Current Technology Landscape for Collecting Hand Anthropometric Data

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Abstract

Historically, three methods have been used to collect hand anthropometric data. The oldest and most known method was developed in the late 1800's, where researchers used rulers, calipers and tape measures to manually collect data from a subject's landmarked hand, or from obvious parts of the limb that can be measured without landmarks (e.g., wrist circumference). The second method uses 2D imagery that is collected from the subject and then measured manually/digitally with rulers or calipers. A variety of devices can collect this type of imagery; including photo boxes, x-ray machines, flatbed scanners and photo copiers. These tools are convenient for collecting hand data, but can be limiting as they only collect one flat view of the hand, at one time. Over the last ten years, 3D scanning technology has been adopted for hand studies because of its' ability to collect data quickly, and with better accuracy, as there are less steps and human error involved. 3D scanning allows researchers to collect data of an entire body part at one time, where it can be analyzed digitally beyond straight measures and circumferences. There are three types of scanners available in the market to collect hand anthropometric data, they include: 1) ones made specifically for hand scanning, 2) foot scanners and 3) hand held/mobile/tablet devices. But which 3D scanner should you select for your hand research? This can be an overwhelming decision, as there are so many options, and knowing what to look for can be confusing and quite difficult to find. Through experimentation with different equipment and hand studies, the researchers, developed a framework of key attributes that are important to selecting 3D scanners. They include: vendor/location, hand-held compatibility, scanner size, weight, envelope, supporting weight, price; along with scanner technology, timing, resolution, color capture, and file saving. Through this research, the authors desire to help others who want to purchase and conduct hand anthropometric research, to be more informed so can use their resources effectively and efficiently to have success with their work.

Keywords: Hands, Anthropometry, 3D Scanning, Technology

1. Introduction

Sokolowski and Griffin cumulatively have over thirty-five years of experience leading anthropometric studies related to product design and sizing. They have conducted work in this field with major manufacturers, start-ups and now respectively at the Universities of Oregon and Minnesota. They are also research collaborators, working on several projects related to Personal Protective Product (PPE), involving hand anthropometry. The impetus of this research came out of necessity, as they are both responsible for developing modern laboratory spaces at their universities, including 3D scanning capabilities, with constrained resources. Given the saturation of the 3D scanning equipment landscape, a selection framework was needed to help make decisions on what tools are most relevant and effective when conducting studies. This paper will review rationale, a selection framework and findings when the framework is applied to 3D scanning equipment available in the current marketplace.

2. Background and Framework

2.1. Historical and current methods to collect hand anthropometric data

Historically, three methods have been used to collect hand anthropometric data. The oldest and most known method was developed in the late 1800's, where researchers used rulers, calipers and tape measures to manually collect data from a subject's landmarked hand, or from obvious parts of the limb that can be measured without landmarks (e.g., wrist circumference) [1, 2]. The second method uses 2D imagery that is collected from the subject and then measured manually/digitally with rulers or calipers [2, 3]. A variety of devices can collect this type of imagery; including photo boxes, x-ray machines, flatbed scanners and photo copiers [2]. These tools are convenient for collecting hand data, but can be limiting as they only collect one flat view of the hand, at one time [2]. Over the last ten years, 3D scanning

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technology has been adopted because of its' ability to collect data quickly, and with better accuracy as there are less steps and human error involved [2]. 3D scanning allows researchers to collect data of an entire body part at one time, where it can be analyzed digitally beyond straight measures and circumferences [2, 4].

2.2. Current hand scanning technology challenges

There are three types of scanners available in the market to collect hand anthropometric data, they include: 1) ones made specifically for hand scanning, 2) foot scanners and 3) hand held/mobile/tablet devices. There are fewer hand-specific 3D scanning devices in the marketplace, however, foot scanners are readily available and in most cases are appropriate. Sometimes, these devices can be limiting, where they may not have a large enough scanning envelope for bigger hands and prevent task-related anthropometric posing (e.g., grasping and pulling) from being captured. Today, technology start-ups are popping-up and competing with new products that are portable and/or hand held device compatible – which are ideal for unique hand posing and the inclusion of objects/props where the researcher desires to learn about grip formation and hand positioning of specific users (e.g., firefighters and athletes), during specialized tasks – as they do not have a restricted scanning envelope. They also allow data to be collected from users anywhere, which is helpful when subjects do not live near a specified research facility.

