

Commercial Devices for a Quick and Non-Invasive 3D Survey and Geometrical Monitoring of Buildings

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SUMMARY

Modern technologies and approaches changed the way we document the real world, leading to an increasing demand for 3D data. The fields of application range from land, water, and resource management, building maintenance, to interior, mechanical and civil design. In this work we will mainly focus on modern strategies available for the surveying and monitoring of buildings. Laser scanning technology and UAV/terrestrial photogrammetry are well suited for a range of applications and largely used to acquire 3D datasets. Recent technological advances in 3D sensors and their deployment in common mobile devices, have opened the way to low-cost methodologies for 3D reconstruction, suitable for non-expert users and useful in multiple applications. The LiDAR sensors, implemented in the latest generation iPhone and iPad, allows to calibrate the data acquired by these devices and make it usable for 3D reconstruction processes. In this paper the workflows proposed by the CANVAS (<https://canvas.io/>) and PIX4D Catch (<https://www.pix4d.com/product/pix4dcatch>) applications will be assessed. The functioning of proposed methodologies will be briefly described, and the obtained products will be presented. Also, the relevance of proposed methodologies will be discussed in specific fields.

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1. INTRODUCTION

Laser scanning technology and UAV/terrestrial photogrammetric surveys are largely used to acquire 3D datasets to record and document buildings conditions and can provide data for further design activities or maintenance planning (Alshawabkeh et al., 2020; Farahani et al., 2020; Boché et al., 2015; Santoso et al., 2015). These methods guarantee excellent performance in terms of accuracy and resolution of the result, when a remote and non-destructive investigation is required (Castagnetti et al., 2016), and offers many advantages over approaches traditionally employed for the geometrical monitoring of building such as contact sensors (e.g., crack meters, piezometers, etc.) and pointwise surveying techniques (e.g., total stations, GNSS). They can be cost and time ineffective if the monitoring of multiple small scale and localized damage phenomena is required (e.g., rooms, small excavations). Generation of 3D datasets in the form of point clouds and meshes is a critical requirement for numerous projects aiming at assessing and monitoring structural health conditions (Torok et al, 2014; Galantucci and Fatiguso, 2019).

The potential of laser scanning systems in three-dimensional reconstruction is widely recognized and they have become the main solution for surveying buildings and construction sites (Mukupa et al., 2017). There are different models available on the market depending on the range, accuracy and resolution required; the laser scanner can work in static or dynamic configuration. Laser scanner systems can be carried by hand, mounted on tripods, trolleys, cars or drones. These numerous solutions make laser scanning a suitable methodology for multiple applications and fields of use (Kaartinen et al., 2008; Lindenbergh and Pietrzyk, 2015). However, specific software and trained operators are required in the processing of the acquired data and the design of the survey.

Image-based modelling techniques such as Structure from Motion and Multi View Stereo (SfM-MVS) has acquired a growing interest in the last decade due to the growing number of research works highlighting the quality of the generated outputs and the multiple potential applications (Eltner and Sofia, 2020). Main advantages of a SfM-MVS approach include area-based measurement, generation of both, geometry and texture coloured of the observed surface, flexible scale and logically and cost-effective equipment. The main limitation of photogrammetric approaches when compared to active sensors are the unfeasibility to work with insufficient light, the need of ground measurements, the planning of specific acquisition patterns and the high images redundancy required.

In order to generate a 3D model, the typical photogrammetric workflow is composed of a series of steps which can be summarized in four main phases including image acquisition, camera calibration, pre-processing of images (optional) and processing of images in dedicated

commercial or open-source photogrammetric software (e.g., Metashape, Pix4D, Zephyr, PhotoModeler, MicMac, etc.). There are many factors that may influence the quality of a 3D reconstruction including camera system selection, calibration, network configuration, acquisition procedure and survey scale, software used and external factors (e.g., site characteristics, weather, and light conditions, etc.) (Niederheiser et al., 2016; Mosbrucker et al. 2017; Parente et al., 2019; Parente et al., 2020). Despite its apparent simplicity, image acquisition is the first critical steps to which the quality of the final outputs depends on. Guidelines and strategical protocols have been described in past literature (Hiremagalur et al., 2007; Mosbruck et al., 2017) to achieve optimal acquisition geometry and coverage which can be quite misleading for unexperienced operators. Recent technological developments in consumer-grade devices (such as iPhones and iPads) and their LiDAR sensors, allow to ease the generation of 3D products. This paper is a first attempt to critically describes these technologies, highlighting advantages and limitations and comparing them with more-established techniques used for 3D survey of buildings. Two dedicated mobile apps, able to provide quality 3D products and a proper image pattern for photogrammetric reconstructions, will be discussed.

