and the need of three dimensional modeling, a method of 3D building or architecture modeling using the aerial images from ALTA platform is assessed empirically. Firstly, we have captured oblique and vertical images of any building or architecture from the camera of ALTA platform through several missions in Villach, Carinthia, Austria. We have taken the advantage of gimbal system of ALTA platform to take oblique images especially and online remote video streaming on the ground from the ALTA platform unit at the low-altitude flight to capture aerial images. Secondly, several-angle and different altitude images including vertical images and oblique images captured by the ALTA platform are utilized for the detail measure of building dense point cloud, surface and texture extraction in 3D model reconstruction using different photogrammetric solutions. Finally, 3D building or architecture reconstruction provides authentication model for building or architecture utilizing gimbal based wide-angle camera images from ALTA platform. These reconstructed 3D models of building or architecture are also visualized online taking 3D point clouds of them on potree-based 3D web visualization tool. It is demonstrated from the mission result that ALTA platform for low-altitude aerial photogrammetry can be used in the construction of 3D building production, fine modeling and visualization.

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1 Introduction

Autonomous Lighter Than Air (ALTA) platform is a "smart" balloon which flies to unreachable places from where it transmits images and information to any internet screen. It carries miniature image capture sensor along with transmission instruments. This balloon can be launched and retrieved by tether to continuously monitor specific patches of land or it can travel on a planned drift journey to an optimized path of image capture points. The platform provides a brand new vantage point, lower than any plane and higher than any street view [1]. The platform controlled via a central system and via an Internet-based application collects high resolution, oblique and geo-referenced images at low angles, from low altitudes and at low cost and also the platform operates below cloud ceilings, transmits tree-top. It provides an order-of-magnitude sharper aerial imagery than the current state of the art. This platform sends real time video streaming of aerial view of any area or event of interest and allows to capture aerial images on the ground at the same time. It gives any photographer the capability of real time remote control of the platform and sightseeing while taking images rapidly. More importantly, ALTA platform gives the photographer freedom to take aerial images from different angles and different heights at same geographical position. An ALTA platform in action is shown in Figure 1.

On the other hand, Unmanned Aerial Vehicles (UAVs) or "aerial robots" are known as Remotely Piloted Air Systems (RPAS). Most of the Remotely Piloted Systems are fixed-wing platforms like drones. In the past, UAV platforms were very important to explore and monitor our environment. Nevertheless, ALTA platforms have advantages over the state-of-the art UAV platforms. Furthermore, Lighter Than Air (LTA) vehicles have many mundane applications such as advertising, aerial photography, freight carrier, transportation, research, construction, and event monitoring as well as many critical applications such as disaster response, crime-scene monitoring, surveillance, spatial exploration, and military tasks. So, we use Lighter Than Air (LTA) systems ("balloons") for long term environmental monitoring in different test sites in Carinthia, Austria where high resolution UAV images are available because these systems provide an interesting alternative to fixed-wing UAV systems. So, our goal of this research is to perform the empirical assessment of such an Autonomous Lighter Than Air (ALTA) imaging/sensing platform for environmental monitoring.

Figure 1: ALTA platform in action

ALTA platforms have more mission endurance compared to the limited mission endurance of UAV platforms. ALTA can be flown for prolonged period of time. ALTA platforms are safe, cost effective, environmentally benign and simple to operate which make them attractive alternative to mechanically propelled UAV platform whose in-flight vibration make accurate geo-spatial data collection difficult. ALTA platforms are powered by natural forces that harnesses natural external forces to fly without fuel or a pilot whereas UAV platforms need large amount of energy for long flight to tackle same natural external forces. ALTA platform altitude can be controlled through tether but UAV platform altitude control is not easy and ALTA platform can be tested in higher altitude still high resolution camera images with the help of zooming. ALTA platform is free from propulsion turbulence and less susceptible to wind but UAV platforms are sensitive to these propulsion turbulence and wind. ALTA platforms need reduced amount of human intervention for danger free mission. On the other hand, UAV platforms require always conscious effort of human operator for safe flight. More importantly, ALTA platforms have increased performance range and capabilities compared to that of UAV platforms.

The purpose of our work is threefold. These are as follows:

- First, we would like to study the advantages of ALTA platform in terms of quality image acquisition and cost effectiveness.
- Second, we would like to reconstruct 3D model from 2D aerial images of any building or architecture with continuously changing locations, angles and altitude over time.
- Third, we would like to evaluate a novel environmental imagery collection empirically from ALTA platform deployed over prolonged period of time by reconstructing different 3D models of same building or architecture.

The remainder of our work report is organized as follows: Section II presents the background of our empirical study of ALTA platform and its motivation; Section III describes the method of 3D model reconstruction of building or architecture from ALTA platform; Section IV presents system description of ALTA platform explaining its different parts in brief; In section V, different ALTA mission modes and comparison of ALTA platforms are described; Section VI explains experimental results of our work; Section VII discusses the comparison of results of our work, web-visualization of the result and cost comparison; and Section VII discusses our conclusions and future directions for our research.

2 Background and Motivation

2.1 Previous Works

In recent times, researchers have used Lighter Than Air (LTA) platforms for low-altitude aerial photography. They are mainly of two types, one is Kite-based Aerial Photography (KAP) and another one is Balloon-based Aerial Photography (BAP). Balloons have normally been used when wind speed in an area is low and kites when wind speed is higher which provides complimentary use in various environmental conditions.

Mozas-Calvache et al. present low altitude photogrammetry from a helium balloon combined with non metric digital reflex camera and additional surveying techniques and it has shown high efficiency in mapping small and medium size areas of archaeological sites [4].

Smith et al. describe high resolution image capture using combination of kite and digital camera on smooth terrain, tor terrain and a glaciofluvial esker and processing of captured images using Leica Photogrammetry Suite [5]. Their results show high accuracy in terms of extracting a high number of sampling points. However, their accuracy largely depends on suitable image texture across the site, measurement variability and user quantification.

Wundram et al. have used kite aerial color photography to map and classify different vegetation types in the alpine zone using both supervised classification and unsupervised clustering of the three-band colour imagery [6].

Marzolff et al. have used kite aerial photography to produce digital elevation models from a small collection of photographs producing topographic maps with pixel sizes of 4 cm over an area of 100-by-100 m [7]. Topographic maps were used to track the progress of gully erosion over a period of 24 years.

Sander presents Kite Aerial Photography(KAP) as a tool for geography field teaching and as a medium to approach the complexity of readily available geodata to understand spatial perception and observational skills in real environment [9].

Silva et al. describe a method of low-altitude remote sensing using balloon-based aerial photography to monitor the post-fire canopy of recovering two competing grassland species [13]. It consists of ecological investigations of competing species in pastures and validation of remote sensing information on mountain environments.

Planer-Friedrich et al. conduct a research on low-cost aerial photography using helium balloon for high resolution change detection in the two exemplary hydrothermal areas of Yellowstone National Park, Germany. They find it useful for mapping rapidly changing environments [11].

Eulie et al. present balloon-based photography along with real-time kinematic GPS to observe sub-annual changes in the shoreline position of the Albemarle-Palmico Estuarine System (APES), North Carolina, USA [8]. Their results demonstrate that this method is well-suited to high-accuracy analysis of shoreline positions over short timescales and that balloon images provide a important spatial context for any measured changes.

Bryson et al. present Kite Aerial Photography for constructing high-resolution, three-dimensional, multi-spectral terrain models of intertidal rocky shores [10]. They use automatic image feature detection and matching, structure-from-motion and photo-textured terrain surface reconstruction algorithms in processing images.

A. Shaw et al. provide a set of multispectral imaging systems on tethered balloons for education and optical remote sensing.They use tiny metal-oxide semiconductor cameras with low-cost optical filters to obtain images in red and near-infrared bands and also blue band [12]. The red and near-infrared bands are used for identifying and monitoring vegetation through the normalized difference vegetation index (NDVI) and blue band is used for studying water turbidity.