The scan equipment landscape as related to hand anthropometry is in great flux today. For many years the market had few vendors that manufactured and distributed equipment. Scanners came at a very high cost. The costs forced researchers, especially ones from academia to choose between a large format 3D body scanner or a foot/hand scanner for their laboratories. The constraint also effected the research landscape, as there are fewer studies with regards to hand anthropometry, compared to full body. But with the larger landscape of 3D scanners, which one should you select for your hand anthropometric research? This can be an overwhelming decision, as there are so many options, and knowing what to look for can be confusing and quite difficult to find. When the attributes of a piece of equipment are not researched thoroughly, the quality of the research could be greatly affected by shortcomings of the device used.

2.3. 3D hand scanner rationale

3D body scanners can be quite powerful tools for researchers that conduct anthropometric studies. In the case of hand studies, when the 3D image is appropriately captured, a multitude of information can be gathered to learn about its' size, shape, and how to better design performing products – like gloves, tools and medical instruments. However, not all 3D scanners are the same, and the data they collect can be quite variable. Through pilot studies with different scanning equipment, the researchers established minimum guidelines (Table 1) of what a 3D scanner must do, in order to effectively collect hand anthropometric data.

Table 1. Minimum 3D scanner guidelines for hand anthropometric studies.

Current Challenges Observed	3D Hand Scanner Minimum Guidelines
Some scanners cannot capture larger hands, including the wrist, because the scanning envelope is not big enough.	Ability to capture the entire hand and wrist of any sized subject.
Some devices cannot capture darker skin colors.	Ability to capture any skin color.
Some scanners cannot capture the subject holding an object, in an ergonomic position as the scanning envelope is not big enough.	Ability to capture the entire hand and wrist in various task-related positions, which may include holding other objects.
Some devices cannot capture finite hand/wrist details.	Ability able to see the skin folds and wrinkles.
Much like skin color, some scanners cannot capture landmark colors or color contrasts.	Ability to see flat sticker/pen landmarks that are used for anthropometric measurement gathering.
Some scanning software do not save files that can be opened in a variety of software packages to measure and design from.	Ability to reuse the data set across different software packages to measure and design with.
Heavy scanners are impossible to pack up, carry and take on flights to capture data from subjects that are not local to the researcher's laboratory.	Ability to be portable, ideally under 11 kg (25 lb) – so it can be packed in carry-on luggage for air travel.

2.4. Selection attributes

With the guidelines, the researchers developed the 3D Hand Scanning Attributes Framework (3D HSAF) to assess individual scanners. The framework was devised to provide researchers a checklist of critical 3D scanner attributes needed to collect appropriate hand data. These attributes are not weighted or prioritized, because every researcher will have different priorities for their work. These are merely levers that need to be considered in totality when making a scanner purchase. They are also the questions any scan vendor should be able to answer clearly when approached about their equipment. Key attributes include: vendor/location, hand-held compatibility, scanner size, weight, envelope, supporting weight, price; along with scanner technology, timing, resolution, color capture, and file saving (Fig 1).

