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3D Laser Scanning: A Model of Multidisciplinary Research

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ABSTRACT

New tools and technology are driving research in the 21st century and encouraging multidisciplinary collaboration. A model of research exploration inspired by the technology of 3D laser scanning is presented in this paper representing disciplines as diverse as Ergonomics, Reverse Engineering, Biomedicine, and Apparel Design. The paper demonstrates how 3D laser scanning technology can encourage the sharing of problem solving strategies and research methodologies across seemingly unrelated disciplines. Such inter- and multidisciplinary collaboration offers the potential for creative design exploration that is beyond the scope of any one perspective or discipline, thus expanding the possibility for innovative solutions to today's complex problems.

Keywords: 3D laser scanning, technology, model, multidisciplinary, research

Introduction

Many new research and technology developments require a multidisciplinary approach to problem solving. This kind of approach combines the expertise of specialists from different disciplines to work together on a common problem. However, when researchers from disparate disciplines pool their approaches and modify their methodologies so that they are better suited to the problem at hand, the approach becomes interdisciplinary. The methodological shift from a single disciplinary, to a multidisciplinary, to an interdisciplinary approach is driven by the need to address complex problems that intersect traditional disciplines. An interdisciplinary approach broadens the scope of the investigation often yielding fresh and unexpected insights.

Single disciplinary approach→ Multidisciplinary approach → Interdisciplinary approach

Figure 1: Evolution of problem solving strategies

New tools and technology continue to revolutionize our lives as we make our way into the 21st century. The accelerating power and presence of technology has produced unlikely partnerships between disciplines as each adapts new technologies for use in their own field or an emerging one. The Charge-Coupled Device, or CCD, is one such example. While invented in 1962 by researchers trying to figure out a way for semiconductors to store data, CCDs have become a ubiquitous component of consumer electronics such as digital cameras and scanners, as well as more sophisticated applications such as the Hubble Space Telescope, the Mars rovers, and the satellite systems circling the earth (McGrath, 2006; http://www.technologyreview.com/TR/wtr_16125,323,p1.html). Another invention based on the CCD is three dimensional laser scanning and forms the basis of this paper.

Three-dimensional laser scanning technology is a tool that is germane to the exploration of a wide variety of research areas encompassing disciplines as diverse as science, engineering, medicine, physical therapy and fashion. Because of the diversity of its application, laser scanning technology encourages a multidisciplinary research focus and collaboration across academic disciplines and with industry. Many of the applications of this technology focus on anthropometry, or the study of the size and shape of the human body. Obvious areas of study that can benefit from the anthropometric capabilities of laser scanning include the biomedical and ergonomic fields. Less obvious are the apparel, e-commerce, and video-gaming industries. Other fields of study may have little or no relationship to anthropometric measurements, but are concerned with measuring surfaces of objects that provide some engineering function. These areas might include reverse engineering or product quality control.

This paper discusses some of the current and potential applications for 3-D laser scanning technology. Figure 2 illustrates ways in which laser scanning technology can be utilized by different disciplines with the ovals representing four major categories: Ergonomics, Reverse Engineering, Biomedical, and Apparel. Brief discussions of these categories and their multiple subcategories (rectangles) will follow a section devoted to anthropometric history and laser scanning equipment description. The paper will conclude with some of the current limitations of the laser scanner, potential research applications and future considerations. It should be noted that Figure 2 is not meant to be an exhaustive list, but a starting point for discussion of interdisciplinary research that would benefit from laser scanning technology.