Unmanned Aerial Vehicles (UAVs) are a relatively recent technology that have been used to produce high resolution maps from their low-altitude flight. Nex et al. present the state of the art of UAV for geomatics applications, giving an overview of different UAV platforms, applications, and case studies [14]. They also state the advantages that can support the adoption of UAVs, such as flexibility, ease of operation, and relatively low-cost of operation and ownership. In an environmental monitoring context, Rango et al. demonstrated the use of fixed-wing UAVs for collecting images over rangelands of southern New Maxico, USA with a spatial resolution of 5 cm per pixel [15]. In rangelands, UAV imagery provides the ability to quantify spatial patterns and patches of vegetation and soil which are not detectable from satellite imagery. Bryson et al. describe in their work that a fixed-wing UAV was used to produce geo-referenced imagery maps with a resolution of 3.5 cm per pixel over an area of 4000-by-600 m in a weed monitoring application [16]. Again hovering UAVs (such as Mikrokopter) have been demonstrated as a promising platform for low-altitude sensing for even higher resolution imaging. Turner et al. outline a hovering UAV was used to produce maps of Antarctic moss beds with a resolution of 1 cm per pixel over an area 100-by-40 m [17]. Harwin et al. use hovering UAV imagery to produce 3D maps of a coastal cliff, producing point clouds with a spatial resolution of 1-3 cm and an accuracy of 25-40 mm [18].

UAVs are potential platforms for gathering high- resolution remotely sensed data; although the costs and technical skills required to operate these platforms are becoming lower over time, they are still relatively high, particularly when considering their use in small-scale ecological studies. Additionally, the current generation of rotary-wing UAVs are typically limited by low endurance (approx. 15-20 minutes) and are susceptible to failure in high-wind conditions, typically encountered in coastal regions. Aside from these limitations, there is a need to improve the reliability and safety of UAV platforms.

Considering the previous works of our focus like the reconstruction of 3D models from 2D aerial images of building or any architecture, Chen et al. present a scheme for building detection and reconstruction by integrating the edges extracted from aerial imagery and the plane derived from LIDAR point clouds [21]. The three dimensional building edges are thus used to reconstruct the building models and determine accurate positions of building walls. Soveg and Vosselman describe a 3D building reconstruction method that integrates the aerial image analysis with information from large-scale 2D Geographic Information System (GIS) databases and domain knowledge [19]. Jizhou et al. design 3D reconstruction method of city buildings from single UAV image by extracting geometry and texture information from UAV images [20]. Lu and Chu present a method that generates 3D models of man-made structure like building by building a 3D mesh, segments the triangles, and forms planar facets that correspond to a roof structure of a target building [22].

Wefelscheid et al. offer 3D reconstruction of building capturing images of building from different perspective [23]. They evaluate their results with the state of the art LIDAR result of 3D reconstruction of buildings. Xie et al. [24] discuss the fast method of 3D building modeling using images of UAV carrying four combined camera by contrasting and analyzing the mosaic structures of the existing four-combined cameras and automatic matching of those aerial images.

Recent Developments in Photogrammetry and Structure-from-Motion. The process of measuring spatial properties from photographs or images is referred to as "photogrammetry" and when large numbers of images are used, typically to reconstruct the three-dimensional spare and dense spatial structure of an imaged scene, this process is referred to as "structure-from-motion" [25]. Recent developments in structure-from-motion [26] which is a open source solution have focused on building 3D models of buildings from large collections of un-ordered, un-calibrated images. These methods utilize multi-core and parallel processing algorithms for efficiently combining images. However, this method is not generally reliable and accurate enough in case of large and complex image blocks with variable baselines and image scale.

Previously no researchers used balloon-borne low cost platform for 3D model generation of building or architecture from oblique aerial images. This has inspired us to employ the ALTA platform in oblique image acquisition and 3D reconstruction of building or architecture.

2.2 Motivation

ALTA platform is a steerable oblique geo-referenced camera system attached to a weather balloon. Use of this balloon can solve various problems associated with UAV or manned aircraft like cost, image quality, and accessibility. This balloon-borne platform is cheaper than any UAV or an aircraft, doesn't require any highly trained person, is easily deployable, and can "fly" at lower altitudes. Even a small aircraft or UAV is expensive, and require a trained and licensed pilot or operator. Additionally most high-end aerial imagery systems require expensive FAA-approved modifications of the airframe. This adds costs, and limits the aircraft or UAV that can be used. However, since ALTA platform is low-altitude aerial imagery systems, so it does not require any of these costs or limitations. Furthermore, FAA does not consider the ALTA balloons in a tethered mode subject to their control, and is currently reviewing it in a drift mode. The very low altitude of operation and dual control of descent should also exempt the drifter from FAA involvement. So, ALTA platform could provide a significant advantage where Unmanned Aerial Systems (UAS) operations are restricted or not practical.

Because the balloon floats at low altitudes, image resolution is an impressive "game changer". Here is just one example comparing a 4-inch pixel Bing image taken from 3,000 feet to a 1-centimeter pixel ALTA platform image of the same location taken from several hundred feet. The comparison result is shown in Figure 2.

A significant factor during disaster response events is transportability and support. Past experience has shown that it can be very difficult to transport and operate even small aircraft in disaster regions, especially if the damage is widespread. Fuel and ground support in disaster sites can also be a serious limitation. By comparison, a balloon-borne ALTA platform can be carried in a suitcase, shipped quickly, and set up in less than an hour. Since the cost is in the range of several thousand dollars, multiple platforms are practical and can be deployed in numerous remote locations. Equally impressive is that operators can be trained in less than an hour.

Figure 2: Bing (left) and ALTA(right) images of stadium seats, compared.

Recently, in response to a South Florida Mall shooting, police launched an ALTA balloon platform to view the crime-scene location. The imagery was instantly and continuously sent to police station computers and mobile devices of responders and an route to the mall for pre-planning of their response. Viewing rooftops and walkways for victims and perpetrators, a near real-time operational picture was provided to police before putting themselves and others in harm way.

This ALTA platform has some potential lifesaving use on numerous occasions like in emergency response actions, and the dominant overarching need was high-quality imagery that could be combined with legacy data and imagery as close to real-time as possible. This system answers that need, and at a low cost. It's possible to make every country ready for nationwide deployment of several ALTA platforms on a moments notice. This platform would be especially valuable for disaster response in second- and third-world countries. Dozens of ALTA platforms and trained operators could be delivered on short notice to major disaster sites, providing almost real-time common operational pictures for first responders. The added advantage is the very light need for logistics and support.

Military applications could be equally important. The silence of balloons coupled with a small visibility profile, including almost total invisibility at night, makes them ideal for reconnaissance and surveillance. The relatively low cost of the platforms also permits them to be expendable. In a tethered mode, the persistent "eye in the sky" could serve as a deterrent, or at a minimum make hostile activity more complicated for the perpetrators as they try to hide activities from the balloon. The "light" logistics and fast operator learning curve are just added benefits.

Considering current state of the art of aerial photography, in this work, we assess the application of our ALTA sensing/imaging platform for monitoring environment capturing oblique aerial imagery collection of any building or architecture from ALTA platform missions in order to study benefits of using our ALTA platform. We also use the oblique imagery to reconstruct different 3D models of the building or architecture and evaluate them in terms of no. of 3D point extraction and their visualization.

3 Method

The typical method of the ALTA platform assessment reconstructing 3D models of building or any architecture through different missions is illustrated in the Figure 3.

The mission operator conducts low-altitude observation through ALTA platform that is deployed in the selected test sites in Villach, Carinthia, Austria. ALTA platform is balloon-borne camera with mission operator underneath with the ability of easy and fast remote control in the hands of operator, allowing the operator to capture images of specific region of interest. The platform is deployed over prolonged periods of time in different test missions with in-situ control of the angle of imagery. The operator follows a mission path to cover the test site. The ALTA platform is operated remotely on the ground by smartphone or tablet through mobile application installed on it. From the ALTA platform mission operator collects the high resolution geo-referenced (based on GPS of smartphone or tablet) aerial imagery. The mission operator also controls the mission altitude of the platform. The gimbal system of ALTA platform is controlled with remote control in the hand of mission operator which provides the aerial images from different angles and perspectives. So, this aerial imagery is a collection of moving geospatial database objects with continuously changing location over time and also images of building or any architecture of interest from various angles and altitudes.

