Validation of the HADRIAN System Using an ATM Evaluation Case Study

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Abstract. The HADRIAN human modelling system is under development as part of the EPSRC funded AUNT-SUE project. The HADRIAN system aims to foster a 'design for all' ethos by allowing ergonomists and designers to see the effects of different kinds of disability on the physical capabilities of elderly and disabled people. This system is based upon the long established SAMMIE system, and uses data collected from 102 people, 79 of whom are registered as disabled, or have age related mobility issues. The HADRIAN system allows three dimensional CAD data of new products to be imported, with a subsequent automated analysis using all of the 102 sample members. The following paper describes the process and results gathered from a validation study using an ATM design as a case study. The results indicated that fine tuning of the behavioural data built into HADRIAN would improve the accuracy of an automated product analysis.

Keywords: Human Modelling, design for all, ergonomics, validation.

1 Introduction

Human modelling systems (HMS) such as SAMMIE [1], RAMSIS, and JACK are used in the design of vehicles, manufacturing environments and workstations. These systems use CAD (Computer Aided Design) software to represent the size and shape variability of humans in simulations of environments such as car interiors (see Figure 1). The ability to simulate how people of different sizes and nationalities are accommodated by a product removes the need for costly early physical prototypes. If used correctly within a design process that includes later physical prototypes that verify the HMS analysis results, HMS can be highly cost effective. Currently HMS systems support design activity with a focus on able-bodied people. The aging population in the UK [2] and a greater awareness of the needs of disabled people (Disability Discrimination Act [3]), have raised the prospect of using HMS to simulate the effects of disability, supporting the design of more inclusive products and services.
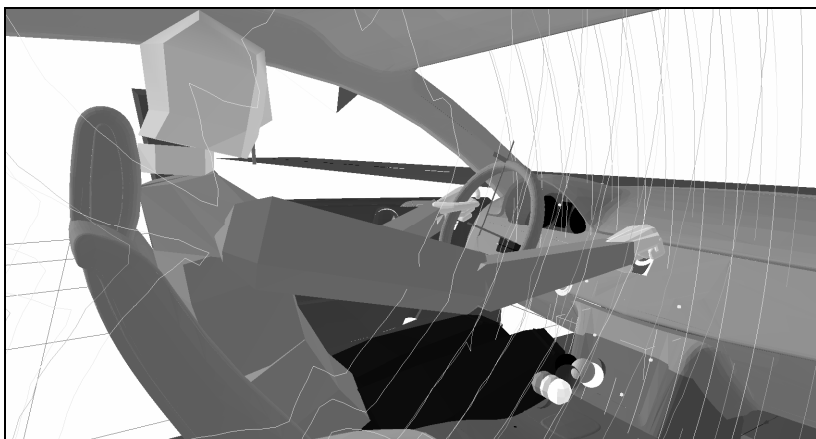
Fig. 1. The use of SAMMIE in the design of an automobile interior (2007)

Using human modelling systems to represent the effects of disability does raise issues in terms of the expertise of the end user. The designers and engineers that use HMS in the product design process generally have little experience of the effects of disability or the coping strategies used by disabled people. Current HMS systems have no methods of representing the joint range of motion limitations, or coping strategies used by disabled people. This paper describes the validation of a new HMS system that has been designed to combine anthropometric, joint range of motion and behavioural data for a sample of disabled and able bodied people. The aim of the new system is to foster a greater awareness of the effects of disability amongst designers and engineers, whilst providing a tool that supports a design process resulting in greater accommodation of the needs of elderly and disabled people. The test bed for the new system (HADRIAN) is the SAMMIE system, established in 1967. [4,5].

