CAPABILITIES OF COMMERCIALLY AVAILABLE SOFTWARE TO DIGITALLY MODEL PEOPLE WITH SCI

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INTRODUCTION

The use of commercial digital human models (DHM) has become commonplace when designing large and complex manufacturing, automotive design, aerospace, defense, clothing, and oil production projects [1-5]. This ability to design virtual humans interacting with the environment has encouraged creativity in design, decreased time from design to completion, improved safety, enhanced employee and employer acceptance and allowed the anticipation and elimination of design problems before physical manufacture or construction. Given these advantages, and aware of the limitations of commercially available systems, our goal was to investigate more carefully, at the technical level, a commercial program's strengths and weaknesses in modeling people with severe movement limitations due to spinal cord injury. The selected program was Dassault Systemes' CATIA Human Builder Suite™, arguably the most widely used DHM software in industrial ergonomics and typical of most commercially available systems.

There is need for such study as the number of people in the United Stated with spinal cord injury is alarming. According to 2007 estimates from the National Spinal Cord Injury Statistical Center anywhere from 227,000 to 300,900 persons were living with spinal cord injury [6]. Of these, approximately 42,000 Americans with spinal cord injury were veterans [7]. Spinal cord injury results in loss of sensation and function below the injury level, and about 55% of all injuries occur between the first cervical vertebra and the first thoracic vertebra, resulting in low quadriplegia [8]. As a result of limited neural innervation, people with cervical spinal cord injury have limited trunk balance and limited upper limb function, and typically have extremely limited or no wrist or hand function.

People with low quadriplegia have neither the same physical body characteristics nor the same movement trajectories as the healthy human datasets currently used in industry. Asymmetrical body dimensions may be present in people with low quadriplegia. Amputations or trunk deformity in a wheelchair user are obvious examples of asymmetrical body characteristics. The person with a cervical spinal cord injury may have different static hand postures that constrain hand capabilities and body shape may be altered due to muscle atrophy. Upper or lower limb contractures may constrain limb postures. Head positions may be fixed or uneven shoulder heights may be present. These features must be precisely captured prior to development of realistic DHM movement.

Changes in upper limb movement compared to healthy individuals can be seen in people with cervical spinal cord injuries. For example, full active elbow flexion may be present when the shoulder is at the side, but may be severely limited when shoulder movement is required in addition to elbow flexion. These difficulties in modeling atypical movement led Kristensen and Bradtmiller, following a review of available literature in 1997, to state that

> "Modeling individuals and their disabilities presents particular problems because the very data which make the models appear realistic (e.g., the range of joint motion, the centers of gravity and moments of inertia for body segments, etc.) are potentially different, and largely unknown, for this population.

It is for this reason that collecting such data on this population is of critical importance." [9]

METHODS

Our collaboration included a master's student in engineering, an engineer, an occupational therapist and a lawyer with low-level quadriplegia. The lawyer was able to complete limited active range of motion in the shoulders and partial to full range of motion in elbow flexion and extension, depending on shoulder positioning. No functional active wrist or hand function was present. He identified that retrieving fallen objects, such as his cell phone, were a particular concern. Therefore, DHM development centered on an avatar retrieving an object from the floor, using a prototype reacher.

The first step in development of the DHM was the collection of critical anthropometric features, such as individual limb length from shoulder to elbow and elbow to wrist, individual shoulder height from the ground, trunk and head circumference and eye position. The greater the number of measurements, the greater will be the model fidelity between the DHM and the person.

Acquiring anthropometric data can be accomplished through either manual or automated means. Human anthropometric data has been collected from various civilian and military sources since 1946, when 64 body measurements were manually measured on U.S. Army female separatees from World War II [10]. Manual anthropometric data collection is highly time-intensive, variable due to subjective assessment of endpoints, error-prone in the data collection and data recording processes, and results in the development of a medium fidelity DHM [11]. It is difficult to collect more than a few datapoints due to the time-intensive nature of the data collection.

Approximately ten bilateral upper limb measurements were gathered manually, with stabilization of the trunk and limb needed due to impaired balance. Other limb and body features were assumed to be at the 50^{th} percentile for a man of his height and weight. Following this step, available active upper limb range of motion and characteristic movements of the shoulders and elbows was recorded kinematically using the Functional Assessment of Biomechanics. Data collection required approximately two hours.

Software integration was then used to develop a static DHM. Dassault Systemes CATIA and DELMIA were used for computer-aided design (CAD) activities. The project used the existing DHM body-building functions and tools available, with the CATIA Human Builder suite, to create the customized DHM.

Significant issues arose when assigning movement capabilities to the DHM from the available motion analysis. DHM software assigns typical movement trajectories to achieve a desired endpoint position, and it is not able to accommodate atypical limitations in movement patterns. For example, typical human movement assumes that one can fully flex the elbow from varying shoulder positions. Thus, with the shoulder partially flexed, as when placing an object on a desk, full elbow flexion and extension is a model assumption. This was not the case for our collaborator. Rather, elbow flexion became more limited with increasing shoulder flexion.

Due to these atypical movements, each movement needed to be individually specified in the program, requiring significant programming time to match the DHM movement to the upper limb movement captured kinematically. As a result, this project was both time and labor intensive, but resulted in development of a relatively realistic DHM of a person with spinal cord injury.

RESULTS

A DHM was developed of a person with low quadriplegia retrieving an object from the floor using a reacher. During this process, design capabilities, limitations and ideas for future directions were collected.

Figure 1 shows an (a) image from a video of the person using a prototype reacher and (b) an image from a video of the DHM using the prototype reacher in a virtual environment.

These photos demonstrate the translation from photo to DHM, given the limited number of upper limb measurements taken manually.

a.

b.

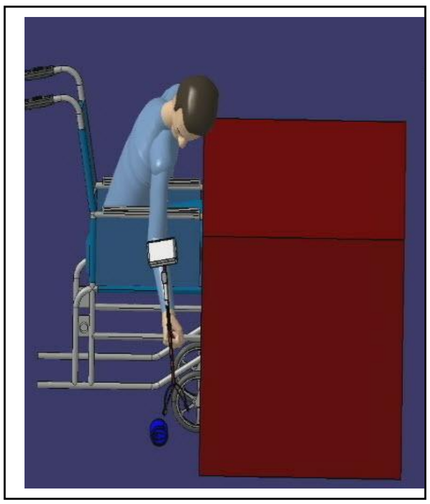

Figure 1: The person picking up an object using a prototype reacher. (b) the DHM using a reacher to pick up a 3D object from the floor.

DISCUSSION

The objective of this project was to investigate the potential to create a realistic moving DHM of a person with low-level quadriplegia using a commercially available DHM program, and to document its capabilities and limitations. Manual collection of anthropometric data and individual setting of movement restrictions was found to be sufficient to create such a rudimentary DHM. Current technology, however, offers the potential to integrate kinematic movement analysis with DHM software. The further development of this integration represents a direction for future research.

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