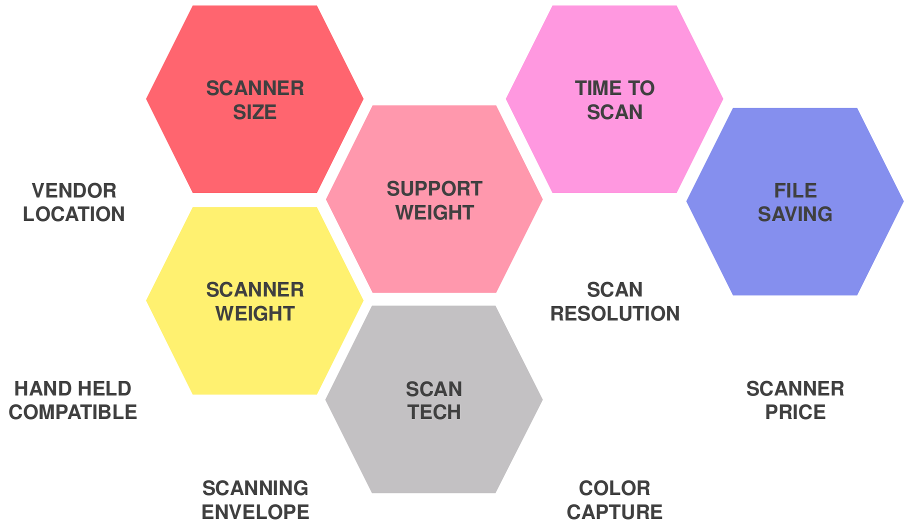

Fig. 1. 3D Hand Scanning Attributes Framework (3D HSAF).

Ultimately, through the 3D HSAF, the authors desire to help others who want to purchase and conduct hand anthropometric research, to be more informed so can use their resources effectively and efficiently to have success with their work.

Furthermore, the attributes of the 3D HSAF are defined in Table 2.

Table 2. 3D HSAF definitions (alphabetically).

Attribute	**Definition**	**Importance to Researchers**
Color Capture	The ability for the 3D scan to be collected in color (including texture map).	Color and texture are important when collecting landmarks, wrinkles/creases and skin color.
File Saving	The suffix portion of the scan file name, when saved.	The file format is important, because the scan will likely to be opened in other software programs for analysis and CAD. Commonly used file names are OBJ and STL. There are many others.
Hand-Held Compatibility	Ability for the scanner to be hand-held as a small tool/wand, run through the camera of a hand-held device or to affix as a scan accessory to a hand-held device.	This is where many start-ups are developing new 3D scanners. These scanners are more economical, quite relevant to hand scanning needs and portable.
Location of Scanner Vendor	The place where the 3D scanner was manufactured and ships from.	Many scan manufacturers will not ship overseas and if they do, it will be costly. Working with vendors that are in-country may be most cost effective.

Scanning Envelope	The capture space of the scanner, including length, width and height.	It is important to know the limits of the scan envelope, as subjects that have larger hands (e.g., basketball players) or are being scanned in task-related poses with objects (e.g., fire fighters with an item of equipment) may not fit in the envelope and data would be incomplete/not useable.
Scanner Price	The total price to purchase the scanner.	Academic researchers have very limited budgets, unless they are able to bring in additional grant funding to build-up their laboratories. This is especially true in the apparel and product disciplines, as there is often competing needs for resources (e.g., machinery/supplies for students, lab space, software).
Scan Resolution	The clarity of the scan.	The higher the resolution, the clearer the scan and ability to analyze it.
Scanner Size	The length, width and height dimensions of the scanner.	Size is important when shipping and delivery. It is also needed for understanding how much lab space is required to operate it, and transporting to other locations for data collection (if feasible).
Scan Technology	The method of 3D scan capture (e.g., photogram-metry, structured light, LASER).	Knowledge of the technology helps inform to how the scan environment should be set-up (e.g., lighting). It also may effect scan quality.
Scanner Weight	The total weight of the scanner.	For hand research, if the device can be portable - under 11 kg (25 lb) – it can be packed in carry-on luggage for air travel. Scanners under 4.5 kg (10 lbs) are even more favorable, as multiple units can be transported together for larger studies.
Support Weight	The maximum body weight that can be placed upon the scanner before it is damaged (e.g., cracked).	This is important for studies where the hand is scanned with heavy objects or put under force. For hand-held devices, this is not an issue.
Time to Scan	The amount of time from start to finish needed to capture one 3D scan.	For large studies, every second counts, so faster scanners help facilitate the work. There is also less subject movement captured.