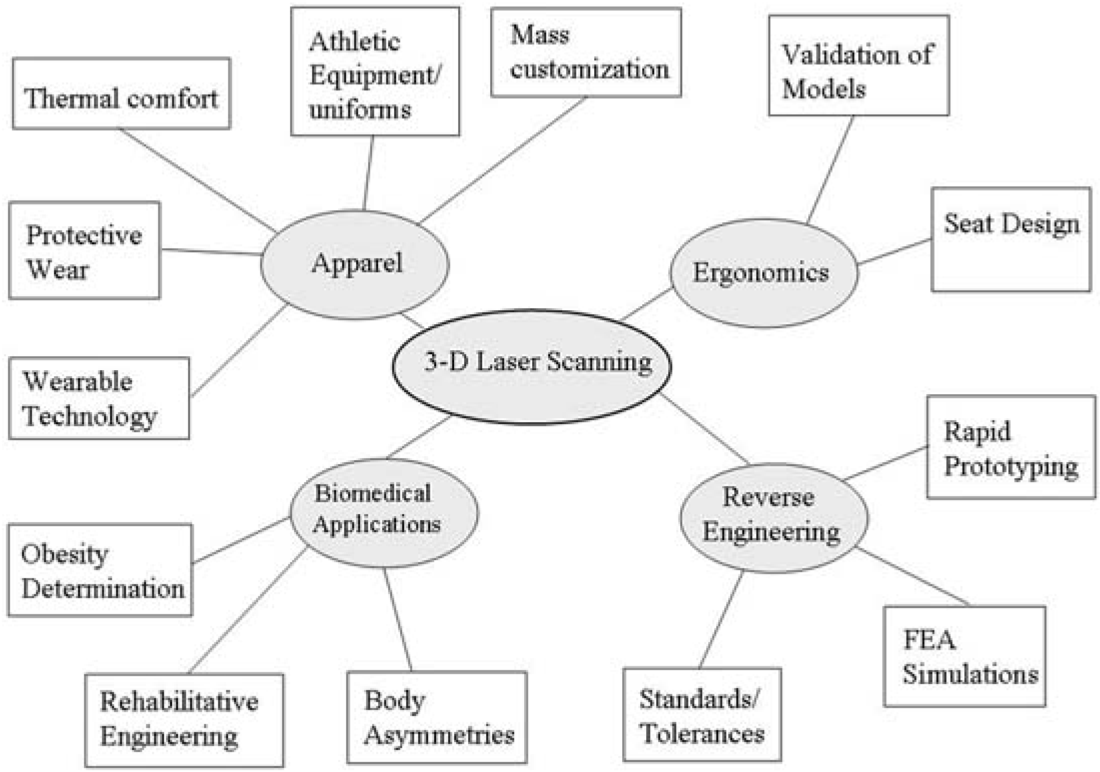

Figure 2. 3D Laser Scanning Ideation Model

History

Anthropometry, or the study of human body measurements, began in 1870 when Quelet attempted to obtain measurements of the average man in order to provide better fitting uniforms for Napoleon's army (CUErgo, 2005). However, anthropometry did not become a recognized discipline until the 1950's (Simmons & Istook, 2003) with researchers utilizing tape measure, weight scale, spreading caliper and sliding compass as measurement tools. These methods of studying anthropometry were subject to both unreliability of the measures (Bray et al., 1978; Cameron, 1986; Foster et al., 1980; Johnston et al., 1972; Marshall, 1937; Simmons & Istook, 2003) and observer error. Over the past 70 years of anthropometric research, observer error has proven to be the most problematic, even by trained observers (Bennett & Osbourne, 1986; Gordon & Bradtmiller, 1992; Jamison & Zegura, 1974; Marshall, 1937). Observer error includes inaccurate instrument placement and readings, subject stance, and imprecise placement of landmark location (Williamson et al., 1997). Overall, the traditional methods of collecting anthropometric data are time-consuming, fraught with observer errors and inaccuracies, and require physical touching of the subject. The development of 3D laser scanning has solved many of the aforementioned problems allowing for the extraction of precise body measurements from scan data in seconds.

Scanning Technology

The 1960's saw the introduction of new scanning technologies, which eventually revolutionized the science of anthropometry. The main function of these scanning devices is to measure the surface topography of the human body. Initial scanning devices were only able to capture one side of the body at a time until 1985 when Magnant developed a system that completely surrounded the body (Simmons & Istook, 2003). These earlier scanners typically utilized light, cameras, and projectors to capture anthropometric data and suffered from limitations including being labor-intensive, time consuming, or unable to accurately represent concavities in the human body (Ulijaszek, et al., 1998). After 1985, systems were developed that made use of white light, lasers, and shadowing to collect body data points.

One of the first large scale research efforts to make use of the newer 3D laser scanning technology was the CAESAR Project (Civilian American and European Surface Anthropometry Resource). CAESAR was the result of a comprehensive research project that brought together representatives from industry including apparel, aerospace, and automotive in order to assist these industries with their ergonomic needs by making anthropometric measurements over large populations of citizens. CAESAR began as a partnership between government and industry to collect the most extensive sampling of consumer body measurements for comparison. Throughout the mid-to late eighties, the project collected data on 2,400 U.S. & Canadian and 2,000 European civilians and a database was developed (SAE International, 2005).

The last fifteen years have seen significant improvements in laser scanning technologies; solving many of the scanning problems of the previous decade. Several companies currently manufacture laser scanners including Human Solutions, TC^2, Hamamatsu, Cyberware, Vitronic, and Wicks and Wilson, each utilizing somewhat different scanning technologies, capturing differing numbers of data points, and producing slightly different results (Istook, 2000; Jones, et al., 1995; Mckinnon & Istook, 2002). As the cost of scanning technology begins to decline, research utilizing 3D laser scanners is becoming accessible to universities and industry. Currently, there are a number of major ergonomic studies underway by consortiums of research universities, government, and industry to create large, accurate anthropometric datasets (Loker, et al., 2004). SizeUK scanned over 11,000 Britons, both standing and sitting, in a collaborative effort between the British government, eight universities, and major British clothing companies. SizeUSA, a consortium of industry and universities, is in the process of collecting 12,000 scans of men and women throughout the United States. France is also involved in a national sizing survey and China, Korea, Mexico, and Brazil are planning similar body scanner- based national surveys (Treleaven, 2004). Complementing the large survey studies is a growing body of academic and industry research. Research topics include: consumer perceptions of body scanning (Locker, et al., 2004; McKinnon & Istook, 1999), limitations and the need for standardization (Istook & Hwang, 2001; Jones et al., 1995; McKinnonn & Istook, 2002; Simmons & Istook, 2003), mass customization of apparel (Lee & Chen, 2000; Xu et al., 2002; Anderson et al., 1997) and analysis of body shape and posture for fit and reengineering (Istook, 2000).

Besides laser technology, capturing surface topography data can be accomplished in many ways for both anthropometric and non-anthropometric applications, such as surface metrology of manufactured parts. They include, but are not limited to:

1. Coordinate Measurement Machine (CMM) Technology. CMM data acquisition is time consuming because it locates one point at a time along the surface to be scanned, which is typically a manufactured part. It also requires a probe to physically contact the object which may become challenging if the surface is easily deformable (foams, rubbers, biological materials) (Chen, 1999).

2. Computed Tomography (CT) Scanning. CT scanning provides both surface and internal data of the scanned subject or object. A disadvantage of the larger industrial and medical CT systems is possible radiation exposure to the subject and equipment operators. Significant safety features and operator training are necessary to reduce the risk of unnecessary exposure. Laser scanning provides an attractive alternative to CT scanning when only surface information of the subject or object is required.

3. Optical Scanning. Optical scanning requires no contact with the object and has no adverse effects for biological materials, but requires 360° rotation of the object on a turntable or multiple cameras stationed around the object to capture the different orientations of the object. These technicalities may become cumbersome depending on the scanning situation, i.e. people who experience motion sickness or balance problems, objects too heavy for the turntable mechanism (Chen, et al., 2002).

4. Industrial Laser Scanning. There are a number of laser scanning systems on the market specifically engineered to scan manufactured parts smaller (10” L x 10” W x 16” H) than the human body. These systems are smaller than the typical laser body scanners mentioned below and employ a different scanning mechanism. The industrial units may pass a single laser stripe over the part or object multiple times at different orientations or rotate the part on a turntable. The smaller systems often have increased accuracy and resolution in their measurements when compared to their larger counterparts because of their reduced size and different scanning mechanisms.