2. MOBILE DEVICES AND APPS

2.1.LIDAR sensor

LiDAR scanners measure the distance from the sensor and surrounding objects and works at both, day and night. It is therefore a time-of-flight technology that fires low-power lasers into an environment. Using reflections, the system calculates the distance from objects and points in the environment and creates a 3D depth map.

The use of LiDAR technology in mobile Apple devices is a bit different when compared to traditional laser scanning instrumentations. The basic principle is the same: bouncing light to determine distance but applied on a smaller scale. The LiDAR scanner in the iPhone 12 Pro and iPad Pro has an effective range of around 5 meters. The miniaturized LiDAR scanner uses a direct time of flight to measure reflected light, both indoors and outdoors. It works at the photon level, operates at nanosecond speeds. The depth framework combines the depth measurements performed by LiDAR with data from motion sensors and cameras to increase the accuracy and the overall quality of 3D experience.

The primary purpose of LiDAR in Apple devices is to improve augmented reality (AR) implementation. It will give apps more useful and accurate information about their surroundings, for smoother, more reliable AR. The LiDAR Scanner also improves measure apps, letting users more quickly and accurately measure objects. The on-board LiDAR scanner takes advantage of ARKit 3.5 to allow a better understanding of external environments. ARKit uses the LiDAR Scanner to create a polygonal model of the physical environment. The LiDAR Scanner quickly retrieves depth information from a wide area in front of the user, so ARKit can estimate the shape of the real world without requiring the user to move. ARKit converts the depth information into a series of vertices that connect to form a mesh. The depth points measured by the LiDAR Scanner and data collected using cameras and motion sensors are combined and enhanced by computer vision algorithms on the A12Z

Bionic for a more detailed understanding of a scene. The tight integration of these elements allows having a complete visualization of surrounding in 3D with an overlap of augmented reality data (see Fig.1).

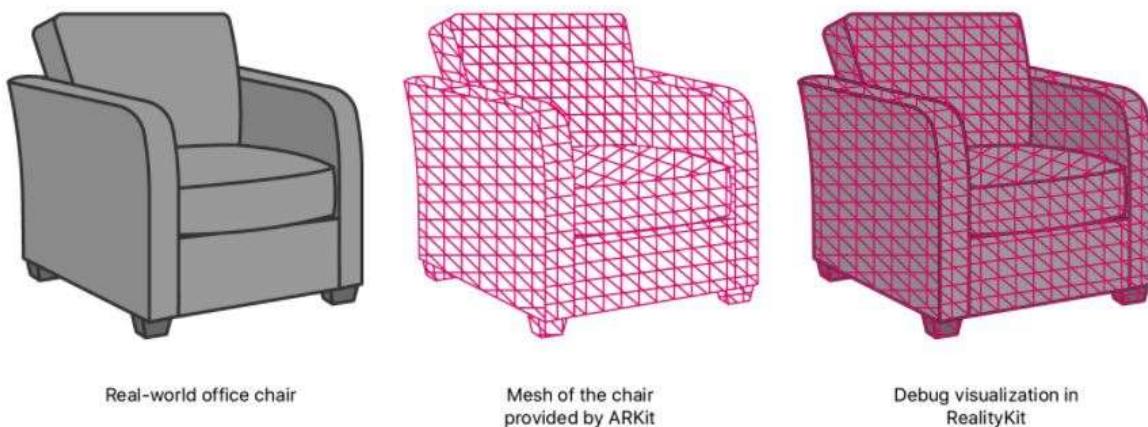


Figure 1. Functioning of LIDAR sensors, ARKit and RealityKit tools. Image credit: Apple

Several 3D apps have been implemented to use this technology and improve the quality of the reconstruction. Some of these, go beyond a recreational use and are addressed to professional users. Canvas by Occipital and Pix4D Catch are two examples described in more details in the next sections.