After collecting high resolution aerial images of a building or any architecture, we process all 2D aerial images using different photogrammetric solutions. Several-angle and different altitude images including vertical images and oblique images taken by the ALTA platform are

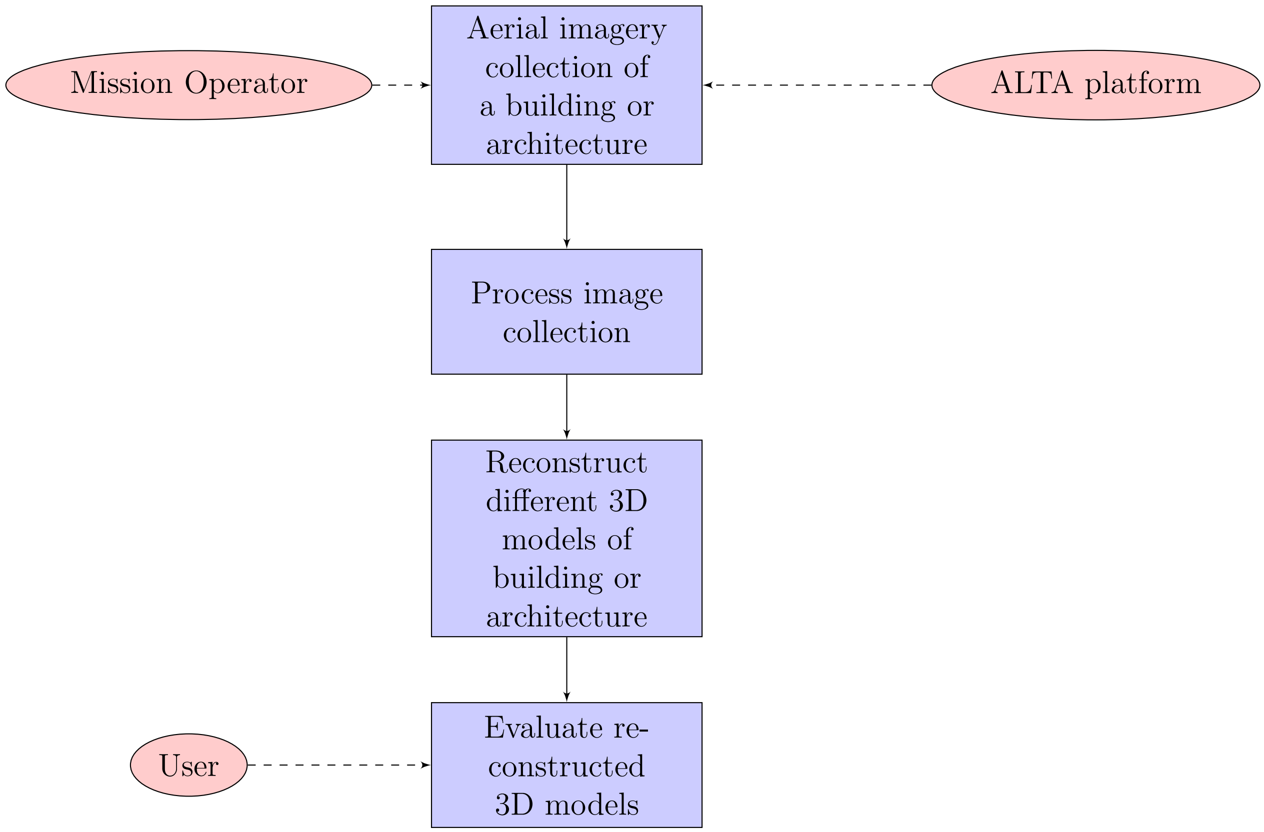


Figure 3: Method of ALTA Platform Assessment

used for the detail measure of building dense point cloud, surface, and the texture extraction.

From the processing of aerial images, we get different 3D models of building or architecture from different photogrammetric solutions. These 3D models are actually dense 3D point clouds consisting of spatial points along with built surface and texture covered by aerial images of building or architecture area.

The user evaluates our reconstructed 3D models of building or any architecture from different photogammatric solutions in terms of no. of points in the dense point cloud and surface smoothness. These 3D models of building or architecture are evaluated by the user visualizing them with web-visualization tool.

4 System Description of ALTA Platform

ALTA platform is not as simple as strapping a digital camera to a balloon. Achieving the image quality, accuracy and dynamic performance of the ALTA platform requires a very sophisticated package, including the balloon, controls, communications and sensors. The balloon system is actually two balloons, one within the other, an outer balloon and inner lift gas balloon. The outer balloon provides some external protection and the lift and the inner balloon carries the entire weight of the unit. Greater lift (meaning more gas inside the outer balloon) is needed on the windy days. Operation with strong winds is not recommended.

The modular payload is complex, but also lightweight and compact thanks to the latest developments in miniaturization. It consists of inertial measurement/navigation unit (IMU) to control the gimbal system of the ALTA platform, an on-board computer system with signal receiver, Wi-Fi communications, and an aimable high-resolution camera as image sensor on a stabilized gimbal system. The camera can be RGB, night vision or even multi-spectral. The imagery is downloaded as captured and delivered almost real-time. Different system parts of the ALTA platform are described in the following:

4.1 ALTA Cardinal Unit

The Autonomous Lighter Than Air (ALTA) cardinal unit is developed to enable low-altitude, high resolution collection of images with enhanced stability and autonomy of flight. The ALTA cardinal unit incorporates a gimbal system with brushless motors, which allows for three degrees of freedom in rotation. This unit also includes a Canon camera as image sensor. This camera allows user to capture and geolocation images based on GPS of smartphone or tablet through Wi-Fi enabled mobile application. The cardinal unit does not have any form of propulsion. Instead, it includes two smart balloons (the "inner" and the "outer") connected to the top of the unit called "plenum". The cardinal unit has also a leg (the "skeg") attached to the plenum by a metal clip. The skeg is attached at the opposite end to the tether. It ensures that the tether will not get tangles around the unit when the wind pushes the balloon around. The ALTA cardinal unit is depicted in Figure 4.

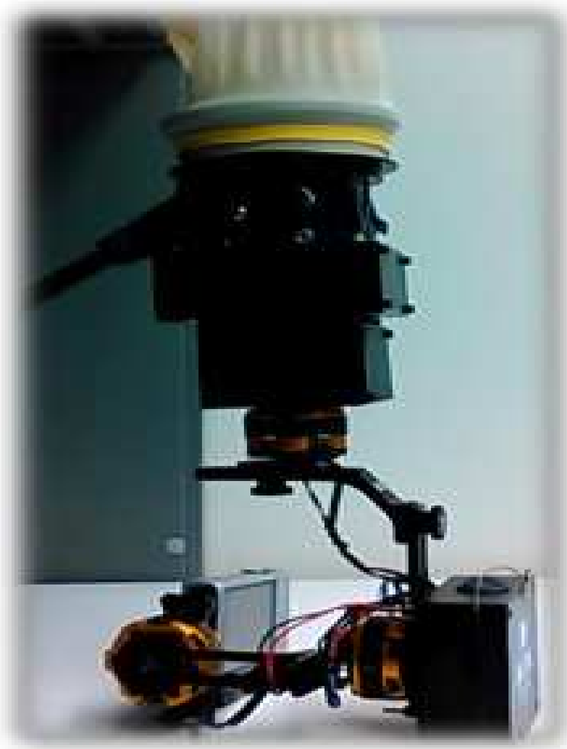
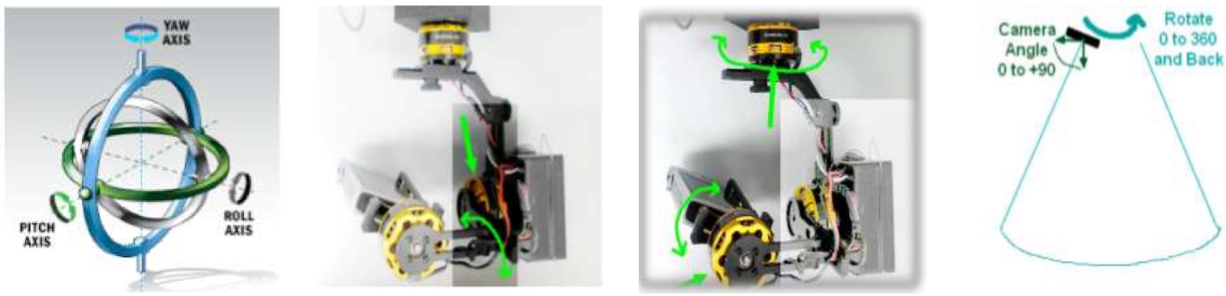


Figure 4: ALTA Cardinal Unit

4.1.1 Gimbal System

The gimbal system provides rotation capability along x, y, and z axis which are called roll, pitch and yaw respectively. It also assures that camera unit will remain stable despite of the turbulence that the balloon section may be experiencing. This gimbal system consists of three motors, IMU and on-board computer system of ALTA cardinal unit. The central motor of this gimbal system controls the horizontal or roll (x-axis) rotation. It remains same from the beginning. The top motor of this gimbal controls yaw (z-axis) rotation from 0° to 360°. The last motor that controls the rotation of the camera along y-axis (up or down from 0° to 90°) which is pitch. The IMU of the ALTA cardinal unit makes the gimbal system active and on-board computer system processes the transmitted actions. This gimbal system of the unit helps to take oblique images of any region of interest which is shown in Figure 5.



