CONSUMER SOLID STATE LIDAR: A VIABLE TOOL FOR HERITAGE DOCUMENTATION?

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Abstract

This research tests the viability of Apple LIDAR scanning technology as a useful and reliable scientific tool for heritage documentation.
Factors such as mobility, ease of use, flexibility, accessibility, and cost, were balanced against quality, consistency, reliability and above all scientific validity.
Empiric testing was compared to other common solutions, such as Photogrammetry, laser, and structured light scanners.
Early results point to the assumption that both the Apple technology as well as emerging competitor solutions will push the boundaries of the technology rapidly forward and change the field of heritage survey, documentation, and research in the years to come.

Keywords: LIDAR, Apple, iPhone, iPad, scanning, photogrammetry

INTRODUCTION

So, what's all this talk about Apple LIDAR and what's its relevance to the field of Heritage documentation? LIDAR stands for "light detection and ranging." It is sometimes inaccurately called "laser scanning" or "3D scanning." Actually, this technology is not new and goes back to the early 60's [1]. It uses laser beams to create a 3D representation of the surveyed environment.
As the name suggests, LIDAR works a little bit like radar (radio-wave navigation used by ships and planes) and sonar (underwater detection using sound, mainly used by submarines) A typical LIDAR sensor emits pulsed light waves into the surrounding environment. These ping off objects and return to the source of the laser, measuring distance by timing the travel, or flight, of the light pulse. Thus, this technique is also known as Time-of-Flight scanning.
Without going into details, suffice to say that there are basically three main types of LIDAR: Spinning, Scanning and Pulse.
A spinning LIDAR, the type of which is rapidly entering the autonomous car industry, employs a spinning mirror, firing invisible laser beams in all directions, catching the reflections, and measuring how long the beams take to return so it can figure out what obstacles are nearby and how far away they are. In airborne survey, a LIDAR unit is mounted underneath a plane, or a helicopter and it scans across the ground as the plane flies across a precise trajectory.
The third type of LIDAR is the Solid-State technology (SSL).
Here, instead of using movable revolving (expensive and bulky) scanners, which scan the laser beam point by point in a traditional mechanical rotary fashion, SSL technology uses a solid-state light source.
The iPad Pro is equipped with a Digital Flash LIDAR (a type of solid-state LIDAR) system. As the name suggests, just like a camera's flash, a flash LIDAR detects an object by emitting a "grid of light" made up of many infrared dots which pulse out, hit the subject and their reflections are measured. Each with its own sensor. This creates a field of points that map out distances in three dimensions, in a form known as a point cloud. The beauty of this technology is that being solid state, it is both very small, extremely robust, cheap to manufacture, and it collects the results in real time as the LIDAR camera moves over the surface to be scanned. The light pulses are invisible to the human

eye but can be detected with an infrared camera [2]. In fact, Apple's LIDAR Is not dissimilar to its Face ID, located at the top of the iPhone or iPad, Apple's TrueDepth camera, which projects 30,000 infrared dots onto your face, which they then use to map one's features, detect the user and unlock the device. The LIDAR is, as said, similar, but has a longer range. Whereas the Face ID is designed to recognize the user's face and thus configured work at an arm's-length, the rear LIDAR sensors on the iPad Pro and iPhone 12 Pro work at a range of 0.4 up to 5 meters.
In all fairness it should be noted that Apple was not the first to explore this technology on a phone, Google had this same idea back in 2016-17 with *Project Tango*, an early AR platform using infrared sensors to map out indoor spaces [3]. This was essentially like the Microsoft Kinect Microsoft's motion sensor add-on for the Xbox 360 gaming console, first introduced in 2010 [4], and based on the Israeli Prime Sense technology back in 2006 [5]. However, Google's Tango- phones did not last long and were soon phased out [6].
As stated, using infrared (IR) lasers, the Apple LIDAR measures the time it takes for light to bounce from objects in the captured environment. Sophisticated triangulation-based algorithms help create a 3D point cloud of the surrounding area. These are then transmitted to third-party apps where the magic takes place. Either to determine the depth of field in photos, to create immersive AR experiences, which place artificial objects in real-world scenery, or as in our case, to create a full 3D point cloud or mesh of the surrounding space or of the object in front [7].