2   The HADRIAN System

The HADRIAN system is currently in the prototype phase of development. A key feature of the HADRIAN system is that the process of evaluating a product is automated, removing the product designer or engineer from key stages of the HMS process that require knowledge of the behaviour of disabled people. The HADRIAN system allows a product analysis to be performed on the basis of a task description provided by the software user. For example, if a ticket machine is to be evaluated, the user would import a CAD model of the ticket machine into the HADRIAN system and build a list of tasks to be performed. Example tasks for a ticket machine include the use of a control to select on screen options, and depositing money into the coin slot. The HADRIAN system can perform these interactions for all of the sample members built into it (n=102), using data on the coping strategies, joint constraints and anthropometry of each individual to automatically perform tasks such as the positioning of the virtual user to allow the best reach to the various controls built into the product. The system can then identify which users were unable to complete certain task stages based upon their ability to reach and

view the interaction points of a product. This allows design changes to be identified that can increase the accommodation of the product, such as lowering a control or changing a screen angle. The system also contains demographic information such as the type of disability, age, sex and occupation.

3   The HADRIAN Sample of Users

HADRIAN is based upon data collected from a sample of 102 people, the majority of whom were registered as disabled, or had age related impaired mobility. The sample members participated in the following data collection activities; anthropometric data, joint range of motion data, reach range data, completion of a questionnaire detailing the use of different modes of public transport, and the collection of baseline data on the ability of the participants to perform kitchen based activities of daily living. Within the sample of 102 people, 59 people have some form of impairment including: limb loss, asthma, blood conditions, cerebral palsy, epilepsy, head injuries, multiple sclerosis, arthritis, vision and hearing impairments, heart problems, paraplegia, Parkinson's disease, stroke, and dyslexia, amongst others. Of the 43 able bodied people, 20 were aged over 60 and had undiagnosed or minor impairments associated with being older. The remaining participants provide baseline information on the capabilities of non disabled people. All of the sample members included in HADRIAN were capable of living independently. Each subject was assessed using a modified version of the OPCS sample frame [6] to allow a comparison of the severity of disability exhibited by the HADRIAN sample to prevalence and severity of disability in the UK.

3.1   Anthropometric Data Used in the HADRIAN Subject Simulations

The following anthropometric measures were collected from each participant. Stature, Arm length, Upper arm length, Elbow-shoulder, Abdominal depth, Thigh depth, Knee-hip length, Ankle-knee length, Ankle height, Foot length, Sitting height, Sitting shoulder height, hip-shoulder length, Chest height, Chest depth, Head height, Eye-top of head, Buttock-knee length, knee height, Shoulder breadth, Hip breadth, Hand length and Grip length. These data were collected using an anthropometer, stadiometer, sitting height table and in some cases, a TC2 3D body scanner.

3.2   Joint Constraint Data Used in the HADRIAN Subject Simulations

The following joint constraint measures were collected from each participant; shoulder extension, shoulder flexion, shoulder abduction, shoulder adduction, arm extension, arm flexion, arm abduction, arm adduction, arm medial rotation, arm lateral rotation, elbow extension, elbow flexion, elbow pronation, elbow supanation, wrist extension, wrist flexion, wrist abduction, and wrist adduction. These data were collected using a goniometer.

3.3   Data Collected on Positioning and Posture

The prototype version of HADRIAN contains automation data based upon the kitchen tasks that were performed in the user trials. The participants were asked to move a

variety of objects onto a high shelf, a work surface, and into cupboards and shelves of standard kitchen units. This process was video recorded to allow the postures that were adopted to be coded (see Figure 2). Table 1 shows the positioning and postural data that were captured for both ambulant and wheelchair using participants. These coded data were used to inform the behavioural aspects of the HADRIAN task automation. A more detailed description of the HADRIAN system can be found in Marshall et al [4, 5].

