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VIRTUAL FITTING TRIALS IN 'DESIGN FOR ALL'

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ABSTRACT

'Design for All' embraces the concept of designing products and workplaces so as not to exclude significant sections of the total user population. In particular the needs of old and disabled people are to be considered alongside the younger and able-bodied population to ensure that products that are equally appropriate for all users. This is to be contrasted with a 'Design for the Disabled' approach where the special needs of disabled people are considered in order to provide products that may only be appropriate for that section of society.

Fitting trials are an established technique in ergonomics where a product or workplace is evaluated by trials (perhaps on a mock-up or prototype) using a carefully selected user group that is representative of the total target population. Typically subject selection would be based on age, gender, size, etc, and total sample sizes limited to perhaps a few dozen. A percentage of the population accommodated by the design can then be determined by reference to a set of elemental tasks such as reaching to controls.

In this research the fitting trials are virtual in that computer modelling techniques are used to create a three-dimensional geometric model of the workplace/product and evaluation is achieved using a human model that can be varied to represent the individuals within the sample. There is a lack of anthropometric and biomechanical data relating to older and disabled people so a small-scale survey is being undertaken so that an appropriate population of computer human models can be created.

Methods are being developed to allow the percentage accommodated by a design to be determined in relation to a description of tasks to be carried out. Currently an ATM (Automated Teller Machine) design is being used as a case study to develop these techniques.

Further research will eventually be undertaken to extend the data, generalise the percentage accommodation evaluation and to optimise the design in terms of percentage accommodation.

KEYWORDS: Design, Ergonomics, CAD

1. INTRODUCTION

A 'Design for All' approach attempts to design products and workplaces that are suited to all members of society and is particularly concerned with including those groups such as the old and those with disabilities that might previously not have been considered. It is estimated that 25% of the European population will soon be in these potentially excluded groups [1], and this provides substantial social and commercial impetus to catering for their needs. The objective is to design products which are equally appealing and suited to the complete user population rather

than to design specialised equipment for the old and disabled. In addition to making good commercial sense by extending rather than segregating markets, the approach also satisfies the desire for non-stigmatised products. It is recognised that this objective is ideal rather than totally achievable and inevitably there will be those relatively small groups that will require products that are not attractive to mainstream markets. However, increasing the accommodation of diverse user populations and gaining a greater understanding of the reasons why some are excluded remains a major aim and forms the basis of the research reported here.

'Activities of Daily Living' include those domestic, social and liesure activities which can define an individual's ability to maintain their independence and are thus extremely important in a design for all context. Despite this studies [2] show that large numbers of older or disabled people are 'designed-out' to the extent that in this particular instance 21% of US 65-74 year olds and 55% over 85 years old had significant difficulties.

1.1. The EQUAL Initiative

It is within this context that the EQUAL (Extending Quality Life) was initiated by the UK Government's Office of Science and Technology in 1995 [3]. The initiative aims to extend the active period of peoples' lives by the avoidance or alleviation of the effects of disability. The thrust of the research is provide personal benefits including better health, a more active life, a better quality of life and greater continuing participation in society. At the same time substantial economic benefits are predicted through reducing the burdens on society and by the creation of new business opportunities in global markets.

The first focus of attention was the Built Environment and was concerned with changes in the design of the home, the design of public access buildings and public spaces and the design and operation of transport systems.

More recently the EQUAL programme has turned its attention to Design for All which has the aim of 'generating the knowledge base to extend the range of application of equipment, services and systems designed for the general population to people with disabilities. The programme aims to identify the needs of designers and commissioners of product and service design for data sets and information relating to capabilities, including in particular those of older and disabled people, to define generic design methodologies and developing suitable design aids and design guidance for the many designers for whom design for all will represent a radical shift in design practice, and the provision of guidance on the need for and process of user involvement in design in the context of a wider user group'.

This research described here aims to support this design for all approach to the design of equipment, services and systems by developing an integrated database concerning the 3D characteristics and abilities of people together with an efficient methodology for its exploitation in design. The focus is on the physical aspects of a particular design so that the whole population, including those who are older or are disabled, can be considered when evaluating multivariate issues including access, fit, reach, vision, strength and posture. An important criterion considered is the ability to predict the percentage of the population that will be catered for by a design, while the ability to determine who has been 'designed out', and why, is considered to be essential in improving the design.