HERITAGE IMAGING TOOLS TODAY

The demand of 3D documentation for tangible heritage has grown exponentially over the past few years. Once the domain of high-end expensive laser scanners, lately, ground and air-based photogrammetry has overtaken and dominated the field. The advantages of photogrammetry are clear and indisputable. Cost, mobility, growing ease of use and ever-increasing accuracy, to name just a few. Possibly the greatest advantage however of photogrammetry lies in its ability to model a subject, virtually irrespective of its size. From the tiniest fragment, only a mere few millimeters in size, to a massive archaeological site and even an entire city. Photogrammetry is based on the optical principles of triangulated photographic images. Thus, nearly anything that can be photographed from multiple angles can be modelled in 3D.
So, if it's all so good, then where is the catch? The answer lies in the fourth dimension: Time. Producing photogrammetric models is time consuming. Depending on the size and complexity of the model, tens, hundreds and even thousands of images may need to be produced. Processing them with sophisticated software can take anywhere between a couple of hours to several days, depending on the processing power of the hardware alongside other factors.
High end laser scanners excel in documenting architectural structures and other large-scale objects. They are renowned for their excellent accuracy over relatively high distances. They can produce immense point clouds of extreme density and in vertex colors. However, beyond their high cost, they also demand experienced users to operate them, making them non-viable in many if not most heritage documentation scenarios, where budgets are notoriously below the needs.
Furthermore, a serious limitation of laser scanners is their lack of photographic texture, which can sometimes be critical in many heritage situations.
High end scanners are also not usually efficient in modeling small objects. Admittedly there are a multitude of smaller laser scanners better suited to the task (such as the NextEngine), however they too suffer from lack of high-quality texture and are slow to use.
Structured light scanners have become very popular as of late, due to their speed and ease of use, moderate mobility, relatively good texture production and ever dropping price range. However, due to their technology based on projected white or blue light, they too are limited in their range, as well as in the lighting conditions in which they can be used.
Thus, all the imaging technologies outlined briefly so far, have their place in tangible heritage documentation. Each has its own unique advantages as well as its inbuilt limitations. The hardware and software of all are constantly improving and the definition of "acceptable quality" is shifting

along with it. What was once deemed good, later became regarded as acceptable and now may be regarded as poor. As such, heritage practitioners must first and foremost define their needs, the working conditions and the practical acceptable limitations, alongside their budgets.
There is no one size those fits all and often only a combination of tools may be sufficient to meet the demands of the job.

THE APPLE LIDAR IN SCIENTIFIC LITERATURE

Several papers have appeared lately, analyzing the performance of the Apple LIDAR in precise scientific parameters.
Luetzenburg, G., Kroon, A. & Bjørk compared it to state of the art Structure from Motion Multi-View Stereo (SfM MVS) point clouds, stating that “Overall, the versatility in handling outweighs the range limitations, making the Apple LiDAR devices cost-effective alternatives to established techniques in remote sensing with possible fields of application for a wide range of geo-scientific areas and teaching” [8].
Vogt, Rips and Emmelmann compared the Lidar to a standard industrial laser scanner on a set of Lego bricks, according to shape and position tolerances, concluding that “Even though the industrial 3D scanner consistently delivered more accurate results, the accuracy of the smart device technologies may already be sufficient, depending on the application” [9].
Spreafico, Chiabrando, Losè, and Tonolo Tested it for large scale 3D rapid mapping, performing both a quantitative analysis on 3D positional accuracy assessment, and qualitative analysis of the achievable metric products. They find that it “appears promising for rapid surveying purposes. According to test outcomes, the sensor can rapidly acquire reliable 3D point clouds suitable for 1:200 architectural rapid mapping” Thus, they conclude: “the iPad Pro could represent an interesting novelty also thanks to its price (compared to standard surveying instruments), portability and limited time required both for data acquisition and processing” [10].
Murtiyoso, Grussenmeyer, Landes, and Macher compare the Apple LIDAR to more traditional techniques for 3D scanning, such as photogrammetry and terrestrial laser scanning. They conclude that “While understandably the geometric quality of benchmark-level techniques such as these remain undeniably better, at least for the moment, SSL sensors may nevertheless be sufficient for some lower-precision applications” [11].