(a) (b) (c) (d)

Figure 5: ALTA gimbal system

4.1.2 Image Sensor

Canon Powershot ELPH 340 HS Silver camera has been used as image sensor in this ALTA cardinal unit which has 16.0 megapixel high sensitivity of CMOS sensor and built-in Wi-Fi. This camera is capable of capturing 16:9 large images (size 4608 $\times$ 2592) with a zoom of up to 12X. Images are stored on an SD card inside the camera. This camera unit includes a 32GB SD card and its own battery. The camera is fixed to the cardinal unit with one screw which can be removed to detach it from the unit. Camera and its attachment with the cardinal unit are shown in Figure 6.

(a) (b) (c)

Figure 6: ALTA Image Sensor

4.1.3 Smart Balloon

The two balloons (inner and outer) are to be filled with a lift gas which is lighter than air e.g. Hydrogen or Helium. These smart balloons provide buoyancy and upward traction. They also provide safety as if the outer balloon pops, the inner balloon has enough lift gas to keep the unit in the sky. The ALTA cardinal unit can stay in the air for hours using these balloons. The inner balloon has a tube attached at the bottom. The inner balloon fits inside the outer balloon and is attached to the inside hole of the top of plenum. The outer balloon is fixed around plenum of the cardinal unit. The front of the plenum has two openings or “filling valves”. The right valve fills the inner balloon and the left valve fills the outer balloon. Two balloons how they are attached with each other and how they are fixed with the cardinal unit and their filling valves are shown in Figure 7. If the outer balloon is perforated, the inner balloon retains enough lift gas for safe recovery of the unit.

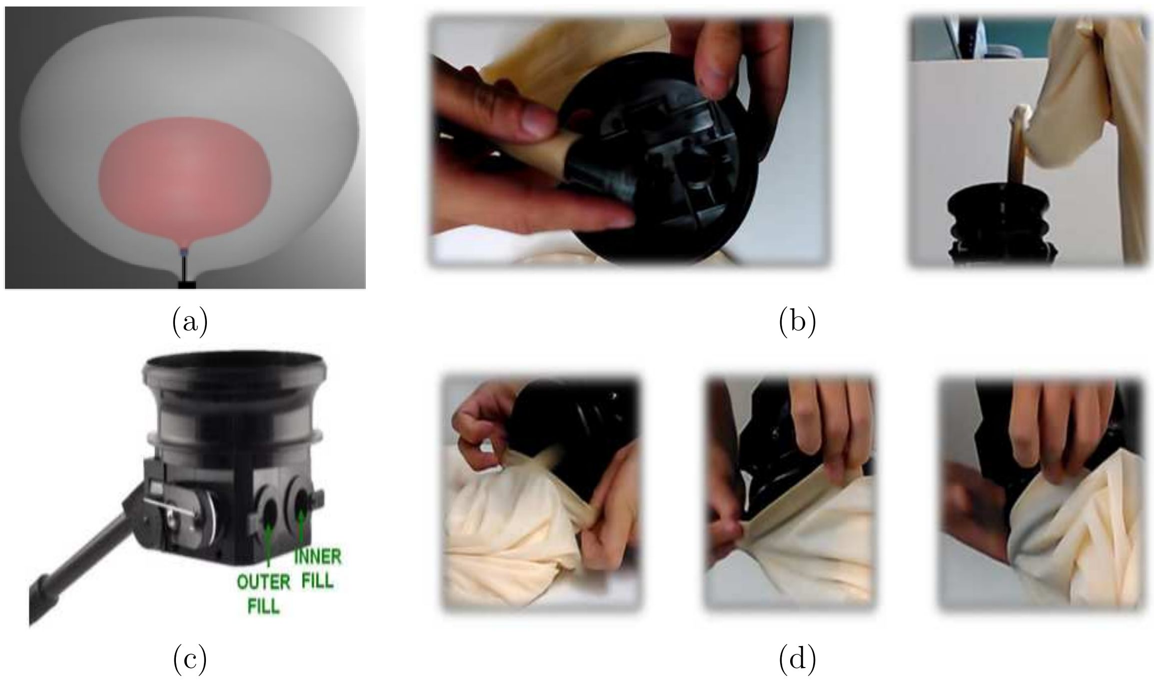
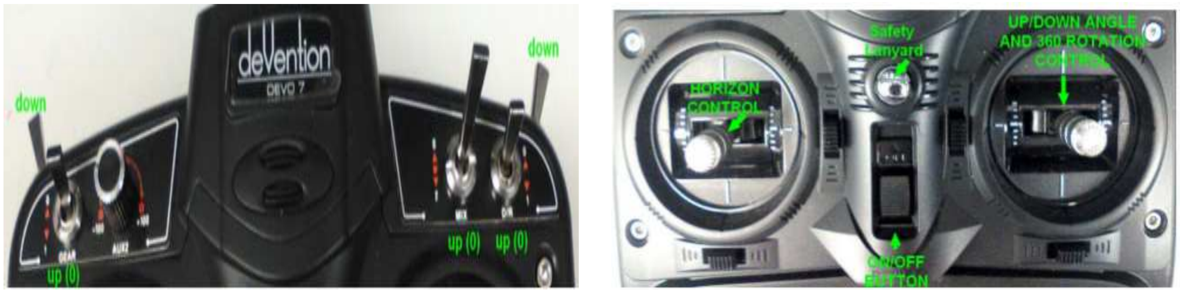


Figure 7: ALTA Smart Balloon

4.2 Radio Control Transmitter

The ALTA cardinal unit is controlled by a radio control transmitter called “remote” and this unit receives signal of this transmitter via on-board signal receiver. This remote has variety of features that are not enabled on this cardinal unit control. The remote control transmitter is in the remote and receiver is in the ALTA cardinal unit. To control this cardinal unit, the power button and two sticks are used. The levers and buttons at the top must be in the forward position or in the zero position to prevent errors. The power button switches on the remote. It’s located immediately below the ring to which the safety lanyard is attached. The remote is powered by a customized yellow Lipo battery (11.1A). The left stick of the remote is horizontal control and it controls the central motor. It’s set up at the beginning of the operation and is not used during the flight. The right stick controls the 360° rotation of the cardinal unit using left/right movement of the stick and the +/− 90° rotation of the camera using up/down movement of the stick. The camera should be rotated between 0° and 90°. To rotate the camera more than that, the cardinal unit should be rotated by yaw rotation from 0° to 360°. The radio control transmitter buttons, sticks and parts that are used for ALTA platform mission operation are demonstrated in Figure 8.



(a) (b)

Figure 8: ALTA Radio Control Transmitter

4.3 Remote Image Sensor Connection Application

Operation of the camera unit is carried out via Wi-Fi through an mobile application called Canon Camera Connect which can be installed on a smartphone or tablet, either Android or Apple. The optimal range of operation over Wi-Fi is limited to approximately 150 feet (45 meters). With the Wi-Fi access point of the camera, this mobile application connects the camera to the mobile device. This application shots online images from the top remotely and sends them to the ground. The application provides the image capturing option from the online video streaming of the aerial images during ALTA mission flight. It also logs the location information of the smartphone or tablet operator through device's GPS and sends the location information of captured images. The ALTA platform camera connection application operations are demonstrated in Figure 9.

4.4 Tether Reel

Tether reel is tether collection to provide tether as required guiding the ALTA platform to its mission altitude. It has a safety clip at the bottom of the reel. The reel is secured to the mission operator's stable position like belt. The ALTA cardinal unit is attached to the reel by fixing the tether clip to the unit skeg. The mission operator controls the mission altitude through his tether reel. The tether reel and its connections are depicted in Figure 10.