<u>Human Solutions Vitus Smart 3D laser scanner</u>

The scanning system consists of two main components: the scanning assembly or booth and a PC with image reconstruction software. The scanning assembly is 4’ wide by 4’ deep by 10’ high. (see figure 3) with a structural frame to keep the device stationary; curtains are hung from the frame to minimize outside light. Located in each of the four corners is a vertical column containing the essential scanning equipment: a low energy laser, and two charge coupled device (CCD) cameras, all of which ride together in an elevator assembly that travels up and down in the vertical column. When the system is calibrated correctly, the four elevator assemblies travel down the columns in unison, sweeping the scanning zone with a horizontal plane of laser light. The laser light illuminates the contours of an object standing within the scanning zone and the CCD cameras record discrete points on these contours at each horizontal plane. The entire scan takes approximately 12 seconds.

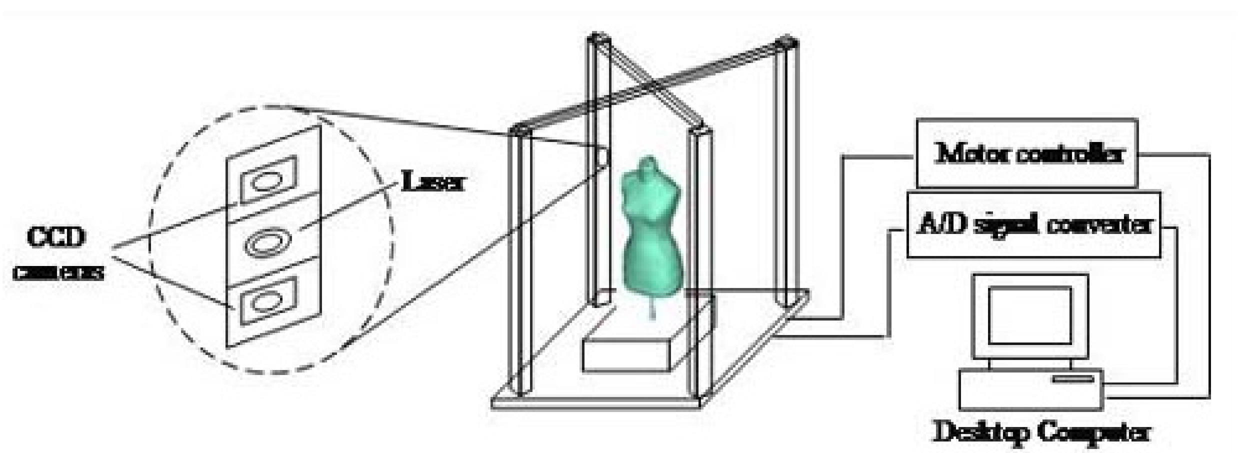

Figure 3. Diagram of 3D Laser Scanner

A computer attached to the scanner contains the user interface, data acquisition/reconstruction, and data analysis software, while interfacing with the motor controller. The computer software acquires data from the A/D converter and triangulates the discrete points for all of the horizontal planes, creating a point cloud representation of the object scanned. This process takes approximately 2 minutes to complete. After the data acquisition/reconstruction program is completed, a 3D image of the object is displayed on the computer screen. The point cloud data can be exported into proprietary and standard file formats (obj, dxf, sdl, ascii) which can be imported into various computer aided design (CAD), finite element analysis (FEA), and rapid prototyping software packages.

Current and Potential Applications of 3D Laser Scanning

Biomedical Applications

Science and technology have always offered enormous promise for advances in biology and medicine. With the development of 3D laser scanning technology, complete and accurate visualization and quantification of the human topography is now possible. The applications for such technology include examination of the body for asymmetries, skeletal alignment, rehabilitative engineering and obesity determination, to name only a few. A selection of areas where laser scanning technology has been applied will be reviewed here.

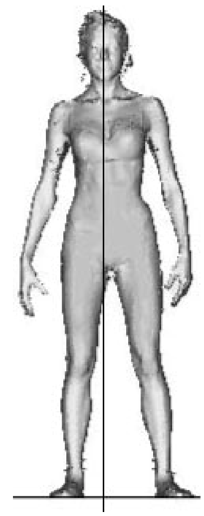

Figure 4: Bilateral Split of 3D body image created by laser scanner.

Body Asymmetries

Fluctuating asymmetry, or FA, may be defined as the differences in degrees of bilateral symmetry within organisms. Most organisms, including humans, are bilaterally symmetric, with the right half of the body a mirror image of the left half. Perfect symmetry between bilaterally paired morphological traits such as shapes and sizes of limbs and facial features is common in nature. Deviations from symmetry (see Figure 4) may occur during development due to environment or genetic stress resulting in fluctuating asymmetry. (Tomkins and Kotiaho, 2001). FA is the main measure of developmental instability used in biology (Gangestad, 2001). Fluctuating asymmetry is a topic of interest to biologists because of the possibility that developmental instability is a meaningful component of an individual's fitness. Anatomical asymmetries are linked with individual differences in cerebral organization (Kertesz 1992) with right- or left-handedness in humans an obvious example. Other claims advance FA as a predictive tool for intelligence, attractiveness, and athletic ability. Thornhill and Moller (1997) suggest that FA is comparable to the physician’s thermometer and that developmental stability is an important marker of human health.

Current methods of quantifying FA are not easy and require subtracting the measurement of the right side of a trait from that of the left side. The opportunities for observer bias and human error in measurement are great. Laser scanning makes possible accurate and objective measurements for assessing bilateral morphologic traits in humans by eliminating human subjectivity.