THE APPLE LIDAR IN PRACTICAL HERITAGE DOCUMENTATION

This research attempts to test the above scientific assessments in empiric situations encountered under practical heritage documentation conditions. To this purpose a LIDAR equipped iPad Pro 2020 was used in several different real-world situations and compared to standard professional Photogrammetry. The iPad was evaluated for several parameters: Range, Accuracy over distance, Light sensitivity, Texture, Detail, Time, Ease of usability.

Test Sites

The tests were performed both indoors and outdoors under different light conditions
For extreme indoor scanning, tests were conducted at the ***Chapel of Saint Helena***, situated under the ***Church of the Holy Sepulchre*** in Jerusalem.
The Chapel of Saint Helena is a 12th-century Armenian church in the lower level of the Church of the Holy Sepulchre, constructed during the Kingdom of Jerusalem (1099 to 1187). The Armenians call it the Chapel of St. Gregory the Illuminator, after the saint who brought Christianity to the Armenians.
For outdoor testing, a small section of a historic street in new Jerusalem was chosen. **Ethiopia Street**, situated near the city center is one of the oldest streets, built in the mid-19th century just off the street of the prophets, which was established during the growth of Jerusalem beyond the walls of

the Old City. Despite being hardly larger than a lane, it is one of the most interesting in the city, packed with historic buildings and homes. One of its most famous, that of the reviver of the modern Hebrew language, Eliezer Ben Yehuda (1858-1922). Whose front door opens directly out on to the narrow street just several meters away from the high-walled and iron-gated entrance to a large courtyard and the impressive silver-domed, circular Ethiopian church opposite.

Scanning Software

Scanning apps for the iPhone and iPad Pro LiDAR began to appear on the market soon after the announcement of the hardware. Today several excellent apps exist, and these are growing in both quality and quantity.

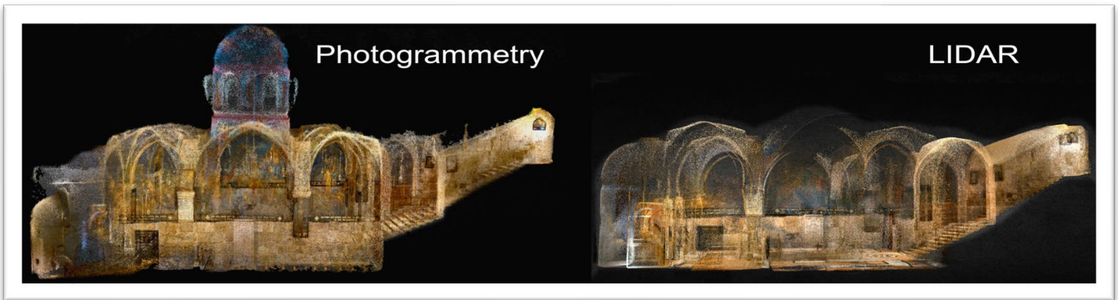
Generally speaking (and at the time of writing), these may be grouped into three categories. Apps for point cloud creation, apps for mesh creation, and those which combine both methods. Whilst this article does not set about to compare the software or recommend a particular one, it is fair to mention a few of the most popular, including: 3D Scan [12], Polycam [13], Metascan [14], Everypoint [15], and SiteScape [16]. For this study we chose to concentrate on point cloud production and have chosen SiteScape, one of the first and undoubtedly also one of the best around currently.