Fig. 2. Examples of the postures adopted during kitchen based tasks

Table 1. The coding system used to classify the postures exhibited by the HADRIAN sample members during the kitchen tasks

Postures and orientations to be coded	Coding criteria for use in HADRIAN
Orientation of the user to the kitchen cupboards	Face on, side on, angled approach
Arm used for the tasks	Left or right
The posture of the legs during the kitchen tasks (ambulant participants only)	Straight, bent 1 (knee angle 170-120°), bent 2 (knee angle 119-40°), crouch (knee angle 39-0°), left kneel, right kneel, full kneel, sitting
Back twist	Left or right >10°
Back bend	Upright (0-10°), lean (11-45°), bend (46°+)
Shoulder	Relaxed, extended
Head orientation	Yaw (neutral, left, right +/- >10°) Pitch (neutral, forward back +/- >10°) Tilt (Neutral, left, right, +/- >10°)

4   The Methodology for the Validation of the HADRIAN System

The HADRIAN validation process aimed to verify and improve the data that drives the automation of the product assessment process. This has been done using an ATM (Automatic Teller Machine) case study in collaboration with NCR, the ATM manufacturer. The evaluation of an ATM provided a suitable task in terms of reaching and viewing of a number of interaction points, e.g. card slot, PIN buttons, statement printer etc. NCR provided the team with an ATM fascia that was then mounted on a

rig that allowed the ATM to be adjusted in height. The height adjustment range selected was based upon the international variability of ATM mounting heights depending upon different national standards, as provided by NCR. The height of the highest interaction point (statement printer output) was therefore adjustable through a range of 250mm from 1200mm to 1450mm in line with international variability in mounting height from the floor. It was anticipated that this range would prove to be difficult for wheelchair users in terms of reach to the highest interaction points. There were 160 tasks performed in each study described below i.e. ten participants performing eight tasks for two ATM heights.

4.1   Study 1: ATM Analysis Using an Expert in the Use of Human Modelling Systems with Experience of the Coping Strategies Used by Disabled People

Ten HADRIAN subjects participated in the validation process. The subjects selected were; an ambulant disabled female with cerebral palsy who uses a wheeled walking frame, an ambulant disabled male who uses crutches due to leg injuries sustained during a car crash, a crutch user with balance and coordination issues, a powered wheelchair user with limited strength in the right arm due to a stroke, a powered wheelchair user with mobility issues due to a broken back, two wheelchair users with good upper body mobility, and a mobility scooter user with balance and coordination issues. Two non-disabled members of the HADRIAN sample were included as a control. These were a UK male with 99th%ile stature, and a UK male with 1st%ile stature. The sample selected was biased towards wheelchair users as it was anticipated that these users would struggle with ATM usage due to limitations in reaching ability. Also, the orientation of wheelchair users to allow the most efficient reach to the various interaction points was seen as an important variable to test. The first study performed involved an examination of the ATM design using the SAMMIE HMS by a consultant with 10 years experience of applying HMS to disability related design problems. The anthropometry and joint constraint data collected from the HADRIAN sample were used by the expert. The positioning of the human models and the posturing of the human were based upon the experts' experience.

4.2   Study 2: User Trials with 10 of the Original HADRIAN Sample Members Using the ATM Rig

Each user was presented with the ATM at the 1200mm and 1450mm mounting heights and were asked to reach and view each of the ATM interaction points. Each participant was video recorded whilst the tasks were being performed so that a later comparison to the HADRIAN automated process could be made in terms of the postures and positions adopted. The position of each user relative to the ATM fascia was collected, in combination with information on task failures, and the postures adopted by the participants.

