Optical and Surface Scanning in the Modern Medicine From Manual Molds to Digital 3D Mapping

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Abstract. In this paper we will discuss different ways and technologies that are and can be used with the purpose of obtaining a model as accurate as possible of the human body or limb with the purpose to create a mold from which a customized orthosis can be built for each patient in particular.

1. Introduction

The modern medicine is depending more and more on a three-dimensional (3D) representation of the human body to improve diagnosis, treatment planning and the design of medical devices such as prosthetics or mechanical implants [1], [2], [3], [4]. Internal imaging technologies play a crucial role in capturing the internal geometry and density of various organs and sections of the human body while the optical and surface scanning technologies play a crucial role in capturing the external geometry of the human body [5]. The modern medicine has many different ways to scan the human body with the goal to create a 3D map of it. These surface scanning technologies are critical in fields such as prosthetics, orthopedics, reconstructive surgery and rehabilitation medicine where precise surface anatomy is mandatory.

Currently there are quite a few body scanning technologies that can achieve such a degree of accuracy to a certain extent and with downsides for each.

2. The classic manual molding technique

First one would be the classical and the oldest method before the digital scanning methods took off such as the manual molding techniques (Fig. [1]) to capture the patient's body. This method is still being used today in certain clinical contexts, particularly in prosthetics and orthotics.

In this approach material such as plaster bandages, alginate or silicone compounds are applied directly on the patient's body or limbs in order to create a negative mold of the area that is applied to. Once the material that was applied onto the patient hardens, it is removed and put together to form a solid mold where it is filled with plaster or resin to produce a positive cast. This cast ends up being used to model and design the prosthetics, sockets, braces or corrective devices.

This approach is very reliable and accurate however it does have it's downsides.

- One of them would be the amount of time that it takes in order to create a mold and it's also labour-intensive.

- The process depends heavily on the skill and experience of the clinician

- The patient has to stand still until the material hardens which could pose a problem if the patient keeps moving or starts to feel discomfort.

- The end result is a single physical object that is difficult to modify or archive due to the varying sizes of the created mold.. 1.

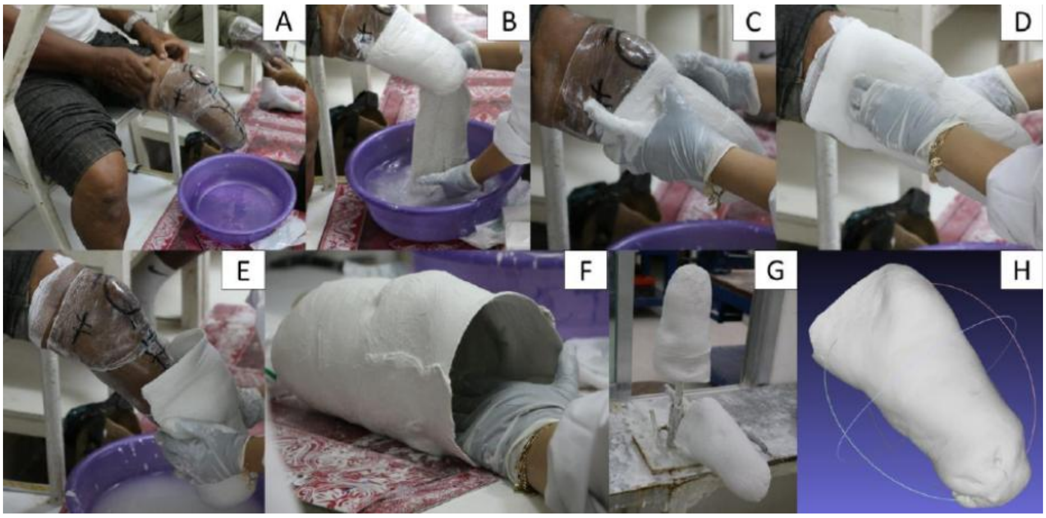

Fig. 1. A seated participant which had their residual limb wrapped in cellophane (A, B). After palpation on both sides for the patellar tendon, the indentations were marked (C) and at the supracondylar level as well (D). After doffing (E) the posterior shelf and flare for the flexion of the knee were formed by adding additional plaster (F). Next up the positive molds were produced and abraded lightly (G). The limb was also scanned directly in between the mold creation process (H). [6]

3. Structured Light Scanning technology

Another method would be to use the structured light scanning which works by projecting light patterns such as grids or stripes, onto a surface in order to capture a three-dimensional shape of it. The cameras capture all the deformations of those patterns and they end up being processed by specialized algorithms to generate a detailed 3D model of the object scanned.