4.5 Ancillary Accessories

This system also consists of lift gas (Hydrogen or Helium) regulator. One side of the regulator is attached to the inner or outer filling valve of the unit and other side of it is attached to gas tank tightly to fill the gas inside the balloons. The system also includes leather gloves to operate the tether reel. These gloves allow the mission operator to slow down the fast spinning of reel and help avoid cuts while working with tether. There is also a safety vest

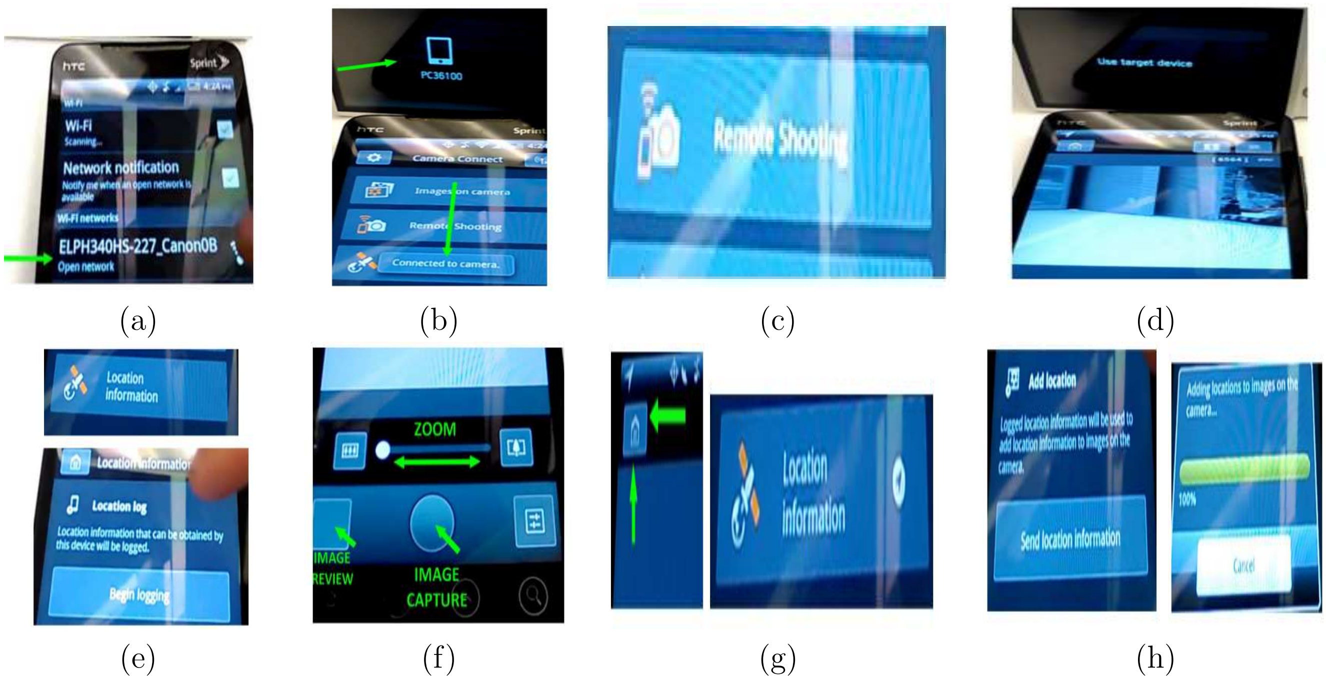


Figure 9: ALTA Camera Connection Application Operation

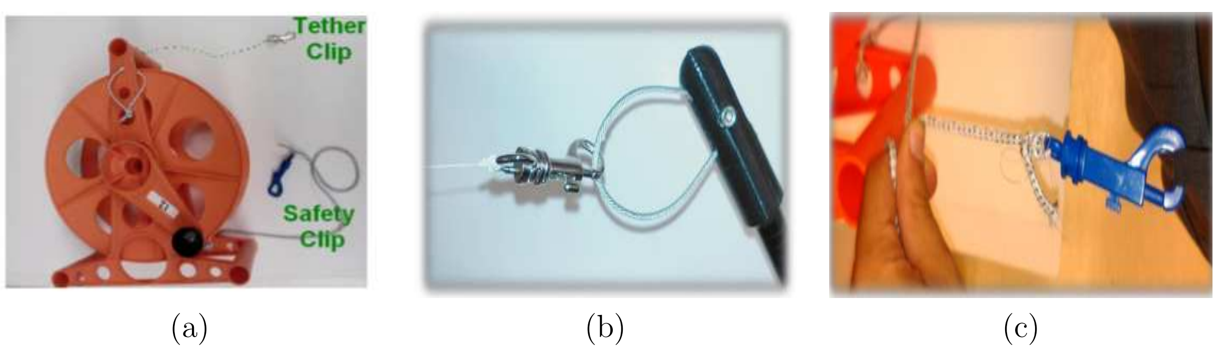


Figure 10: ALTA Tether Reel

available to make the mission operator visible when he is working in the middle of somewhere. Remaining ancillary parts for mission operation of ALTA platform are shown in Figure 11.

5 ALTA Mission Modes and Platform Comparison

5.1 ALTA Mission Modes

There are several modes of operation of ALTA platform that are determined by the mission operator prior to launch:

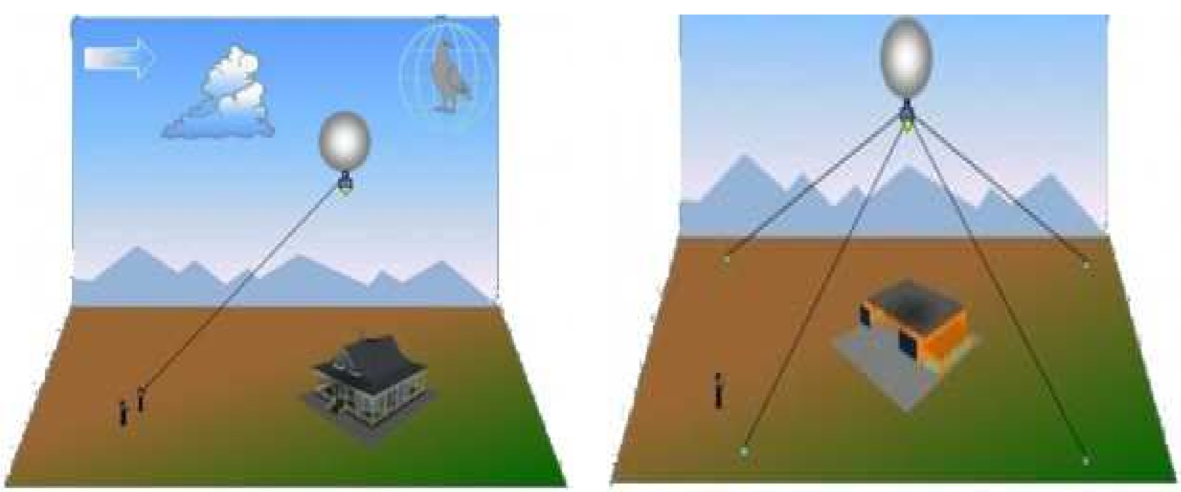
- **"Path Mode":** The balloon is released, ascending to the programmed altitude, then

(a) (b)

Figure 11: ALTA Ancillary Accessories

drifting with the wind currents before descending back to the ground.

- **"Patch Mode – single tether":** The balloon ascends to altitude, and its position is downwind based on the strength of the wind acting on both the balloon and tether. Launching and retrieval of balloon are accomplished manually by a single tether.
- **"Patch Mode – multiple tethers":** Very precisely controls the location of the balloon over a limited area. This is very similar to the overhead cameras used in televised football games but in reverse, since the balloon wants to fly up. Launching and retrieval of balloon are accomplished manually by a multiple tethers.



(a) Patch Mode with single tether (b) Patch Mode with multiple tethers

Figure 12: ALTA Mission Modes

This platform can also be equipped with a parachute for emergency landings, a solar trickle charger for extended missions, and even a quadcopter that can steer the balloon to specific target areas. The lift capability of the balloon permits significantly longer duration flights than a quadcopter alone. The two common modes of ALTA platform have been demonstrated in Figure 12.