4.3   Study 3: An Automated HADRIAN Analysis of the ATM Design

The final stage of the validation process involved the use of HADRIAN to perform an automated analysis on the ATM design using the same variables as found in stages 1 and 2. A full description of the HADRIAN automated analysis procedure can be

found Marshall et al [4, 5]. A summary of the automation process for the analysis of interaction point accessibility is as follows;

1. Determine the relative positioning of the reach/view target and the human model. The human model is automatically positioned to enable reach to the currently selected interaction point if possible.
2. Measure straight-line distances between the target and the key human model reference. (eye-point for vision, shoulder for upper-limb reach, hip for lower-limb reach). If out of reach by a large margin then we move to stage 4. If not, we continue.
3. Depending on the reference to target distance one or more of the following will be applied:
   – The head /neck is rotated such that the head is facing the target
   – The head /neck is rotated and extended / flexed such that the eye-point to target distance equals the desired parameter value
   – The torso is rotated and flexed such that the eye-point to target distance equals the desired parameter value
   – The reference to target vector is calculated and the shoulder 'pointed' along that vector to achieve a successful upper-limb reach
   – The torso is rotated and flexed in the direction of the target to achieve a successful upper-limb reach.
   If there is still a failure we move on to point 5.
4. If the reference to target distances are greater than those accommodated by a posture change one or more of the following will be applied:
   – The human model is turned to face the target.
   – The human model is moved closer to the target.
   If there is still a failure we move on to point 5.
5. In the event of absolute failure, a failure is flagged for the results and the next task element is addressed.

The comparison between the three stages of the validation process provided an opportunity to examine the effectiveness of the HADRIAN automation algorithms and to highlight opportunities for the fine tuning of the HADRIAN process.

5   Results

The following section discusses the comparison of the results obtained from the three studies in terms of the number of task failures and the orientation of the user to the ATM.

5.1   Task Completions

The task completion data for each study were compared. In studies 1 & 2 there was only one participant that was unable to reach an interaction point. This participant (Participant 2) is a powered wheelchair user who has suffered from a stroke and therefore has weakness down the right hand side of the body, and is unable to walk. The tasks that were identified as fails in studies 1 & 2 were reaching to the statement printer and receipt output slots, when the ATM was in the highest position (1450mm

to the statement printer). The results from Study 3, the HADRIAN automated analysis, showed nine task failures across all participants and tasks (160 tasks were preformed). Six of the task failures that were generated by the automated analysis in HADRIAN were associated with interaction points that were in the top half of the ATM panel, being reached to by wheelchair users. Five of the nine task failures were associated with one participant. This participant was the same participant that had task failures in stages 1 and 2 (participant number 2). The reason for the additional task failures produced by the HADRIAN system was found to be that participant number 2 was able to shuffle forward in his seat when using a facing orientation, allowing reach to the interaction points that were shown as fails in the HADRIAN simulation.

5.2 Orientation of the Human Model

Ambulant users. All ambulant users faced the ATM and did not need to reposition the feet to allow control interactions in all three studies.

Wheelchair users. The orientations adopted by the wheelchair using participants in each study were categorised according to a facing, oblique and lateral position i.e. facing equals a perpendicular orientation of the wheelchair user to the ATM, oblique equals a diagonal orientation, and lateral equals a lateral orientation to the ATM .
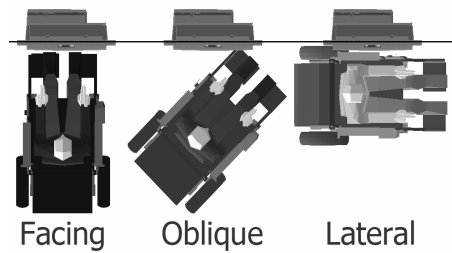

Facing   Oblique   Lateral

Fig. 3. The classification of wheelchair user orientation in relation the ATM

Table 2. A comparison of the orientation of the wheelchair to the ATM for each of the three studies performed

Wheel chair subject	ATM Height	Study 1. Expert user	Study 2. User trials	Study 3. HA-DRIAN
1	Low	oblique	oblique	Facing
	High	oblique	oblique	Facing /Lateral
2	Low	lateral	Face	Facing /Lateral
	High	lateral	Face	Facing /Lateral
3	Low	lateral	lateral	Facing /Lateral
	High	lateral	lateral	Facing /Lateral
4	Low	oblique	oblique	Facing
	High	oblique	oblique	Facing /Lateral

Fig. 4. The reach to the receipt slot of the ATM performed in the three studies, from left to right, the SAMMIE study, user trials and HADRIAN analysis

Each of these three orientation categories had a range of +/- 15 degrees from the positions shown in figure 3.