The working principle is that a narrow band of light projected on a three-dimensional surface which creates a distorted line of illumination that appears distorted to every other perspective other than the projector itself. (Fig. 2)

This deformation of the projected light can be analyzed to recover the surface geometry through a process known as light sectioning. By projecting patterned illumination such as multiple stripes or complex fringe patterns simultaneously onto the surface, a large number of spatial data points can be captured in a single acquisition, significantly increasing scanning efficiency. Fig . 3 [7], [8] [9].

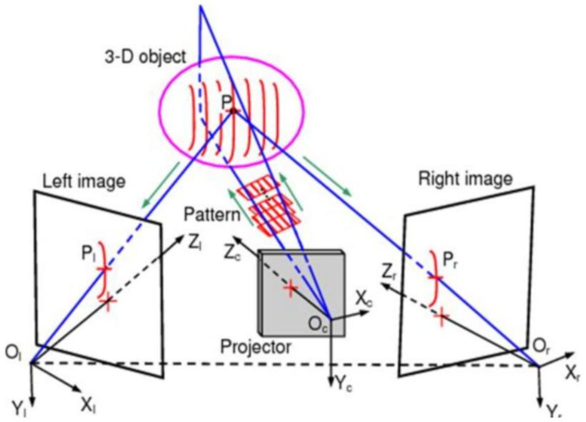

Fig. 2 The principle of structured lighting and stereovision system. "Slightly location (xi , yi) of a pixel pi in the image constrains the 3-D location of the corresponding object point Pi(Xi , Yi , Zi) to a certain sub-space in the scene. Therefore, by using a disparity between each corresponding points and known camera geometry parameters, the 3-D position (Xi ,Yi ,Zi) is obtained." [9]

Among the various structured light projection, the most common pattern used is the parallel stripes. The three-dimensional coordinates of surface features are derived by measuring the displacement of these stripes relative to a reference pattern which enables an accurate reconstruction of the objects surface. (Fig. 3)[10]

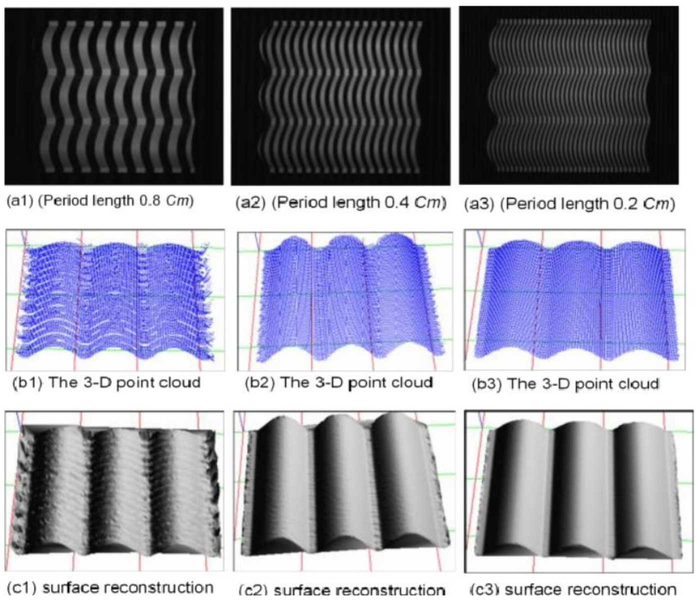

Fig. 3. Stripe pattern effect of a "Sinusoid" object. Three structured light of stripe pattern with varying period length (0.8Cm; 0.4Cm; 0.2Cm) projected onto the scene in (a1, a2, a3), a 3-D point cloud of the computed disparity map in (b1, b2, b3) and the 3-D surface reconstruction in (c1, c2, c3). [10]

One such device that uses this type of technology is the Shining 3D EinScan H2 made by Additive Manufacturing Systems. (Fig. 4.)[11], [12]

Fig. 4. Shining 3D EinScan H2 made by Additive Manufacturing Systems. It has a 5MP camera assisted by 3 projectors and one infrared sensor. [11], [12]

This technology offers very high accuracy and resolution especially at close range making it ideal for detailed anatomical capture such as limbs, faces and dental structures. It is non-contact and safe, causing no tissue deformation and allowing repeated use on the human body. The data acquisition is fast and the resulting scans integrate well into digital CAD and CAM workflows with good repeatability.

The disadvantages however lies in how sensitive to motion it can be. The subject movement can introduce errors. Another point to be made is that it's required to have a controlled environment with adequate lighting conditions since a strong ambient light can interfere with the projected patterns. Reflective, transparent or very dark surfaces might also reduce the data quality and the technology is generally limited to short working distances and the equipment cost are much higher compared to other simpler depth-sensing methods.

3. LiDAR (Light Detection And Ranging) technology

A third way that is not yet used but it can be implemented in the medical industry but with careful calibration would create highly accurate results would be LiDAR scanning technology.