Scoliosis is defined as a structural lateral curvature of the spine that presents itself in humans at the onset of puberty and for which no cause has been established. Currently, it is diagnosed by the visual presence of body asymmetries. Examination of the patient in the standing position may reveal asymmetries in shoulder height, shoulder blade prominences, chest prominences, and other spinal abnormalities. Schmitz et. al (2002) scanned subjects with scoliosis and used the 3D generated model to measure defined anthropometric parameters. The authors concluded that the laser scanning system allowed a rapid, touchless and accurate 3D measurement of the whole body in scoliotic deformities. Images generated by body scanning have enormous potential for precise and repeated measurement of a host of conditions which demonstrate deviation from symmetry.

Rehabilitative Engineering

The design of a properly fitting prosthesis requires an examination of the biomechanical interaction at the interface between the limb and the prosthetic device (Vannier, 1997). The subject's comfort, acceptance and potential for ambulation are dependent upon the quality of fit of the prosthesis. Laser scanning allows the 3D image generated by scanning the body to be a useful tool in the design, development and fitting of prostheses for patients without limbs. Two factors contribute to the comfort of fit of a prosthetic: matching the limb to the prosthesis surface and providing stability to the remaining bone structure of the limb. Laser scanning has been found to provide rapid and accurate description of the skin surface of the limb residua while (spiral) computed tomography (CT) provides complete and accurate assessment of bone and soft tissue components. The symmetry function built into the scanning software is capable of creating an image of the interfacing surface (http://www.polhemus.com/Hanger.htm). Each of these tools provides the requirements for 3-D reconstruction of the prosthetic.

Three dimensional scanning has been found to be a useful tool in breast surgery for breast augmentation, reconstruction after mastectomy, breast symmetry and breast reduction (Hannapel, 2003, January 1; Losken et al, 2005). The body scanner and its associated software can provide quantitative analysis of breast volume, distance, surface area and shape. The technology allows the surgeon to examine pre- and post-operative dimensions of the breast as well as how its volume changes over time. Plastic surgeons have employed the use of 3D image data, reverse engineering and CAD software to simulate a model of the breast. Sun & Chen (2003) used a rapid prototyping machine to make a full sized model of the breast for use in evaluation and consideration of post operative treatments. The potential exists to create much better fitting and more comfortable breast prostheses for mastectomy patients by using this scanning technology.

The use of 3D scanning has also shown important application to wound healing sciences. For burn patients with extensive facial wounds, 3D anthropometry has been used to provide non contact scanning of the face in order to develop transparent facial orthoses (TFO), or masks, at an earlier stage of healing. The 3D scanning replaces the development of masks based on conventional plaster molding that generally take place later in the healing process but also tend to deform the facial tissue of the burn victim (http://www.cyberware.com/news/newsletters/newsletter10.html). This particular application is an excellent example of the advantage of the non-contacting method of measurement characteristic of laser scanning.

Obesity Determination

Anthropometric measurements have long been used as a means for assessing nutritional status and health risks. Health risk has been shown to be highly correlated with body habitus in the young and the old alike. Body habitus refers to one's body shape, size, and disposition as well as one's perception of the body. The increasing trend towards obesity and its complications have prompted investigations from the cellular to the environmental levels with regards to prevention, intervention and care of persons suffering from the complications of obesity. Assessing body habitus has become the standard way of identifying and intervening in the population at large in hopes of curtailing the burden of rising health care costs as the population ages (Okosun, 2004).

Traditional methods for assessing the body include circumference measurements like the waist to hip ratio, waist circumference, thigh girth, neck girth, maximal hip girth and mid-arm muscle circumferences. Such measures have been used for predicting health risk based on large scale epidemiological trials. One of the problems with such measures however, is the inaccuracy with which the measures are made. Traditional methods of collecting anthropometric data are time-consuming, fraught with observer errors and inaccuracies, and require physical touching of the subject.

Laser scanning technology offers the health professional a fast, reliable, accurate and cost effective device for body habitus assessment. The major advantages of the laser scanner are that it is easy to use, non-invasive, safe, fast and possesses the potential to provide anthropometric data with increased validity, reproducibility and overall generalizability. Extensive body measurements can be made on a subject in a matter of seconds with no touching of the subject whatsoever. The obesity epidemic warrants investigation into novel technologies such as laser scanning that foster the assessment of body habitus in large numbers of persons.

Summary

In sum, laser scanning technology offers the biomedical community a quick, efficient method of visualizing and quantifying the human body. For example, quantifying body irregularities such as scoliotic deformities and fluctuating asymmetry is difficult and requires subtracting the measurement of the right side of a trait from that of the left side. The opportunities for observer bias and human error in measurement are great. Laser scanning would allow for accurate and objective measurement of a host of conditions which demonstrate deviation from symmetry. Additionally, laser scanning has proven to be a useful tool in the design, development and fitting of prostheses for patients without limbs. On a broader scale, laser scanning technology offers the health professional a dependable, precise and cost effective device for health risk assessment.

Apparel Applications

Clothing has been defined by Watkins as a "portable environment" (1995). It surrounds the individual creating its own environment within the larger environment and its own climate within the climate of our surroundings. As the surroundings in which we work and play become ever more complex, the interface between our bodies and the larger environment plays a role not only in modesty and adornment, but also in protection and in increasing our own functionality. Modern consumers ushering in the 21st century are already conditioned to expect functional, comfortable products tailored to meet their specific needs. From anti-microbial socks to wearable electronics, well designed functional apparel is everywhere from NASA to Walmart (MacGillivray, 2004).

Functional apparel may help an individual with physiological functions such as maintaining thermal balance in a range of environmental temperatures; or aid a person in allowing a full range of motion for tasks that they must perform. Functional apparel may be protective from harmful effects of the environment such as pesticides, radiation, or other toxins. The functions that the apparel must help to perform are defined by the needs of the wearer or user group. Expectations for apparel in the 21st century are high. Consumers want apparel that is customized to their bodies as well as to their wants and needs. Laser scanning offers the opportunity for garments to be customized by function as well as by fit, not only to the masses, but to the individual consumer as well.