2.2.Canvas app

Canvas is an app developed by Occipital, the company already known for the Structure Sensor (<https://structure.io/>). Canvas is available for free and allows owners of LIDAR enabled devices to obtain 3D reconstructions. Given the characteristics of the on-board LIDAR, the system is recommended for indoor environments. By framing the walls and moving the system into the rooms of interest (see www.canvas.io for more details about data acquisition) a 3D mesh can be easily obtained.

With Canvas a “digital twin” of a space of interest can be quickly created and used for revisiting, share projects, document, perform measurements and reimagine interiors. Every dimension and measure are detected, so revisiting and mistakes reviewing costs can be avoided. A project with a texture less mesh is automatically stored in the device, the mesh can be exported for free in standard format (such .ply file) for further analyses. Occipital offers reprocessing and CAD creation services (see Fig. 2); these services require a payment of a single fee or annual subscription. The reprocessing of the on-device mesh is performed through more powerful algorithms than those run in real-time. During this step texture is added to the mesh, the space can be better visualized, and the acquisition of measurements become easier. Scan to CAD is a semi-automated service that converts reprocessed meshes into editable CAD files (such as 2D plans, Revit or SketchUp file, ...).



Figure 2. Example of products generated by Canvas app and reprocessing services (Canvas webpage).

Canvas is optimized for residential environments. It can be successfully used also in different spaces (for example commercial, industrial, archaeological, etc), but certain limitation factors may influence the final result including scanning range (max of 5 m), number of scans, presence of highly reflective, transparent, or dark surfaces, and not suitable lighting conditions. In residential environments it is recommended to scan each room separately, scanning through doors may increase errors. Different scans can be merged, if an overlap between them is given, and the scan to CAD service will provide a single CAD file on the entire home.

The accuracy of 3D scanning with mobile devices depends on the user and the environment (enclosed spaces have a minor absolute error than large areas). If a 3D reconstruction is required for construction purposes traditional methodologies should be used, otherwise the need to verify Canvas model with manual measurements is critical. Experiences made by Canvas community show a mean discrepancy of 1-2% between the final CAD and manual measurements. If higher accuracies are required, few manual measurements can be acquired and integrated with the 3D model when generating CAD outputs.

2.3.Pix4D Catch – an acquisition app.

In June 2020, Pix4D (a well-known company providing photogrammetry software technology) released ‘Pix4Dcatch’ a simple and free to use mobile application for quick acquisition of digital imagery for creating photogrammetric reconstructions. The app can be freely downloaded for use on recent compatible iOS and Android devices. However, it is currently optimised for the newest iPad Pro and iPhone 12 Pro and Pro Max with LiDAR sensors. The use of the cited devices allows to provide the user with scene completion feedback through the use of AR. The use of this app offers the opportunity to easily implement terrestrial image acquisition with no expertise required. Also, it allows to potentially operate in a range of different site conditions in a comprehensible and manageable way. Once the app is up and running, the user only needs to walk around the area of interest in a recording video mode. The app can carry out a real-time overlap calculation which allows to automatically extract from the video the exact number of frames needed to achieve a full coverage of the

site. Thanks to the AR, the user can easily recognise on the device's screen the portion of the site that still needs to be acquired or where more pictures are needed (see Fig. 3). Each extracted frame is geotagged (GPS and IMU data from the device are collected during the acquisition) allowing to create a georeferenced 3D model.

For the 3D reconstructions and downloading of outputs, it is critical to own a licence with other products offered by Pix4D such as Pix4Dcloud and Pix4Dmapper which offer to store the captured images and create the 3D models. Alternatively, pictures can even be stored on the storage available on the device and can be later exported and used by a more experienced user for 3D generation in the desktop software.



Figure 3. Pix4D catch during the acquisition of images. The purple area, enclosed in the black line, indicates to the user which portion of the site was already correctly acquired.