3. Methodology

The purpose of this research was to use the newly developed 3D HSAF, to understand the current 3D scanner technology landscape, related to hand anthropometry research. To insure consistency of knowledge gathering, one point of contact was appointed to reach out to vendors, to collect data. Through marketing materials from the 2018 3DBody.Tech Conference and Google searches, vendors throughout North America, Europe and Asia were identified. A three pronged approach to obtaining information was used. First, initial data was collected through the specified vendor's website. Secondly, connections were made over via email, as in most cases scanner attributes were never all present on the vendor's website. If the email communication was not successful or a reply was not received within 48 hours, follow-up telephone calls with the vendor's sales department were made. The calls were also used to clarify additional questions. All data were inputted to a spreadsheet.

4. Results

Twenty-four vendors from nine countries were contacted, and provided information for this study. Additional vendors were contacted, but they were not included in the results as they did not reply or provide enough information to have a clear explanation of their products. Through the initial research phase of finding and reviewing vendor websites, there was an obvious lack of publicly available attribute documentation, including important operating, user features and price. Once emails were sent, the attributes were documented for each vendor/scanning device. However, there were some vendors contacted that did not reply with clear information, and those correspondences were followed up with a telephone call. Overall, the researchers found great inconsistency with how vendors listed their measures, including weights, envelope size and resolution. All results were converted to be in the same scale, with metric and imperial results. Additionally, many vendors were not able to provide evidence (e.g. research studies or published papers) to support claims of their products. Based upon the 3D HSAF, the results of the study are presented (Tables 3 to 10).

4.1. Location of 3D hand scanner vendor

Table 3 presents the twenty-four vendors in alphabetical order, and where they manufactured and ship their 3D scanners from. Some companies may have other satellite offices that were not noted on their website or during the data collection process.

Table 3. City and country location of 3D hand scanner vendors.

Vendor Name	**City/Country**
3D Footbank by Dream GP	Osaka, Japan, Wood Dale, Illinois USA
3DMD	Atlanta, Georgia USA
Anatomi Metrix	Montreal, Canada
Aetrex Technology	Teaneck, New Jersey USA
Artec	Luxembourg, + subsidiaries in Palo Alto, California, USA and Moscow, Russia
FlicFit	Meguro-ku, Japan
Global Inspection Solutions/3D3 Solutions	Portland, Oregon USA
Hewlett-Packard (HP)	Palo Alto, California USA (+27 US subsidiaries)
Human Solutions	Kaiserslautern, Germany & Raleigh, North Carolina USA
IBV: Instituto de Biomecánica de Valencia	Valencia, Spain
Leica Geosystems	Heerbrugg, Switzerland & Norcross, Georgia USA
Netvirta	Boston, Massachusetts USA & Singapore
Occipital	San Francisco, California & Boulder, Colorado USA
Paromed	Queensland, Australia & Neubeuern, Germany
Precision 3D	Weston-Super-Mare, United Kingdom
Scandy LLC	Elmwood, Louisiana USA
Shenzhen 3DOE Technology	Shenzhen, Guangdong, China
Shining 3D	Hangzhou, China, Stuttgart, Germany & San Francisco USA
STT Systems	San Sebastián, Spain
TechMed3D	Quebec City, Canada
Thor3D	Moscow, Russia
Trnio	San Francisco, California USA
Volumental	Stockholm, Sweden
Vorum	Vancouver, British Columbia Canada

4.2. Hand-held compatibility and scan technology

Of the twenty-four vendors, only 8% manufactured hand-specific 3D scanners. Forty-six percent of the vendors produced scanners that were hand-held (including tablet/phone). The ability for scanners to be hand-held is quite relevant to hand scanning studies, as they are portable and can allow for variable scanning envelopes (Table 6). The method of 3D scan capture (e.g., photogrammetry, structured light, LASER) is also presented (Table 4). Knowledge of the technology used helps inform to how the scan environment should be set-up (e.g., lighting and wall coloring). It also may effect scan quality.

Table 4. 3D scanner hand-held (including tablet/phone device) capability and capture technology, by vendor.