Thermal Comfort

The thermal resistance that clothing offers is a critical factor in maintaining thermal balance and therefore, clothing comfort (Fan and Chen, 2002). The microclimate is defined as the interface between the textile and the body's skin (Jirsak, Gok, Ozipek, & Pan (1999). It is relevant in virtually all clothing and personal equipment applications because it acts as a thermal buffer between a person and the environment, thus altering the flow of heat, vapor and liquid between them (Kim and Sun, 2000). Too much or too little resistance will cause a change in the person as he/she strives to maintain thermal equilibrium. Too little thermal resistance for the lightly clothed person at rest in a cool environment will most likely result in a behavioral change in the person (Olesen, Sliwinska, Madsen & Fanger, 1982). On the other hand, clothing that offers too much thermal resistance may cause the body to emit moisture in vapor or liquid form. If the clothing system allows moisture to transfer to the outside where it can evaporate, the body will not have to work so hard to maintain equilibrium. However, impermeable clothing sets off a cycle that begins with increasing the temperature of the microclimate that, in turn, signals the brain to sweat. Because the clothing hampers the body's ability to cool itself, moisture continues to increase at the skin surface resulting in thermal unbalance that may involve uncomfortable tactile sensations or, in the worst-case scenario, heat prostration. There is a voluminous literature on methods to measure heat and moisture transfer through fabric layers. Much of this literature is reviewed by Levine, Sawka and Gonzalez (1998). However, the microclimate presents a challenge because its properties are so difficult to accurately measure or computationally model for realistic geometries.

Protective Wear

The variety of hazardous environments that require protective clothing for workers presents a daunting task for the designers of protective apparel and equipment. Requirements of such apparel might include protection from one or more of the following risks to the body: extreme cold or heat, flame, toxic gases, liquids, chemicals, particulate dirt, dust or other toxic matter, bacteria, bodily fluids, bullets and sharp projectiles, to mention only a few. Protective clothing evokes visions of bulky, ill-fitting, one-size-fits-all garments that result in heat stress, worker inefficiency and limited range of motion.

The wear comfort of protective clothing is a major component of its protective function (Bartels and Umbach, 2004). It is imperative that the design of protective clothing take into consideration the thermal, physiological and mechanical functions of the human body. Protective clothing that hampers worker movements, or prevents a worker from being able to complete a job due to heat prostration, is ineffective and will ultimately be rejected by the wearer. National Fire Protection Association (NFPA) statistics demonstrate that excessive physiological strain caused by overheating of the body is the most frequent reason for fire fighter deaths (Waschburn, LeBlanc and Fahy 1992). While improvements in fire fighter apparel afford wearers more thermal protection, they may also reduce worker time by requiring more physiological energy demands (Malley et al, 1999).

Athletic Equipment/uniforms

The design of apparel for sports-specific activities has often led the way in functional apparel design. Four-way stretch fabrics that incorporate padding, mesh inserts that provide ventilation for sweat inducing activities, pleats to accommodate joint extension and flexion, fabrics which allow moisture vapor transport but are water resistant – all of these innovations first appeared in sports apparel.

Innovation in textile materials and apparel design continues to emerge from the sports sector today. For example, Adidas is promoting a new clothing technology that purports to enhance athletes' movements in 1) running, 2) upper body rotation and quickness and 3) lower body power and movement (http://www.gizmag.com/go/3573/). The clothing technology developed by Adidas utilizes a combination of compression fabrics, sculpted silhouettes and 3D engineering to optimize fit and comfort and to "boost athletic freedom of movement." In addition to this technology, Adidas has used infrared thermography to map the body's critical heat and sweat zones and then used these results to place heat and moisture dissipating fabrics where they are needed to optimize an athlete's thermal regulation. Nike, also a leader in sports apparel design, has used the concept of creating a body map from a laser scan to design garments with increased airflow by using strategically placed ventilation zones to facilitate heat transfer ("New Nike," 2005, December 5).

Research on the effectiveness of these innovations is limited at this point in time. The efficacy of compression athletic apparel to enhance muscular strength and endurance was evaluated in one study and did not demonstrate any advantage in spite of product advertisements stating a 30% enhancement of endurance and power (Maitland and Vandertuin, 2002).

Wearable Technology

The integration of technology into clothing has produced a new area of design - intelligent or "smart" clothing. According to Dunne, Ashdown and McDonald (2002), an intelligent garment differs from ordinary clothing in its ability to receive input from the wearer or from the environment and to use that input to activate or change the state of an associated technology. Smart clothing can be seen as a subset of both wearable technology and functional clothing (see Figure 1; from Dunne, 2004, August). A smart garment may be structured to respond to a change in light, temperature, pressure, sound or chemical reaction. Garments responding to a change in blood pressure, heart rate, or breathing need to be customized to the individual for proper fit and placement of the sensing mechanisms; otherwise, intervention may not occur.

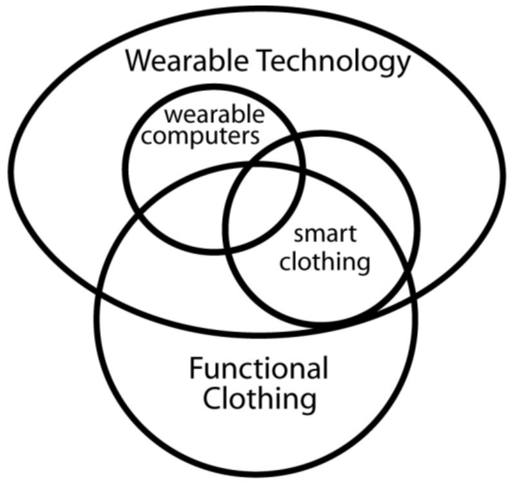

Figure 3: Relationship among clothing technologies.

Dunne L.E. (2004, August). The design of wearable technology: Addressing the human-device interface through functional apparel design. Master's thesis. Cornell University. Used with permission of author.