3. PRACTICAL TEST

The above-mentioned mobile apps were tested for the 3D reconstruction of an office room of about 100 m² (see Fig. 4). The 3D survey was performed by:

- terrestrial laser scanning (Faro Focus 3D), used as reference data.
- iPAD Pro – Canvas system.
- iPAD Pro – Pix4D Catch system.

In the investigated area, some targets were positioned to register the generated 3D models and allow an evaluation of accuracies.

3.1 Results

Fig. 4 shows the results generated by Faro Focus, Canvas and Pix4D Catch (this last without the processing of acquired images). The 3D mesh automatically provided by Pix4D Catch, is used here (note that the mesh lacks in texture and is only shown as horizontal section).

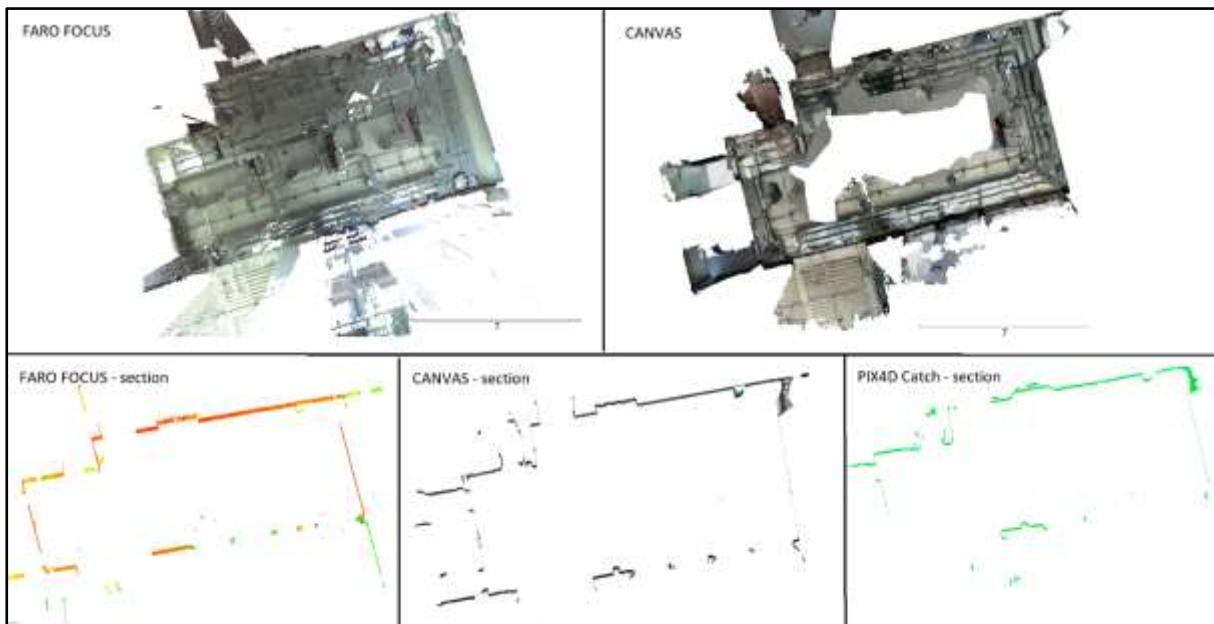


Figure 4. Generated 3D models, units: meters. Top: view of the point cloud generated by Faro Focus; textured mesh generated by Canvas. Bottom: views of horizontal sections (some centimetres of thickness) of 3D models generated by Faro Focus, Canvas and Pix4D Catch

The 3D point cloud generated by Faro Focus has a resolution of 6 mm at 10 m and each point is coloured according to images acquired by the laser scanner. The scanning time was about 7 minutes, and 26100000 points were acquired (about 872 MB).

The reconstruction performed with Canvas App, after the reprocessing is a 3D textured mesh. The acquisition required 5-10 minutes, the operator moved the iPAD within the room (as suggested by Occipital) and a model constituted by 600000 triangles (41 MB) was obtained. The 3D mesh showed in Fig. 4 is the results of the post-processing service provided by Occipital with 3\$ fee. The original Canvas project needs to be shared with the company, and within one working day they send back the reprocessed model. The reprocessing is an automatic procedure that involves all the data acquired by the device (LiDAR data, images, and other sensors) to provide an optimized and texturized 3D mesh. Central portions of floor and ceiling are missing in Canvas result because an acquisition focused on walls and corners is recommended to thin the acquisition and reduce noise.