Vendor Name	Yes or No	Capture Technology
3D Footbank by Dream GP (foot scanner)	No	LASER light
3DMD (hand scanner)	No	Stereophotogrammetry
Anatomi Metrix (hand scanner)	No	LASER light
Aetrex Technology (foot scanner)	No	Structured light
Artec (multi-use hand held scanner)	Yes	Structured light
FlicFit (foot scanner)	Yes	LASER light
Global Inspection Solutions/3D3 Solutions (multi-use scanner)	No	Structured light
Hewlett-Packard (foot scanner)	No	Structured light
Human Solutions (foot scanner)	No	LASER light
IBV: Instituto de Biomecánica de Valencia (foot scanner)	No	LASER light
Leica Geosystems (multi-use scanner)	No	LASER light
Netvirta (multi-use hand held scanner)	Yes	Photogrammetry
Occipital (multi-use hand held scanner)	Yes	Structured light
Paromed (foot scanner)	Yes	LASER or Structured light
Precision 3D (foot scanner)	Yes	Stereophotogrammetry
Shenzhen 3DOE Technology (foot scanner)	No	LASER light
Shining 3D (multi-use hand held scanner)	Yes	Structured light
STT Systems (foot scanner)	No	LASER light
TechMed3D (multi-use hand held scanner)	Yes	White light
Thor3D (multi-use hand held scanner)	Yes	Structured light
Trnio (multi-use hand held scanner)	Yes	Photogrammetry
Volumental (foot scanner)	No	Structured light
Vorum (multi-use hand held scanner)	Yes	Structured light

4.3. Scanner size and weight

Table 5 presents the size (millimeters/inches) of each scanner and their weights (kilograms/pounds). All results were converted for consistency, as vendors shared their information in a wide array of units. The smallest scanners are from: Netvirta, Occipital, Scandy LLC and Trnio – they are all hand-held mobile device systems. The largest scanners were the 3DMD hand system and Precision 3D. The lightest scanners were from Netvirta, Occipital, Scandy LLC and Trnio, as they are operated on a mobile phones between 0.1 to 0.2 kg (0.2 to 0.4 lb). The heaviest scanner was STT Systems at 128 kg (282.2 lb).

Table 5. 3D scanner size and weight, by vendor.

Vendor Name	Size	Weight
3D Footbank by Dream GP	610 x 457 x 203 mm (24 x 18 x 8 in)	12 kg (26.4 lb)
3DMD (hand system)	1940 x 1760 x 1120 mm (76 x 69 x 45 in)	4.5 to 5.5 kg (10 to 15 lb)
Anatomi Metrix	*Information not available*	*Not available*
Aetrex Technology	1036 x 719 x 142 mm (40.8 x 28.3 x 5.6 in)	8.2 kg (18.0 lb)