A host of wearable products have been developed that answer the growing need for continuous body monitoring in areas such as weight management, cardiac disease, sleep disorder, and assisted living. These wearables generally include donning some kind of device such as an armband that contains sensors that auto-record personal data. The data is then uploaded wirelessly to a computer with software that analyzes the data. The medical professional, healthcare professional, nutritionist, trainer, or the individual themselves then determines whether a change in behavior or practice is warranted. The combination of wearable monitors, wireless devices and software tailored to meet specific clinical needs are especially welcomed by medical professionals who can monitor their patients from remote location.

A further development in the evolution of wearable technology is the convergence of electronics and textiles. This junction has led to the development of electro-functional fabrics capable of collecting, transmitting and receiving energy within the textile structure itself. With electronic textiles, the functional components are embedded in the structure of the fiber or fabric, eliminating the need for wires or cables. Electronic textiles can conduct and sense and are being used in a host of intelligent wearable applications including biophysical monitoring, motion and position sensing, illumination, and warming.

As a portable environment, wearable technology must take into account factors related to the human/machine interface: comfort, mobility, utility and aesthetics. Intelligent wearables are a new technology and, as such, will go through several adaptations as new applications are explored. Presently, most wearables are designed by individuals or teams including computer scientists, engineers, athletic trainers, occupational therapists, or other medical professionals. The integration of wearable technology into customary apparel in the 21st century requires an interdisciplinary approach that blends the methodologies of the various disciplines so that a comprehensive and innovative solution can be found for functional apparel that 1) fits, 2) is comfortable, and 3) is acceptable to the wearer.

Mass customization

Mass customization is a hybrid of mass production and customization (Lee and Chen, 2000). It encompasses a strategy that uses information technology to produce customized goods and services with efficient low-cost mass production methods. According to Pine (1993) advanced technology is a prerequisite for the implementation of mass customization.

Mass customization of apparel requires automation in at least three processes: body measurement, pattern design, and fabric cutting (Xu, Yuang, Yu, and Chen, 2002). Laser body scanning provides a method of non-contact measurement which results in extensive and accurate measures of the body. Once measured, the customer selects a garment design and the fabric from which to make it. Interfacing pattern- making software alters the selected pattern to fit the individual's measurements. The pattern is then sent digitally to a single-ply fabric cutter that cuts the garment out of fabrics pre-selected by the customer. The garment is assembled (sewn) and sent to the customer within days of order placement. According to Anderson et. al. (1997), emerging technologies like laser body scanning and the translation of body measurements to a portable digitized format such as a smart card will help to move mass customization into the mainstream.

Kamali and Loker (2002) investigated on-line consumer involvement in apparel product design and found that consumers' satisfaction increased as interactivity based on design involvement was offered. The number of design feature options for a mass customized product did not make a difference in the satisfaction of consumers with the process – they were as satisfied with 50 feature options as with 37,500. Kamali and Loker (2002) concluded that mass customization strategies that promote consumer involvement in product design are an attractive approach for web-based businesses.

Summary

The laser scanner is an important tool for apparel applications that require a close examination of the microclimate. Because the laser scanner is capable of measuring both the dimensions of the body as well as the outside layer of a garment, the physical dimensions of the microclimate can be quantified in unprecedented detail for its impact on heat and moisture transfer. Utilization of microclimate data can then be used to guide the development of a functional garment that facilitates optimum moisture management and climate comfort resulting in a longer, safer, and more comfortable wear time. Lastly, the emerging industry of wearable technology will require the use of individual body measurements and 3D imaging in the design process so that specific body measurements and body conformations can be examined in relationship to the wearable technology and its potentially seamless interface with the human body.

Ergonomics

Understanding the interaction between the human body and its work environment will be improved with laser scanning technology by providing more accurate information on the size and shape of the human body. Anthropometric information derived from large population studies, such as Size USA, is providing a wealth of information to ergonomic researchers allowing them to validate digital human models, "fit" the job to the individual, and to examine special ergonomic issues of particular subsets of the population, such as the elderly.

Validation of Models

Human modeling, or the modeling of the human body interacting with its environment, has evolved rapidly over the last 20 years bridging computer-aided design, human factors engineering and ergonomics. Digital Human Modeling (DMH) is an important component of the design process for products that require user-friendly interface, proactive ergonomics or when analyzing and improving the physical ergonomics of a product is critical to its commercial success (Chaffin, 2005). 'Jack' (U. of Penn.) and 'Santos' are commonly used DHMs. Case studies published by Chaffin (2001), indicate that the most common use of DHM tools is to simulate people of extreme sizes in order to create designs that accommodate a large variety of people, to allow them to reach, see and/or fit in a given space. Current difficulties include digital human models whose skeletal joint angles are anatomically correct, but neglect to incorporate restrictions in range of motion owing to clothing on the body or physical disability due to age or injury and the need for specialized ergonomic knowledge to use them correctly. Range of motion may include twisting, turning, extending or flexing limbs, reaching or grabbing with arms and hands. Laser scanning offers an accurate and time efficient way to measure realistic ranges of motion for various anatomical joints.

A growing number of industries are incorporating DMH into the design process including the automotive industry where digital human models provide information regarding a number of user interface variables such as: comfort rating for the evaluation of postures, dynamic movement of the body in relationship to ingress and egress, position of the seatbelt and the space necessary to access controls, and the contact between human and seat. Work environment and interior designers have begun to use DHM to improve the efficiency of working methods and production equipment, as well as indoor environmental simulations of airflow and containment concentration fields. The integration of a DHM simulating a physical handicap with 3D visualizations of products and living spaces, allow real-time simulation and interaction; testing a product or environment's performance prior to construction and therefore avoiding the need for expensive 'mock ups' (Duffy, 2005). NASA is using digital human models to provide information about the volume that a crewmember occupies (R. Rogge, et.al., 2005) and the video game/entertainment industries are employing DHM to provide the framework for the creation of realistic virtual humans (Magnenat-Thalmann et. al. 2004, Seo & Magnenat-Thalmann, 2003, 2004). For a more sophisticated model, motion capture data can be combined with anthropometric data to allow a designer to simulate a diverse set of manual tasks (Chaffin, 2005).