Range and Accuracy over Distances

Apple specifies the effective range limit of its LiDAR as between 0.4 - 5.0 Meters [17]. This automatically excludes situations below that range, such as close up of small, detailed objects, or large scenes beyond the specified range. Empiric testing verified these limitations. Thus, we may conclude that the current Apple LIDAR is useful only in the mid distance range.

However, the size of scanned area is not necessarily the same as the shooting distance. The above-mentioned limitation refers only to the maximum distance that the LiDAR can be from the surface at any given time. However, in fact this is less of a limitation than would appear at first. This is due to the fact that LIDAR scanning is a continuous process, not a single shot. The LIDAR process involves sweeping the scene in a continuous vertical and/or horizontal movement along the scene, slowly building up the area and volume.

In the chosen SiteScape software, the size of the single scan is limited by cloud density and point size, with an upper limit of some 12,000,000 points per scan [18]. Nevertheless, the number of scans is only limited by the device storage capacity. Therefore, as long as the scanning app remains open between scans, these can be easily aligned in open-source software such as CloudCompare [19], to form one large area. In this way, volumes of hundreds of square meters may be scanned, such as in the example of the entire Chapel below.

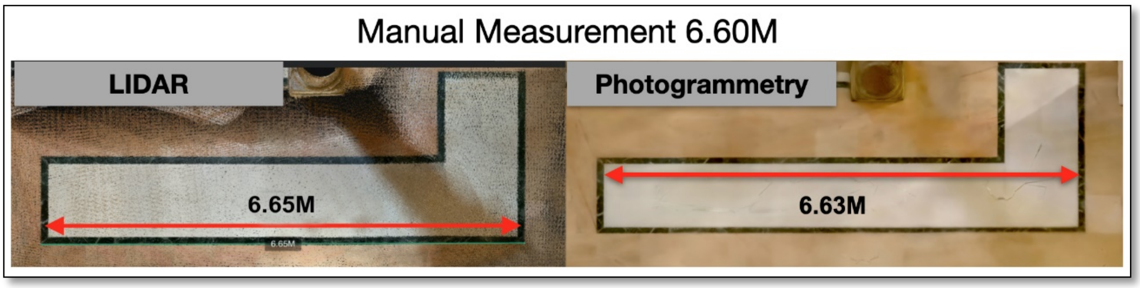


Digitization of entire Chapel. Left: Photogrammetry. Right: LIDAR

The range limitation was apparent here specifically when attempting to capture the upper portions of the chapel, the high wall paintings, the ceiling, and the dome.

As for accuracy over distance, In the tests carried out, dimensions of the scanned areas were measured manually for total accuracy and the results compared to the photogrammetry and the LIDAR. It is worth noting that the scanning resolution had no effect on the accuracy of the measurements. The following table shows the results:

	Manual measurement	Photogrammetry	Apple LIDAR
St. Helena Floor	660 cm	663 cm (0.706%)	665 cm (1.060%)
Ethiopia street	930 cm	925 cm (0.537%)	922 cm (0.867%)
Average accuracy	**100%**	**99%**	**99%**



Accuracy of LIDAR scans and Photogrammetry. Top: Helena floor, Right: Ethiopia Street

Light Sensitivity

Though the new phones and iPad Pro are equipped with "night mode" [20]. The introduction of LIDAR into the high-end iPhone range was designed to enhance the camera's depth sensing capability for AR applications, to improve occlusion and provide a more realistic augmented experience [21]. LIDAR is not based on existing light, but rather on pulsed infrared, therefore, it could be expected that it would work in the dark. Unfortunately, testing shows that current software is not yet able to translate this into a point cloud or mesh and thus that it is useless in the dark. However, in Low light conditions, up till approximately 25-30 LUX it still proves to be remarkably efficient.