Artec	190 × 140 × 130 mm to 262 × 158 × 64 mm (7.5 x 5.5 x 5.1 in to 10.3 x 6.2 x 2.5 in)	0.9 kg (all models) (1.9 lb)
FlicFit	775 x 872 x 257 mm (30.5 x 34.3 x 10.2 in)	30.0 kg (66.1 lb)
Global Inspection Solutions/3D3 Solutions	165 x 310 x 455 mm (6.5 x 12.2 x 17.9 in)	11.3 kg (25.0 lb)
Hewlett-Packard (HP)	740 x 430 x 320 mm (29.1 x 16.9 x 12.6 in)	26.0 kg (57.3 lb)
Human Solutions	400 x 400 x 800 mm (15.7 x 15.7 x 31.5 in)	68kg (150 lb)
IBV: Instituto de Biomecánica de Valencia	350 x 450 x 450 mm (13.8 x 17.7 x 17.7 in)	4.6 kg (10.1 lb)
Leica Geosystems	178.5 x 120 x 25.8 mm (7.1 x 4.7 x 1 in)	2.8 kg (6.2 lb)
Netvirta (phone Ap)	138 x 67 x 7.3 to 160 x 78 x 8.1 mm (5.4 x 2.6 x .01 to 6.3 x 3.1 x .32 in)	Between 0.1 to 0.2 kg (0.2 to 0.4 lb)
Occipital (affixes to an ipad)	119.2 x 29 x 28 mm (4.7 x 1.1 x 1.1 in)	0.1 kg (0.2 lb)
Paromed	269 x 320 x 707 mm (10.6 x 12.6 x 27.8 in)	11.3 kg (24.9 lb)
Precision 3D	1000 x 1000 x 250 mm (39.4 x 39.4 x 9.8 in)	35 kg (77.2 lb)
Shenzhen 3DOE Technology	570 x 390 x 310 mm (22.4 x 15.4 x 12.2 in)	20.0 kg (44.0 lb)
Shining 3D	248 × 156 × 48 mm (9.8 x 6.1 x 1.9 in)	0.8 kg (1.8 lb)
STT Systems	550 x 800 x 670 mm (21.7 x 31.5 x 26.4 in)	128 kg (282.2 lb)
TechMed3D	96 x 140 x 258 mm (3.8 x 5.5 x 10.2 in)	85 kg (1.9 lb)
Thor3D	360 × 250 × 110 mm (14.2 x 9.8 x 4.3 in)	2.3 kg (5.1 lb)
Trnio (phone Ap)	138 x 67 x 7.3 to 160 x 78 x 8.1 mm (5.4 x 2.6 x .01 to 6.3 x 3.1 x .32 in)	Between 0.1 to 0.2 kg (0.2 to 0.4 lb)
Volumental	800 x 800 x 300 mm (31.5 x 31.5 x 11.8 in)	9.7 kg (21.4 lb)
Vorum	15 cm x NA x NA (5.9 x NA x NA in)	0.9 kg (2.0 lb)

4.4. Scanning envelope and supported weight

The best way to define the scanning envelope is by knowing its' length, width and height. The envelope is the area that gets captured by the scanner. By just having one dimension (e.g., height), it is not useful, as the researcher needs to know how wide and long the object can be, in order to be completely scanned. When vendors were asked about the scanning envelope attribute of their scanners, they shared quite inconsistent information. Many vendors shared only 1 or 2 of the envelope dimensions. Table 6 presents scanning envelopes along with supported weight when relevant – as the hand held devices do not have this measurement limitation.

Table 6. 3D Scanner envelope and supported weight, by vendor.

Vendor Name	**Scanning Envelope**	**Supported Weight**
3D Footbank by Dream GP	305 to 381 mm high (12 to 15 in)	Up to 90.7 kg (200 lb)
3DMD (hand system with 5 camera units)	Variable depending on camera configuration	Not Applicable (no platform)
Anatomi Metrix	*Information not available*	Up to 50 kg (110.2 lb)
Aetrex Technology	360 x 360 mm (14.2 x 14.2 in)	Not Applicable (hand held)
Artec	90 × 70 mm (3.5 x 2.8 in)	Not Applicable (hand held)
FlicFit	300 mm high (11.8 in)	Up to 200 kg (441 lb)
Global Inspection Solutions/3D3 Solutions	165 mm high (6.5 in)	Not Applicable (hand held)
Hewlett-Packard (HP)	400 x 200 x 180 mm (15.7 x 7.9 x 7.1 in)	Up to 136.1 kg (300 lb)
Human Solutions	180 mm high (7.1 in)	Up to 90.7 kg (200 lb)
IBV: Instituto de Biomecánica de Valencia	250 mm (9.8 in)	Up to 200 kg (441 lb)
Leica Geosystems	1800 mm high (70.9 in)	Not Applicable (hand held)
Netvirta	up to 2000 mm high (78.7 in)	Not Applicable (hand held)
Occipital	400 mm high x 3500 mm wide (15.7 x 137.8 in)	Not Applicable (hand held)
Paromed	200 mm (7.9 in)	Up to 130 kg (286.6 lb)
Precision 3D	350 x 170 x 170 mm (13.8 x 6.7 x 6.7 in)	Up to 200 kg (441 lb)
Shenzhen 3DOE Technology	350 x 170 x 150 mm (13.8 x 6.7 x 5.9 in)	Up to 150 kg (330.7 lb)
Shining 3D	300 × 170 mm (11.8 x 6.6 in)	Not Applicable (hand held)
STT Systems	250 mm (9.8 in)	Up to 200 kg (441 lb)
TechMed3D	Unlimited	Not Applicable (hand held)
Thor3D	*Information not available*	Not Applicable (hand held)
Trnio	up to 2000 mm high (78.7 in)	Not Applicable (hand held)
Volumental	200 to 300 mm high (7.9 to 11.8 in)	Up to 65 kg (143.3 lb)
Vorum	Unlimited	Not Applicable (hand held)