Seat designs are of great interest in the automotive, aircraft, and furniture industries. Consumers often do not notice when a seat is ergonomically designed and comfortable. However, if the automobile seat or office chair is uncomfortable, the consumer's attention is drawn to that seat in a negative way, which may lead to dissatisfaction with the entire product and little if any repeat business with the product's manufacturer. By measuring subjects in a seated position with the body scanner, seat designers can make more comfortable fitting seats and may be able to mass customize seats molded specifically for the conformation of individual customers' hips.

The design of airline and automotive interiors is now facilitated by the use of 3D human models (Roach, 1998). For the automotive industry, comfortable seating is considered a requirement by consumers. High-resolution human models provide ergonomic information regarding appropriate seat height, necessary leg room and will once "seated" can generate a computerized pressure map (Reed, Manary, Flannagan, Schneider, 2002). Seat and cushion designers for high performance vehicles have also made use of digital human models in order to better understand vibration and the body's limited tolerance to cope due to body dynamics (Rosen & Arcan, 2003).

Summary

Statistics derived from body scanning measurements may be used for validation of various ergonomic models including the aforementioned range of motion studies, length of reach studies, ingress/egress from automobile designs, and seat designs. Other areas where validation is needed include: field of view models of heavy equipment (for safety), posture of the body when lifting light, moderate, or heavy loads, and positioning of automotive airbags for optimum protection (Lockett, et al., 2005).

Reverse Engineering

In many areas of engineering, medical sciences and the arts there is a strong demand to create an appropriate computer representation of existing objects from huge sets of measured data points. This process is called reverse engineering or reverse engineering of shapes. Product information generation applications are very common and include reproducing and redesigning legacy parts, when no original drawings or documentation are available or in areas where aesthetic design is particularly important, such as the automotive industry. Another important area of application is custom fits to human surfaces, for mating parts such as helmets, or prostheses. Three-dimensional CAD models are the industry standard communication tool for manufacturing and design. By converting physical parts, through 3D scanning to a CAD format, efficiencies can be realized in areas such as product development, manufacturing technology, enterprise communication, market evaluation, and, time to market.

Data captured with the 3D laser scanner can be imported into many existing engineering applications including CAD, FEA -finite element analysis, or CFD - computational fluid dynamics, simulations, rapid prototyping processes and quality control. The major advantage common to all these applications is that the scanned data can replace the time consuming and tedious step of generating CAD models of the part. In some cases, such as aerodynamic or heat transfer simulations, computational results may be more realistic by using a 3D model of the actual scanned shape as opposed to idealistic representation generated from CAD models.

FEA Simulations use B-spline curves or NURBs (non uniform rational B-spline), both mathematical representations of a curved surface, derived from the point cloud data to accurately represent the part or component without the need to create a model of the part. Stress analysis, fluid dynamics, heat transfer of the *existing* object can be modeled if the point cloud data can be efficiently imported into the simulation software. Objects with complex geometries and curvatures such as automobile bodies, can be represented more accurately and efficiently with scanned data instead of generating a theoretical CAD model.

Rapid Prototyping or Miniaturization of an existing part into a scaled down version of itself is useful when designing or redesigning an assembly consisting of new and existing parts. By laser scanning the existing part, time and effort can be saved that would have been spent on measuring and drawing a CAD model of that part. Williams, Torrens and Hodgson (2004) used anthropometric data to generate CAD models which were then, through rapid prototyping techniques used as a design and quality manufacturing tool to produce better fitting military gloves.

Standards and Tolerances

Three-D laser scanning may also become an important tool in the area of geometric dimensioning and tolerancing (GD&T) of part surfaces. Tolerance evaluation (how to assess geometric deviations of a part from its intended design) has traditionally been performed with data acquired with coordinate measurement machines (Hong-Chang, 2002). For parts with complex curvatures, single point measurements characteristic of coordinate measurement machines may not provide enough data to accurately capture the true shape of the part's curvature or may be unreasonably time-consuming. 3D laser scanning overcomes this shortcoming by providing a more adequate sampling of the part's surface and may ultimately lead to new paradigms in GD&T inspection practices. For example, computer aided verification (CAV), where the 3D measurements of a manufactured part or prototype can be directly compared to its CAD model and any dimensional deviations can be shown in color over the part's surface. Numerous businesses specializing in metrology offer inspection services that offer CAV capabilities and can convert files of scanned data for FEA simulations of the scanned part.

Summary

The concept of reverse engineering began with traditional engineering applications but now has spread into a variety of disciplines including ergonomics, medical sciences, and archeology. Through laser scanning, existing objects become virtual, allowing for easier modification and re-design. This process eliminates the need to create multiple physical mock-ups of the original, saving time and money in the redesign of the object.

Limitations

Anthropometric

While 3D laser scanning technology is quick and produces accurate, reproducible data, there are still limitations. First, there is incomparability of measuring techniques between scanners as well as the lack of standards, published or unpublished, on the interpretation of human measurements or measurement terms. Most scanners are intended to be non-contact, but touch of the human body to find the appropriate landmarks (predefined key measurements such as waist, chest, and wrist) is occasionally needed (Simmons & Istook, 2003; Xu, et al., 2002). Secondly, the human body and its positioning impact results. A subject's stance and foot positioning can impact the height, inseam and hip measurements and respiration can significantly impact chest measurements (Mckinnon & Istook, 2002). Finally, no body scanning system is currently able to capture 100 percent of the body's surface (Istook & Hwang, 2001; Ulijaszek, et al., 1998) and may miss horizontal surface features since the laser light shines parallel to these features. Lastly, access to scanning equipment may be difficult as there are few portable devices and they tend to have even more problems and limitations.