5.2 ALTA Platform Comparison

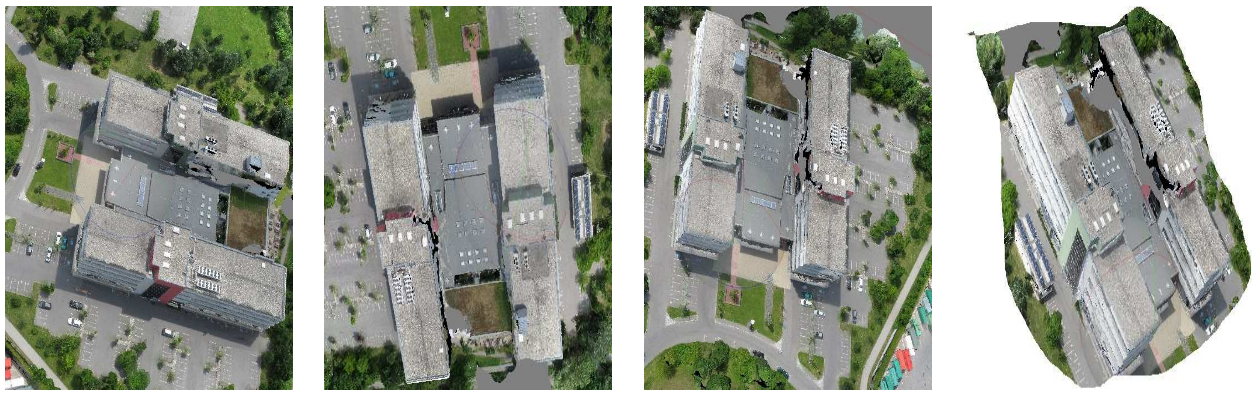
The previous R-series ALTA platform provided only one degree of freedom in its gimbal system (mainly $0°$ to $360°$ rotation) and two manually set angles ($45°$ and $60°$ respectively). Image metadata collected from computer on-board system were embedded in the imagery and includes details such as angle, position, and heading of the camera of the unit, IMU data of gimbal, unit location through on-board GPS, altitude, etc. However, R-series ALTA platform provided lower-resolution imagery and less dynamic imagery collection.

Present G-series ALTA platform is the one we have used here in Austria. The unit does not incorporate the same kind of metadata as the R-series ALTA platform did. This platform focuses on (a) highly dynamic imagery collection through 3-axis gimbal system which provides 3 degree of freedom in the unit, (b) long-term airborne state. The camera of this new series ALTA platform has two great features: (i) Wi-Fi control of camera with zoom, trigger and with preview on smartphone or tablet, (ii) 16 Megapixel and 12X zoom. In addition, the GPS coordinates of the controlling smartphone or tablet are automatically written into the metadata. So, geolocation of the images is based on the controlling phone or tablet. The on-board computer system is not present in new G-series ALTA platform. The gimbal or IMU is completely independent of the camera, and no IMU can be written into metadata of the imagery. So, there is no information about unit orientation, camera heading, and location information (based on the unit) on the metadata of collected imagery [2].

6 Experimental Results

6.1 First ALTA Mission Result

We have completed first mission of our ALTA platform at Carinthia University of Applied Sciences (CUAS), Villach, Carinthia, Austria on June 4, 2015. We were two mission operators to control tether and capture images. We have followed a mission path to complete the mission around CUAS campus and capture images. And we have captured around 450 vertical aerial images of the CUAS campus from the ALTA platform remotely connecting the camera of the platform to the Camera Connect application on IPhone 6.0 from the ground through Wi-Fi. The mission starts at about 12:30 pm and ends at around 2:00 pm. The temperature was $24°C – 28°C$ and the wind speed was 1 – 3 km/h. The flight was stable and steady because of low wind on the mission day. The flight height of the mission was about 40 m. We have used Helium as lift gas for the balloon of ALTA platform. We have sent location information to captured images on the camera from the mobile application which allows us to use the mobile device's own GPS for the stored images. In the connected application, we have kept logging the location information of dynamic and continuous aerial images from the platform. Thus we have collected the geo-referenced (based on mobile device) images on the camera of the platform. The image format of the captured images is large image format that has the dimension of 4608×3456. The image quality of captured images is "fine" which encompasses 6883 images that fill 32GB SD card of the camera. The focal length of the platform camera ranges from 4.5 mm to 54 mm. The camera mode is ISO Auto 100-3200 and the shooting range is infinity.



(a) (b) (c) (d)

Figure 13: 3D Model of CUAS Campus Building, Villach, Austria

Since we have collected vertical images of CUAS campus on first mission day, so we have chosen around 200 vertical images of CUAS Campus Building, Villach, Austria for post-processing of collected aerial images. To reconstruct 3D model of CUAS Campus Building, Villach, Austria we process these 200 selected vertical images using commercial "Agisoft Photoscan Professional" software. As part of processing these images in Photoscan software, the application aligns all 200 loaded vertical images to find the camera positions of images and their height and creates a sparse cloud with 24,000 points. In this alignment step, we have chosen "High" accuracy and "Generic" pair preselection for faster processing of these images. Afterwards, the application builds dense point cloud of 2,400,322 points based on the estimated camera positions and the program calculates depth information for each camera to be combined into a single dense point cloud. We have chosen the quality and depth filtering as "medium" (good for large set of images) and "Aggressive" (limits points that are too far from the surface) in this dense cloud building step. After dense point cloud has been reconstructed it is possible to generate polygonal mesh model based on the dense cloud data in building mesh step of 3D model reconstruction. We have chosen "Arbitrary" as surface type (best for complex mesh surface), dense point cloud, "Medium" as polygon count (maximum number of faces in the resulting model and good for large point cloud) and interpolation enabled to interpolate over small holes in the surface of the resulting model. In building texture to the resulting surface model from dense cloud, we have chosen "Generic" as mapping mode to create as uniform texture as possible, "mosaic" as blending mode to create a mosaic from the input images. Finally, we reconstruct 3D model of CUAS Campus Building that can be exported for further visualization. The resulting sparse and dense point cloud of the 3D model consist of 18,024 points and 15,904,625 points respectively. The resulting surface model of the reconstruction has 1,066,015 faces. The different perspective views of reconstructed 3D model of CUAS Campus Building, Villach, Austria are shown in

Figure 13.

We have used open-source Visual-SFM (Structure from Motion) application to create 3D map reconstruction of the CUAS Campus, Villach, Austria. We have loaded all captured vertical images of CUAS campus from our first mission, run feature detection and full pairwise image matching in the application. Finally, we have created sparse and dense reconstruction from paired and matched images. The 3D reconstruction view of the CUAS campus from Visual-SFM is depicted in Figure 14. The no. of points in dense reconstruction of this model is 51,102. However, the result from this open-source application is not satisfactory.

Figure 14: 3D Reconstruction of CUAS Campus, Villach, Austria from Visual-SFM

6.2 Second ALTA Mission Result

Our second mission of ALTA platform is taken place at Intel Mobile Communications Building, Villach, Austria near CUAS Campus, Austria on July 5, 2015. Again we have used same lift gas, camera as image sensor, image parameters, and image capturing technique as first mission. However, we have used android smartphone for second mission to take geo-referenced images. Also we were two mission operators to control tether, gimbal system and capture images. This time we have captured oblique images of the aforementioned building from different perspectives and altitudes using the gimbal system and tether control of ALTA platform respectively. We have aligned the horizontal surface of the gimbal system from the beginning of the flight. Then we have controlled the rotation of camera from 0° to 90° or we have moved the camera up or down as it's required during the flight. Also we have controlled the rotation of the unit from 0° to 360° around the ALTA platform during the flight. We did the gimbal system control on the ground during the flight with the help of radio control transmitter or remote. Thus we have captured around 500 oblique aerial images of the Intel Mobile Communications Building from the ALTA platform remotely connecting the camera of the platform to the Camera Connect application on Android from the ground through Wi-Fi. The mission starts at about 10:00 am and ends at around 12:00 pm. The temperature was 25°C – 33°C and the wind speed was 3 – 6 km/h. The flight was little bit unstable because of windy weather on the mission day.

(a) (b) (c) (d)

Figure 15: 3D Model of Intel Mobile Communications Building, Villach, Austria

The oblique aerial images of Intel Mobile Communications Building are loaded into the workflow environment under the project of Photoscan software. As a part of workflow of 3D model reconstruction of Intel Mobile Communications Building, images need to be aligned. At this step, Photoscan finds the camera position for each image and builds a point cloud model. After alignment having been completed, computed camera positions of images of stated building and a sparse point cloud are displayed. The following step is the actual computation of the dense point cloud based on the previous image alignment and sparse point cloud. This computation retrieves the actual 3D representation of the area covered by the aerial images. The resulting sparse and dense point cloud consist of 15,180 points and 27,587,747 spatial points respectively. The resulting surface model has 443,385 faces. The next step in this workflow is the computation of the mesh, which generates a surface among the points based on dense point cloud. The result is a generic surface model of the images captured by the camera. The last of the workflow is the adding texture to the reconstructed surface model. Thus, the reconstruction of 3D model from the aerial images along with a generic textured model is accomplished. We have chosen same parameter values for each step of this 3D model reconstruction as before. The different perspective views of reconstructed 3D model of Intel Mobile Communications Building, Villach, Austria are shown in Figure 15.