4.6. Time to scan and file saving

Table 7 presents scan times and file saving formats, by vendor. The hand-held scanners usually take the longest time to capture 3D scans, as they have to carefully “wave” around the object (360º). Most scanners can save scans in OBJ and/or STL formats, except the Anatomi Metrix, Artec, Leica Geosystems models. For designers, the OBJ and STL formats are most useful with measurement software and CAD programs.

Table 7. 3D Scanning time and file saving format, by vendor.

Vendor Name	Time to Scan	File Saving Format
3D Footbank by Dream GP	15 seconds	OBJ/STL/DXF
3DMD	.0015 seconds	OBJ/STL
Anatomi Metrix	.03 seconds	DAS
Aetrex Technology	10 seconds	OBJ/STL/PLY
Artec	30 to 60 seconds	AOP/ASCII/E57/OBJ/PLY/STL/ WRL
FlicFit	10 seconds	OBJ/STL/DXF
Global Inspection Solutions/3D3 Solutions	1.3 seconds	OBJ/STL/DXF
Hewlett-Packard (HP)	<1 second	STL
Human Solutions	7 seconds	OBJ/STL
IBV: Instituto de Biomecánica de Valencia	60 seconds	OBJ
Leica Geosystems	10 seconds	DXF
Netvirta	2 minutes	STK/OBJ/STL
Occipital	30 to 60 seconds	STK/OBJ/STL
Paromed	12 to 25 seconds	OBJ/STL
Precision 3D	4 seconds	STL/VRML/DXF
Shenzhen 3DOE Technology	10 seconds	OBJ/STL/ASC
Shining 3D	30 to 60 seconds	ASC/OBJ/PLY/STL
STT Systems	10 seconds	OBJ/STL
TechMed3D	15 to 20 seconds	OBJ/STL/PLY
Thor3D	30 to 60 seconds	OBJ/STL/PLY
Trnio	2 minutes	STL
Volumental	5 seconds	OBJ/STL
Vorum	30 to 60 seconds	OBJ/STL

4.7. Scan resolution and color capture

The most inconsistent attribute information shared by vendors, pertained to the resolution of their 3D scanners. A large variety of responses were shared; some of them were vague (e.g., high resolution, with no measure), and some had limited research to validate their resolution claims. Color capture (including texture mapping), is also presented in Table 8.

Table 8. 3D Scan resolution and color capture, by vendor.

Vendor Name	Scan Resolution	Color Capture
3D Footbank by Dream GP	High resolution	Yes
3DMD	Submillimeter resolution	Yes
Anatomi Metrix	Submillimeter resolution	No
Aetrex Technology	4,000 pixels	Yes
Artec	1.3 megapixels	Yes
FlicFit	High resolution	Yes
Global Inspection Solutions/3D3 Solutions	64 Megapixels (8,000 texture maps)	Yes
Hewlett-Packard (HP)	High Resolution +- 0.5 mm	Yes
Human Solutions	High Resolution +- 0.5 mm	No
IBV: Instituto de Biomecánica de Valencia	High Resolution within 1 mm accuracy	No
Leica Geosystems	High Resolution +- 0.25 mm (800 x 480 pixels)	Yes
Netvirta	High Resolution +- 0.5 mm	Yes
Occipital	VGA (640 x 480 pixels)	Yes
Paromed	High Resolution +- 0.5 mm	Yes
Precision 3D	High Resolution +- 0.5 mm	Yes
Shenzhen 3DOE Technology	4,000 pixels	No
Shining 3D	*Information not available*	Yes
STT Systems	High resolution (752 x 480 pixels)	No
TechMed3D	High Resolution +- 0.5 mm	Yes
Thor3D	1.3 Megapixels	Yes
Trnio	High Resolution +- 0.5 mm	Yes
Volumental	+- 2 mm	No
Vorum	High Resolution +- 0.1 mm	Yes