Pix4D Catch required 10-15 minutes for the survey of investigated room, an amount of about 200 images and 132 MB. The project is constituted by a log file, a GNSS file, a mesh, the automatically acquired images, location and orientation values for each acquired images, confidence and depth maps. In this paper only the automatically generated mesh file is shown, the photogrammetric processing in Pix4D cloud or mapper will be addressed in future activities of the research group.

The 3D products generated by Faro Focus and Canvas were registered to compare obtained results. The registration was performed in Cloud Compare and resulted in an RMS of 0.11 m

with a theoretical overlap of 75%. A view of horizontal sections extracted by Canvas (mesh) and Faro (point cloud) is shown in Figure 5 (with red and grey lines, respectively).



Figure 5. Focus of extracted horizontal sections. Red line: Canvas mesh; grey line: Faro point cloud

4. DISCUSSIONS

All the proposed methodologies allow to obtain a complete 3D model of the investigated room. In this discussion the results obtained with Pix4D Catch are not considered because it is a preliminary mesh as the image processing have not been carried out yet.

The use of mobile devices allows to reduce the occlusions caused by the viewing geometry; some parts of the adjacent rooms have also been rebuilt (see Fig.4).

Extracted sections show that the results obtained with iPAD and Canvas app are less accurate in the definition of sharp geometries than the reference dataset, the edges are smoothed, and the complex geometries are simplified and smoothed (see Fig. 4 and 5). A misalignment of some portions of Canvas mesh is pointed out in Fig. 5, and a 10 centimetres rms error of the registration between Faro point cloud and Canvas mesh was detected. We think that a deeper investigation on detected misalignments is necessary to evaluate whether they are related to differences in the definition of sharp geometries or to local or extensive distortions of the Canvas' 3D model.

The resolutions and quality of the products are very different from the reference. Canvas methodology is well suited for surveying small areas (one room at a time) if geometric details or high accuracy measurements are not required. If more rooms need to be surveyed, more canvas projects need to be created. Also, an overlapping area between projects is necessary for the subsequent merge of the products and it is strongly suggested to provide Occipital services with some manual measurements to “constraint” and adjust the result.

These mobile 3D systems have the potential to address fields of applications different from traditional ones, that require results (both in terms of accuracy, areal extension, and frequency

of use) different from those provided by traditional laser scanning systems. The application of photogrammetric techniques for the reconstruction of indoor environments is not the ideal approach. Even using an application that controls the acquisition, difficulties in framing the exact area of interest were experienced. Also, the need to capture a huge number of images (200 for a single room modestly sized) slows down both, the acquisition step and the following image processing.

5. CONCLUSION

The ease of use of the presented apps and the new chances offered by consumer grade devices are a powerful tool for all levels of users, which enables quick data collection and 3D reconstruction for a range of applications (e.g., building health condition assessment, construction management, indoor crime/fire scene reconstruction, inspection of boiler room or similar facilities, etc.). Furthermore, while on the site, an operator can easily carry out measurements of scanned objects, add annotations and share them with other users which can remotely access the datasets in real-time. The use of these quickly acquired datasets can offer promising solutions for the integration of 3D information derived from different sensors also. Quick and automated data collection can represent a suitable solution even for more expert users to achieve good results in a time efficiency manner. Commercially available photogrammetric software can be costly and difficult to use without proper training. The solution offered by Pix4D catch, to automatically generate 3D models from a set of redundant and well distributed images appears extremely significant for many fields of applications. The purchase of a laser scanning system requires a considerable investment, including equipment, software and staff training. For occasional use or small interventions, the choice of simple, commercial solutions with subscription services can help calibrate the investment according to the needs.

Despite all the advantages of using such technologies, there are several key aspects that require further investigations. The authors are undertaking further tests and new acquisitions in order to define repeatability (ability to generate the same outputs under similar conditions) and accuracy (comparison with independent reference coordinates) of the two pocket-sized solutions described in this paper.

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