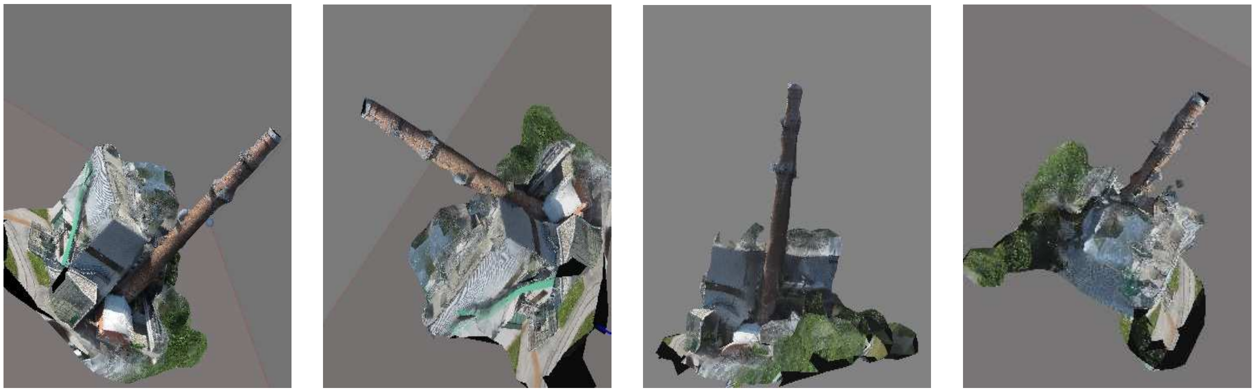
Also we have used open-source Visual-SFM application to create 3D map reconstruction of Intel Mobile Communications Building, Villach, Austria. We have utilized same set of captured vertical and oblique images of Intel Mobile Communications Building from our second mission like we used in Photoscan software and followed feature detection, pairwise image matching, sparse and dense reconstruction same as previous 3D building reconstruction and got the 3D model of Intel Mobile Communications Building. The 3D reconstruction view of the Intel Mobile Communications Building from Visual-SFM is illustrated in Figure 16. The no. of points in dense reconstruction of this model is 1,38,760. Here again, the result from this open-source application is not impressive.

Figure 16: 3D Reconstruction of Intel Mobile Communications Building from Visual-SFM

6.3 Third ALTA Mission Result

Our third mission of ALTA platform is arranged on July 18, 2015. As before, we have used same lift gas, camera as image sensor, image parameters, gimbal system and image capturing technique and completed the mission with two mission operators. The mission starts at about 9:00 am and ends at around 11:00 am. The temperature was 28°C – 33°C and the wind speed was 6 – 8 km/h. The flight was unstable because of windy weather on the mission day. We have captured around 300 aerial and oblique images of a chimney in front of the CUAS campus, Villach, Carinthia, Austria. We followed the mission path around the chimney. We have taken images of aforesaid chimney from different angles and altitudes using the gimbal system of ALTA platform remotely connecting the camera of the platform to the Camera Connect application on IPhone 6.0 from the ground through Wi-Fi. We have maintained low-altitude mission flight than the height of the chimney and taken oblique upward images when it's been required to cover the whole chimney.

We have filtered 204 oblique aerial images of the chimney. Then we have used Photoscan software to process those images of chimney with a view to reconstruct 3D model of chimney from 2D aerial images. We have followed all the steps of workflow of 3D model reconstruction in Photoscan software and chosen parameters at each step as before. Finally, we have got the 3D model of chimney reconstructed from post-processing of selected 204 oblique images of the chimney. The sparse cloud of the result model creates 23,826 points and dense cloud of this model creates 1,05,677 points and the surface model of this 3D chimney model has 1,432 faces. The different perspective views of reconstructed 3D model of Chimney are shown in Figure 17.



(a) (b) (c) (d)

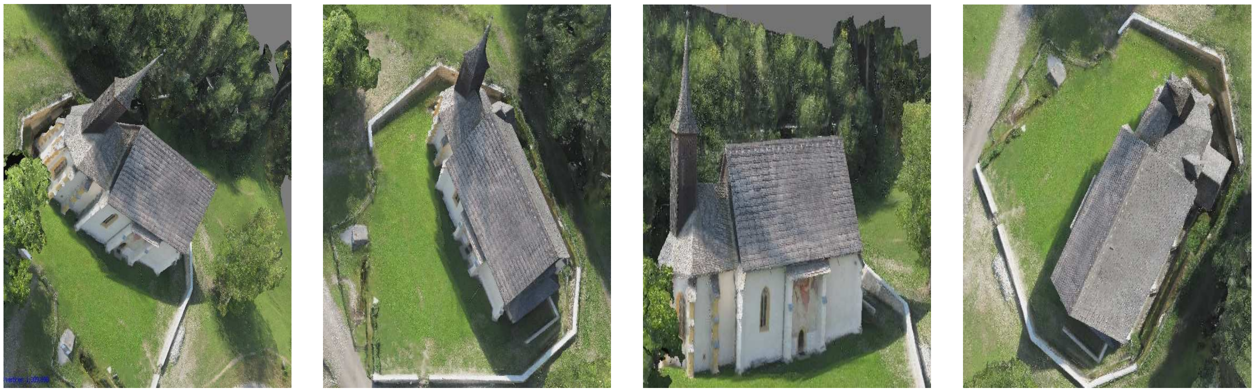
Figure 17: 3D Model of Chimney

Again we have used open-source application Visual-SFM to reconstruct 3D model of chimney using same set of oblique images of the chimney. We have followed the steps of feature detection, pairwise image matching, sparse and dense 3D reconstruction in the application as before and got the 3D reconstruction of chimney. The result reconstruction view is shown in Figure 18. The no. of points in dense reconstruction of this model is 8,760. It does not give good 3D reconstruction of chimney from the selected set of images either like the previous cases of 3D building reconstruction using Visual-SFM.

Figure 18: 3D Reconstruction of Chimney from Visual-SFM

6.4 Fourth ALTA Mission Result

Our third mission of ALTA platform is accomplished on August 7, 2015. Likewise, we have used same lift gas, camera as image sensor, image parameters, gimbal system and image capturing technique and completed the mission with two mission operators. The mission starts at about 9:30 am and ends at around 11:00 am. The temperature was 24°C – 28°C and the wind speed was 2 – 4 km/h. The flight was stable because of less windy weather on the mission day. We have captured around 430 aerial and oblique images of a small and old church in Villach, Carinthia, Austria. We followed the mission path around the old church. We have taken images of aforesaid old and small church from different angles and altitudes using the gimbal system of ALTA platform remotely connecting the camera of the platform to the Camera Connect application on IPhone. We have maintained higher low-altitude mission flight height than the height of the old church and taken oblique images when it's been required to cover the whole old church building.



(a) (b) (c) (d)

Figure 19: 3D Model of Old Church, Villach, Austria

We have filtered 340 oblique aerial images of the old church. Then we have used Photoscan software to process those images of old church with a view to reconstruct 3D model of old church from 2D aerial images. We have followed all the steps of workflow of 3D model reconstruction in Photoscan software and chosen parameters at each step as before. Finally, we have got the 3D model of old church reconstructed from post-processing of selected 340 oblique images of the old church. The sparse cloud of the result model creates 29,163 points and dense cloud of this model creates 13,668,513 points and the surface model of this 3D old church model has 2,747,975 faces as we have used high face count from dense point cloud. The different perspective views of reconstructed 3D model of old church are shown in Figure 19.

Also we have used open-source application Visual-SFM to reconstruct 3D model of old church using same set of oblique images of the old church. We have followed the steps of feature detection, pairwise image matching, sparse and dense 3D reconstruction in the application as before and got the 3D reconstruction of old church. The result reconstruction view is shown in Figure 20. The no. of points in dense reconstruction of this model is 11,229. It also does not give good 3D reconstruction of old church from the selected set of images like the previous cases of 3D building or architecture reconstruction using Visual-SFM.

Figure 20: 3D Reconstruction of Old Church from Visual-SFM

7 Discussion

From the ALTA mission flights and their results, we can say that ALTA platform is suitable for mapping low-altitude objects like building, architecture or any landscape. This is low-cost alternative to usual aerial imagery platform like UAV or any aircraft. This platform flies low-altitude than the UAV or other aircraft. So, it collects high-resolution images from low-altitude compared to those of UAV or any aircraft with same camera.