4.10. Scanner price

Vendors reported a wide range of prices associated with their 3D scanners. Several vendors were reluctant in discussing price, as they sought to negotiate each and every sale. Few of them had definitive, clear prices – except for the vendors that produced smaller hand-held devices. To provide vendor confidentiality, a price code (Table 9) was developed to report ranges of scanner prices. Table 10 presents prices by vendor.

Table 9. Scanner price codes (in USD).

Under $10,000	$10,000 to $19,999	$20,000 to $29,999	Over $30,000
✶	✶✶	✶✶✶	✶✶✶✶

Table 10. 3D scanner price, by vendor.

Vendor Name	**Price**
3D Footbank by Dream GP	★ ★ ★
3DMD	★ ★ ★ ★
Anatomi Metrix	★ ★
Aetrex Technology	★ ★
Artec	★ ★ ★
FlicFit	★ ★
Global Inspection Solutions/3D3 Solutions	★ ★
Hewlett-Packard (HP)	★ ★ ★ ★
Human Solutions	★ ★ ★
IBV: Instituto de Biomecánica de Valencia	★
Leica Geosystems	★
Netvirta	★
Occipital	★
Paromed	★ ★
Precision 3D	★ ★
Shenzhen 3DOE Technology	★
Shining 3D	★
STT Systems	★ ★ ★
TechMed3D	★ ★ ★
Thor3D	★ ★ ★
Trnio	★
Volumental	★
Vorum	★ ★ ★

5. Conclusion

Through the use of the 3D HSAF, information was gathered, in order to share the current scanning equipment landscape to other researchers interested in hand anthropometry. The technology landscape is evolving so quickly today, that it is possible new scanners have debuted since the data were collected. It is also possible that some scanners were missed, as mentioned some vendors did a very poor job of communicating their products and capabilities. Nevertheless, keeping track of products in the 3D scanner space through the 3D HSAF is beneficial and could be updated annually to keep researchers accurately informed.

So, what can vendors do? There is a need for consistent communication of scanner attributes between vendors. The researchers suggest developing a more consistent method of explaining metrics and units, so it is easier to weed through the information. Share all the scanner's attributes. If researchers cannot find information about a particular scanner – it "raises a red flag." It says something is hidden, or there may be technological glitch. This makes researchers reluctant to invest. Make the information clear, make it available on public websites, make it easy to understand.

There are also obvious technology gaps presented in this research that can direct future scanner development. For vendors that have existed for over 10 years, it may be advantageous to develop hand-held scanners or ones that operate off of a mobile device – as researchers are keen to collect data beyond their laboratories. Perhaps collaborating with another company could be beneficial, effective and improve sales. For 3D hand anthropometric studies, if the scanner cannot accurately and clearly collect any subject's hand/wrist, in color, with details and landmarks – then it is not worthwhile investment.

As for the 3D HSAF, there are secondary attributes that could be added to further understand scanner capabilities, including: wireless, tripod, rotating table, robotic arm, USB, Wifi, Bluetooth, SD card and ethernet features. The 3D HSAF could also be re-developed for other types of 3D scan studies (e.g., body and foot). In reality, no matter what type of 3D scanning research is being conducted – it is very difficult to find accurate information without spending a lot of time doing research. Ultimately, the researchers strive to help others find the right scanner products by giving them the context and guidance they need to make informed purchases.

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