Indoor: Wall painting in chapel Outdoor: Ethiopia Street. Different light intensities

Surface Texture and Detail

All optical imaging technologies today are based on the principle of registering and measuring light reflected off the subject's surface. This true both for active technologies such as scanners, as well as for the passive principle of photogrammetry. In all these cases, the character of the surface plays an important part in the quality of the resulting point cloud. Matt, rough textures with multiple points of reference are best. Surfaces such as stone, wood and earth will always yield a better result than flat, smooth, reflective, or shiny ones, such as plastics, metal, glass, etc. In this respect, there is no major difference in the performance of the various digitizing devices. High end laser scanners will yield far better resolutions. Structured light scanners will outperform in cases of small, detailed objects, and photogrammetry will always be king when it comes to texture reproduction. But all these will Respond in a similar manner to the surface being digitized.

In this research only point clouds were produced. Texture quality would usually be estimated based upon the UV maps. As point clouds do not produce UV maps, the texture could not be estimated here.
Detail however is the ability to resolve fine details and is primarily a function of resolution.
In all three technologies the resolution can be controlled. Detail is also a function of distance of the camera or scanner to the surface. As the LIDAR distance is limited, all imaging was performed at a similar distance of approximately 2 meters.
Here it was clear at the outset that the Apple LIDAR would not be able to compete against high-end laser scanners or photogrammetry.
For testing purposes, a stone cross measuring 320X80 cm was imaged at 2.5 meters.

- Photogrammetry was performed with Agisoft Metashape Pro (22) with a dense point cloud setting of High.
- SiteScape settings: Scan Mode: Detail, Point Density: High, Point Size: Low.

Surprisingly, the LIDAR scan yielded a file with just under 7 million points, compared with nearly 5 million from the photogrammetry. Hence the cloud was denser with more information at close-up.

Detail and Texture. Left: Photogrammetry. Right: LIDAR

Digitizing Time

The time spent in achieving the results was comprised of three stages: Digitizing, processing, post processing and cleaning.
Here, the results clearly confirmed that which was expected: The LIDAR was the clear winner. It was extremely quick to use, producing results virtually instantly.
This test was performed outside in an area of approximately 80 square meters (Ethiopia Street).
LIDAR: Digitizing was performed in real time and consisted of the time necessary to walk along the surface and scan the area. The point cloud was produced instantly. As the entire scan was created in a single pass, no combination of scans was necessary.

- SiteScape settings:
  Scan Mode: Area, Point Density: Medium, Point Size: Medium. Time: 3 minutes
- Photogrammetry Settings:
  150 photos were taken over a duration of 6 minutes
  Processing to a dense cloud (high detail) in Metascan took 18 minutes on a Dell PC i7 with 64 GB RAM and Nvidia 1080 graphic processor.

No post processing or cleanup was performed.

Ease and Usability

Again, the LIDAR excelled in this parameter. The iPad Pro is light and manoeuvrable. The iPhone pro is even smaller and lighter. Operation of the hardware/software involves virtually no learning curve. The software is totally free to use. Furthermore, all processing of the point cloud is performed offline and, in the device, instantly. Therefore, no additional hardware (laptop, etc.) is necessary. The result can be synced online to the SiteScape cloud, where additional operations may be carried out (with a pro license), make measurements, leave comments, and download the scan as an. RCP or PLY file.

CONCLUSIONS

Practical operation of the Apple LIDAR and SiteScape Point cloud software in varied real-life heritage documentation situations yielded several conclusions. Some expected and others surprising. The range limitation of 0.4 - 5.0 meters was, as expected, a clear disadvantage, as too was the point cloud lack of texture detail. However, its accuracy over distance, light sensitivity, scanning time, ease of use and surprisingly even its detail, were better than expected.
All these point to the conclusion that the Apple LIDAR is already today an effective and reliable heritage documentation tool. It is to be expected that with future hardware and software developments, this effectiveness will only improve.

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