UAV or any aircraft collects vertical aerial images only. However, this ALTA platform helps the mission operator take oblique aerial imagery as well as vertical aerial imagery. From the first two missions of ALTA platform, we have seen that vertical aerial images do not cover every parts of a building or any landscape. On the other hand, oblique aerial images do cover every parts of a building or any landscape. Here in the first mission of ALTA platform, only vertical aerial images were collected and in the second mission of ATLA platform, vertical and oblique images were collected from lower altitude than the first mission. From the result of first mission in Figure 13, we have observed low-resolution and low-quality 3D model of CUAS campus building and this model has some unmapped regions and holes. On the other hand, from the result of second mission in Figure 15, we have observed high-resolution and high-quality 3D model of Intel Mobile Communications building in Villach, Austria and this model has minimal number of holes and unmapped regions even though this building is a bit bigger and complex to map compared to the building of first mission. From the result of Photoscan software, we have come to conclusion that the more we use overlapped images of building or architecture, the more 3D model of that building or architecture gets clear and impressive.

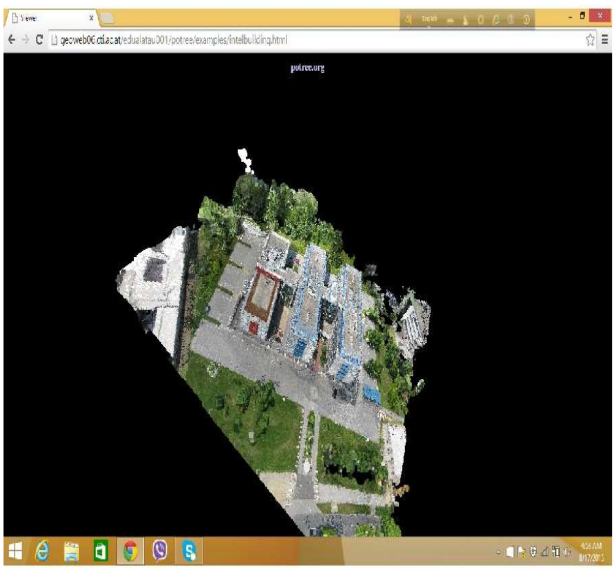
The results of 3D model reconstruction of building or architecture show the usability of ALTA platform. The commercial Photoscan software provides clear and almost hole free 3D models from same set of oblique images and vertical images of a same building or architecture compared to the open-source Visual-SFM application. From the results of Figure 13, 15, 17 using Photoscan software and the results of Figure 14, 16, 18 using Visual-SFM, we can see the clear distinction between two photogrammetric solutions in terms of resolution, no. of holes availability, no. of points in corresponding 3D point clouds. The comparison result of two photogrammatic solutions in terms of no. of points in the dense point cloud of reconstructed 3D models of building or any architecture using same set of images of that building or architecture in two photogrammetric solutions i.e. commercial Photoscan software and open-source Visual-SFM application is tabulated in the Table 1.

Name	No. of Points in 3D Point Cloud Using Photoscan	No. of Points in 3D Point Cloud Using Visual-SFM
CUAS Campus Building	2,400,322	11,102
Intel Mobile Communications Building	27,587,747	1,38,760
Chimney	1,05,677	8,760
Old Church	2,747,975	11,229

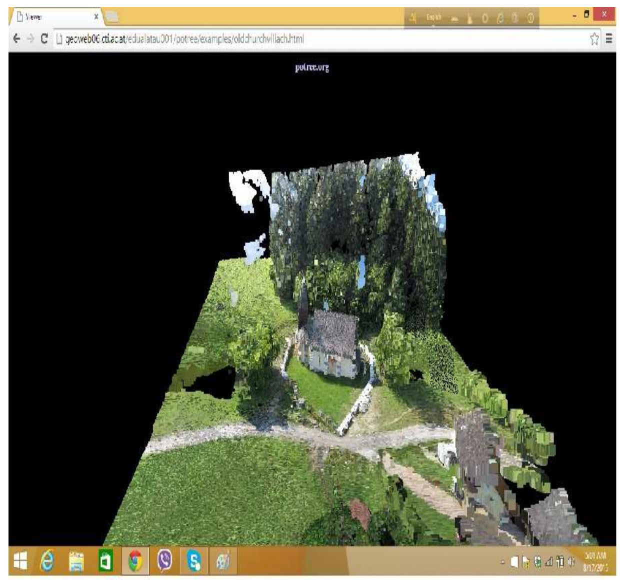
Table 1: Comparison of no. of points in 3D dense point cloud of different buildings and architectures using commercial Photoscan and open-source Visual-SFM software

It takes 2-3 days to process aerial images in reconstructing 3D model of any building or architecture for around 300-400 aerial images in the system we used for processing. The system processor is Intel(R) Core i5-2400 CPU at 3.10GHz and physical memory is 8.00 GB and 64-bit Windows operating system. The strong workstation can facilitate the faster processing of images in building 3D model of building or architecture and encourage to take more overlapped images with a view to reconstruct more fine 3D model with more points in 3D dense point cloud of the model.

These reconstructed models of building or architecture especially from commercial "Photoscan" are used for online visualization. We have employed potree web-based visualization exporting point clouds of building or architecture from the Photoscan software. The web-based visualization 3D point clouds of Intel Mobile Communications Building and Old Church at Villach, Austria are demonstrated in Figure 21.



(a)Intel Mobile Communications Building



(b) Old Church

Figure 21: Web-Based 3D model Visualization

As we have stated before that ALTA is low-cost Lighter Than Air (LTA) balloon-borne low-altitude aerial photographic platform, so we have tabulated the cost of some UAV platform and our ALTA platform cost [3] approximately in the Table 2. It shows that our ALTA platform is really affordable and cost-effective platform for low-altitude aerial photography.

Name	Type	Cost
QuestUAV Q-Pod	UAV	€6,700
Trimble UX5	UAV	€10,930
ALTA	LTA or Balloon	€700 (approx.)

Table 2: Cost comparison of some UAV and ALTA platform

8 Conclusion and Future Work

ALTA platform is a smart balloon-borne aerial photographic platform. This ALTA platform is a low-cost and low-altitude oblique aerial imagery capture system compared to UAV or any aircraft. The most striking feature of this ALTA platform is the availability of gimbal system in its cardinal unit which provides 3 degree of freedom. It allows the operator to capture images of area of interest or event of interest from different perspectives at the same position. Taking the advantage of the gimbal system of this ALTA platform, we have reconstructed 3D models of different buildings and architectures of Villach, Austria. This gimbal system has facilitated to take oblique images of buildings or architectures. Also this platform allows the mission operator to observe online remote aerial video streaming from the unit and capture necessary and required aerial images. This video streaming helps mission operator change the orientation of the camera and unit to focus on area or event of interest. This is how this ALTA platform is advantageous over any UAV or aircraft.

The assessment of this ALTA platform can be concluded stating that this platform is applicable for numerous applications as mentioned before. Its application of reconstructing 3D models of building or any architecture in our empirical work is a new utilization of ALTA platform. Our experimental results demonstrate its effectiveness for reconstructing 3D models of building or any architecture with this low-cost platform. These 3D models are also visualized in potree web-based 3D model visualization which can be deep-linked to any mapping site. The cost comparison between UAV and ALTA platform will also encourage photogrammetric users or researchers to use this low-cost platform for low-altitude aerial photography.

The limitation of this new-series ALTA platform is that it doesn't geo-reference captured images based on the ALTA cardinal unit instead it geo-references captured images based on the location of mission operator who is operating the smartphone or tablet since it uses the GPS of smartphone or tablet. So, the geo-referencing of captured images is not quite accurate for aerial images of this platform. To address this problem, either we can attach a separate GPS in the ALTA cardinal unit and synchronize the location of the unit with captured images based on the time of taking those captured images and time of the GPS location traces or we can use GPS-enabled digital camera as image sensor in ALTA platform.

Though ALTA platform offers online video streaming and allows the capability to capture images remotely but it doesn't provide automatic video recording remotely of an event of interest instead it allows manual video recording of camera which can not be shown on remote application of this platform.

The Wi-Fi connection of the camera in this ALTA platform gets switches off and disconnected to the mobile device frequently in an area where a strong Wi-Fi connection is available as it causes interference to the Wi-Fi of the camera. Every time prior to the mission, the mission operator needs to forget this Wi-Fi except the camera one or else take images in an area where no strong Wi-Fi connection is available.

Our future direction of the research work is to overcome the limitations of new ALTA platform and make it more practical and professional aerial imagery capture system. We have plan to embed these reconstructed 3D models in a commercial and professional mapping site based on their locations.

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