Table 2 shows a comparison of the orientation of the wheelchair to the ATM for each of the three studies performed. The analysis performed by the SAMMIE expert user matched the wheelchair orientations exhibited in the user trials, with the exception of participant number 2. The HADRIAN technique produced only facing and lateral positions for the wheelchair users. Figure 4 shows a task being attempted by a single user (participant 2) in each of the three studies performed.

6   Discussion of Results and Recommendations for the Improvement of the Automated HADRIAN Protocol

The comparison of the task completion and wheelchair positioning results for the three studies have highlighted areas in which the HADRIAN automated analysis protocol can be improved. The task failures that were found by HADRIAN system, but not in the other two studies were the result of four issues that have been identified in the analysis process, these were;

1. The prototype HADRIAN system works on the assumption that a facing orientation to the product interaction points will be used. If a failure occurs in the facing orientation a lateral orientation is used.

As has been demonstrated in the validation user trials wheelchair users often adopt an oblique orientation to the task interaction points. An oblique orientation allows users to improve the reach to the interaction points when compared to the facing orientation, whilst also allowing vision without excessive body and neck rotation to allow vision of the reaching target. It is therefore recommended that an oblique orientation attempt should be added to the HADRIAN automated protocol.

2. The prototype HADRIAN protocol uses a standard sitting posture for the wheel-chair users built into the database.

The postures adopted by the wheelchair users often differed from the assumed posture used in the HADRIAN protocol in terms of the angle of the lower leg, increasing the distance from the reach targets in a facing orientation of the wheelchair in HADRIAN. It is therefore recommended that the posture adopted by the wheelchair user should be more accurately replicated by the HADRIAN system.

3. The prototype HADRIAN system does not use a CAD model of the specific wheelchair used by each participant. Instead the wheelchair user is placed at the correct sitting height for the specific wheelchair used.

Data was gathered during the original HADRIAN data collection that allows all wheelchairs to be accurately modelled in terms of the length, width, sitting height, handle height and user orientation in the volume of the wheelchair. It is therefore recommended that the wheelchairs that were modelled by the SAMMIE expert user in study 1, should be used in the HADRIAN automated analysis. This will allow the exploration of situations where the wheelchair geometry blocks required postures, or orientations of the wheelchair to the reaching and viewing targets of products.

4. The prototype HADRIAN system does not use the data collected that quantifies the ability of the user to twist the upper body. This was highlighted a reason for task failures in lateral wheelchair orientations in all cases other than those found for participant 2, discussed above.

The implementation of the upper body twist data in the automated HADRIAN analysis is recommended.

In addition, it is recommended that the HADRIAN system includes a collision detection routine, which can detect if the postures adopted are interfering with the structures of the products being interacted with. On a small number of occasions the arm of the HADRIAN human model would intersect with some part of the ATM structure. This should be avoided.

7   Conclusions

The HADRIAN validation process was designed to verify and improve the automation of the HADRIAN analysis of products. The results for the ambulant disabled and non-disabled participants that were predicted by the HADRIAN system were found to be accurate. However, the exercise highlighted that additional data gathered from the wheelchair users needs to be incorporated into the HADRIAN analysis protocol in order to increase the accuracy of the results. The next stage in the development of the HADRIAN system will be to implement the changes recommended in this paper, and to perform a further validation exercise to test the system further. Initially the revised version of HADRIAN will be tested using the ATM example. A second validation study will be performed in June of 2009, and will involve the analysis of the interaction points found in the Greenwich Docklands Light Railway train station in London, England. This process will analysis the use of ticket machines, lifts and rail vehicles by elderly and disabled people.

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