This technology is based on active ranging technology that measures the distance by emitting short pulses of laser light and detecting the time it takes for the reflected light to return from a surface. Due to the fact that the LiDAR does not rely on ambient lighting it can operate consistently in a wide range of environments. This technology most commonly collimated light beams of wavelengths around 850 nm up to 1550 nm towards an object. The reflected pulses are captured by a photodetector and then the system calculates the distance using the time-of-flight principle, where the measured round-trip travel time of the light is multiplied by the speed of light and divided by two. By repeating this process rapidly while scanning the beam across space, the system builds a three-dimensional representation of the environment. Fig. 5 [13]

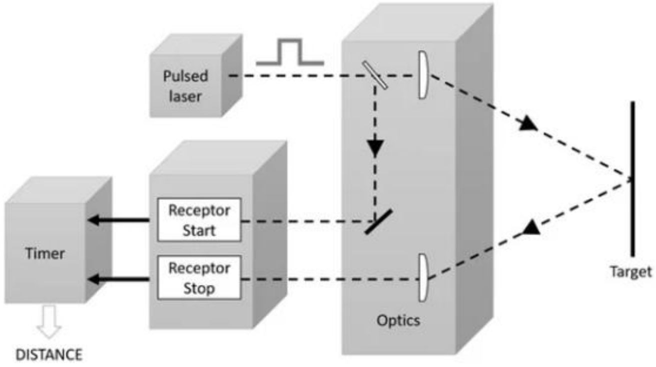

Fig. 5. The time of flight principle with pulsed laser.

A device which uses this sort of technology is the FJD Trion P1 3D Handheld LiDAR Scanner [14] Fig. 6. which is able to accurately create a map of it's environment Fig 7.

Fig. 6. An image of the FJD Trion P1 3D Handheld LiDAR Scanner [14][15]

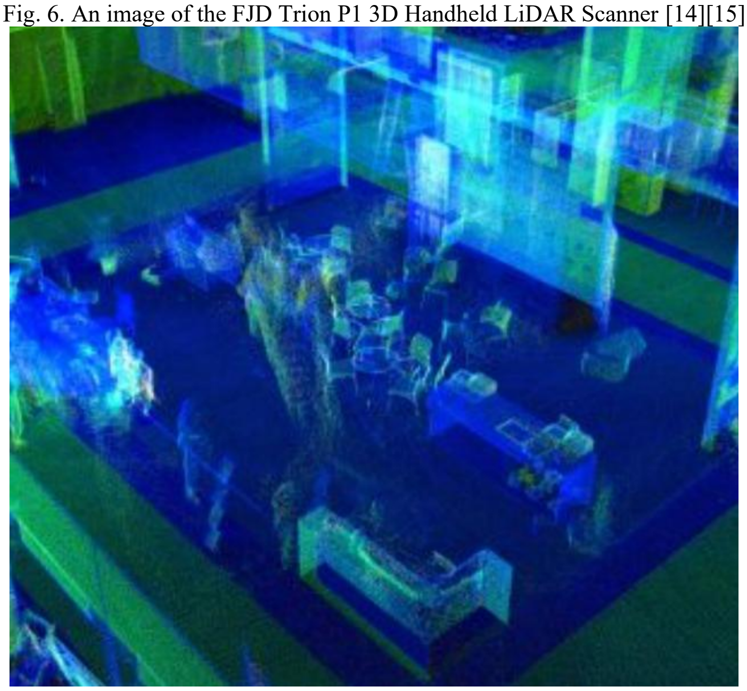

Fig. 7. One example of a scan done with the FJD Trion P1 3D Handheld LiDAR Scanner [14] of an office. [15], [16]

The advantages of this technology lies in it's working principle of measuring the time-of-flight laser pulses which is making highly robust to ambient lighting and it's capability of operating in both indoor and outdoor environments. It tolerates subject movement better than the pattern-based methods and can capture data in real time over larger working distances and scales well for large surfaces and full-body scanning not relying on surface texture to function. [17]

The disadvantages however is on the fact that it provides lower spatial resolution and surface detail at close range compared to structured light limiting it's suitability for precision fitting applications. It is often less accurate for fine anatomical contours such as those needed in prosthetic sockets. LiDAR systems can also be more expensive and produce noisier point clouds which require additional processing to achieve smooth, high-quality surface models. [17]

4. Conclusion

Manual molding remains the tactile benchmark for prosthetics and orthotics, yet its laborious, patient-dependent process is increasingly complemented by two digital techniques: structured light scanning—fast, high-resolution, non-contact but motion-sensitive and lighting-dependent—and LiDAR—robust to ambient light, tolerant of movement, scalable to full-body scans yet delivering lower close-range detail and noisier point clouds; when combined, the precise but slow manual casts can be digitized with structured light for fine anatomical fidelity, while LiDAR's broader coverage and motion resilience can capture overall form or larger surfaces, allowing each method's strengths to offset the others' weaknesses and yielding a richer, more versatile dataset than any single approach alone.

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