Non-anthropometric: Other limitations exist that are associated with non-anthropometric applications. One is the large number of data points (> 300 000) generated by the system when creating the point-cloud representation of the object's surface. Cumbersome data files result and there is research under way to reduce the point cloud data to more efficient B-spline or NURB representations of the scanned surface that can be more easily manipulated in CAD or FEA simulation software (Lee, et al., 2001, Steinberg, et al., 1998).

Current laser scanning systems are capable of measuring only static objects as opposed to motion capture systems commonly used in ergonomic or health-related studies which can measure the dynamic motion of a limb or joint. However, most surface measurement technologies (CMM, CT, optical) are inherently engineered for scanning stationary objects.

Irrespective of its limitations, 3D body scanning can produce precise, useful data for a multitude of different applications and thus the technology is currently being extended far beyond its original function of collecting anthropometric measurements.

Future Applications of Laser Scanning Technology

As laser scanning becomes more practical and cost efficient, new applications can be realized. The breath and scope of applications for this technology demonstrate its use for today's multidisciplinary problems. Potential applications of laser scanning technology are listed below:

Asymmetries of the Body: In-depth research can now be performed and stronger correlations among various asymmetries in the body and maladies can be made using laser scanning technology due to its ability to accurately measure small changes in shape and size of body parts. Laser scanning may become an important diagnostic tool for the health professions.

Cosmetic Surgery: Laser scanning has huge potential for a variety of cosmetic medical procedures including eye, nose, or other facial features, breast, stomach, hip, and leg modifications. The data from laser scanning can provide a 3D image that can be used with CAD to build a model of the body modification providing the patient with a more realistic view of the outcome. In addition, the patient can be actively involved in the actual design of the modification.

Body Size Assessment: Instead of relying on one measurement (weight) or the combination of two measurements such as height and weight (Body Mass Index), laser scanning can introduce the next generation of body size assessment. A simple calculation converts the surface measurements of the human body to the actual space a body takes up in terms of volume. In the future, dieticians and health professionals may speak in terms of "volume reduction" instead of "weight reduction". Health organizations may propose a "Body Volume Index" that calls out acceptable chest, torso, hip, arm, and leg volumes for the given height of a person. Much more accurate and detailed changes in body size and shape can be measured with laser scanning technology and people attempting to alter their body shape, such as body builders gaining weight or persons in weight loss programs, can measure their progress from the scans. Changes in body volume may be much more affirming and motivating to an individual trying to reduce or reshape their physique, especially when weight stays the same or is slow to change.

Protective Clothing: Great improvements in wear comfort for soldiers, haz-mat teams, fire fighters, police, and other first responders should result by combining laser scanning technology, functional apparel design expertise, and heat/mass transfer engineering. Functional apparel designers will be able to use microclimate data together with heat transfer simulations to create more comfortable, better fitting protective wear, thereby increasing their productivity and effectiveness.

Athletic Equipment and Apparel: By combining 3D laser scanning with temperature profiles obtained from infrared imaging systems, important advances in athletic equipment and sport apparel can be made. Better fit and heat transfer properties of uniforms will undoubtedly lead to enhanced athletic performance. Custom-fit shoulder pads, knee pads, and helmets could be made using procedures similar to those described for prosthetic fittings.

Thermal Comfort of Clothing: Potential applications include modeling heat transfer from the body's skin through a garment draped over the body, where the microclimate could be incorporated into the model.

Aerodynamic Modeling: Aerodynamic modeling of the underbody of automobiles (mass produced or specialty e.g. race cars) might reduce the amount of drag produced by the car. If the effects of minor changes in the aerodynamic shape of an object are to be modeled, then it would be much more efficient to make them through computer modeling than developing a physical model and going through a series of tests at a wind tunnel facility. In the future, sports trainers may be able to identify optimum body shapes, sizes and positioning that create minimal aerodynamic or hydrodynamic drag for sports such as bicycle racing, downhill skiing, running, and swimming using 3D laser scan data and CFD (computational fluid dynamics) simulations.

Animation: Video game players may soon be able to place 3D versions of themselves in their favorite video games simply by sending a scan of themselves to the game manufacturer, and having the manufacturer create a video game character from the scan data. Inanimate objects, animals, and other items may be scanned and animated for purposes of fantasy characters in films or videos. Persons who have been laser scanned and animated may remain perpetually "virtual" for use in a variety of applications.

Virtual brand try-on for apparel sold over the Internet: Laser scanning and its resultant 3D body image is a key technology enabling the support of more accurate on-line product visualization, automated garment sizing and size selection. A consumer wanting to know what they would look like in a particular garment featured by their favorite online e-tailer would only have to swipe their magnetic card (or other media) that holds their own body scan data and their computer screen would project an image of themselves wearing the garment. The image could be rotated for a full 360° turn of the body, showing front, back, and sides. The consumer could "try-on" different colors, styles and brands; whatever the e-tailer offered.

Conclusion

It is anticipated that many more opportunities for creative collaboration will be explored as 3D laser scanning receives increased exposure through the dissemination of research and innovative product development. The intersection of diverse fields such as apparel, engineering, ergonomics and biomedicine encourages the sharing of problem solving strategies and research methodologies. Such collaboration offers the potential for creative design exploration that is beyond the scope of any one perspective or discipline. New technologies perpetuate a range of design possibilities, creating what Parsons and Campbell (2004) refer to as a "complex and multifaceted set of decision points" for designers, researchers, technicians and product developers. The 3D laser scanning capability allows for more flexibility in conceptualizing prototypes and in altering and adapting existing products and processes, thus expanding the possibilities for innovative solutions. As the role of digital tools in the design process illuminates new modes of thinking, it also encourages new approaches to design (Cross, 1984). Most notably for 3D scanning, new approaches will undermine the "one size fits all" paradigm in product development and pave the way for customization in a range of applications currently beyond the imagination.

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