1.2. Human Capabilities and Anthropometry

Many databases exist that are concerned with human capabilities and in particular with anthropometry (e.g. [4-12]), but typically these sources provide very limited information concerning people who are older and/or disabled. Those studies that are specific to the disabled or aged are often limited in sample size or relate to very specific conditions (e.g. 78 UK women

aged 70 and older [13], USA older males [14], 502 lower extremity disabled, 758 aged 65 and older, UK [15], 11 post-polio paraplegics [16], 62 spinal cord injuries, Canada [17], 822 older males and females, The Netherlands [18], 61 post-polio spinal cord injuries, India [19], 203 injuries and deformation of the spine, upper limbs, lower limbs and other, UK [20], 77 systemic deformity, motor organ diseases, Poland [21] and 170 spinal injury, cerebral palsy, muscular dystrophy, Poland [22]). Added to this problem of quality and quantity of data available is its often limited applicability to practical design problems.

1.3. Modelling

The effective support of design for all requires that data on human capability be presented in a form that matches designers' methods which are now predominately three-dimensional and computer-supported. Three-dimensional information is required on aspects such as peoples' size, functional reach, vision, mobility and strength related to the specific tasks demanded by the design under development. Computer-based human modelling systems such as JACK and SAMMIE [23] provide models that are capable of representing such information and applying it in design situations. The main limitation of these systems is that they do not adequately represent people who are older and are disabled.

1.4. Multivariate Analysis

Clearly, the prediction of the percentage of the intended population physically accommodated by a design is fundamental to the design for all approach, and successful use of any product or workplace requires a *multivariate analysis* to simultaneously consider a number of body dimensions and capabilities. Access, reach, vision, strength and mobility may be important for a design and failure on any one of these might cause an individual to be excluded. However, a common method of ergonomic evaluation is to use percentiles, a univariate measure that used simply implies good correlation between body dimensions and capabilities. Typically the 95th percentile by stature (representing all individuals in the group who are less than or equal to 95% of the maximum stature) is used to evaluate access problems and the 5th percentile is used for reach assessments. Unfortunately poor correlation between dimensions. (the 10th percentile by stature might for example be 70th percentile by weight) seriously compromises this method. Hertzberg's famous anthropometric survey [24] graphically illustrates this difficulty, and several authors have discussed its significance for design [25,26].

1.5. Multivariate Database

In this research it is the intention to create a multivariate database of real individuals, including those who are older and disabled, covering a range of physical characteristics and capabilities. One hundred individuals, the majority of whom are older and/or disabled, are to be selected as representative of the real population and to provide a preliminary database for the development and validation of a predictive tool for estimating 'percentage accommodation'. It is recognised that a very much larger survey will eventually be required. The data collected will include individual's anthropometry, reach, strength and mobility in relation to typical activities of daily living that are known to be problematic for people who are older or disabled.

2. METHODOLOGY

2.1. Survey of current design practice

In order to establish the current situation regarding design in relation to the needs of older and disabled people, existing products, procedures and systems have been investigated [27].

Telephone and person to person interviews have been conducted with some 50 product designers, engineers, clinicians and others involved in product design in the UK. Issues such as: information sources currently used; methodologies used; technical data used; preferred format of data; product performance; product evaluation; modular products; quality; cost; and knowledge of user needs have been explored.

2.2. Survey of user needs

Currently, semi-structured interviews are being conducted with approximately 50 older and disabled people with the aim of identifying representative 'reach-manipulation-grip' activities of daily living on which to base the data collection and modelling phases of the research. Common elements will be identified in the different tasks based on factors such as reach, posture, grip, manipulation and viewability.

2.3. Collection of data

Data concerning ability to undertake the selected tasks will be collected using laboratory based rigs. For this preliminary work a small sample of 100 individuals will be selected to represent a variety of people including wheelchair users, the elderly (ambulant), individuals with conditions such as arthritis, multiple sclerosis, CVA's and those with multiple disabilities, able-bodied, disabled and older people

The data to be collected includes anthropometric data on stature, sitting height/wheelchair sitting height, buttock knee length, knee height, shoulder elbow length, elbow fingertip length, hand length, handbreadth (metacarpal), abdominal depth, shoulder breadth and hip breadth, reach-manipulation-grip' data by investigating the full reach-envelope for the previously identified tasks, together with task specific manipulation and force data and physical ability data including grip strength and weight handling capacities.

2.4. Virtual Fitting Trials for Design Evaluation

The use of fitting trials is a common technique in ergonomics evaluation. A panel of users that are deemed to be representative of the eventual user population are used to evaluate the product or workplace against a pre-determined set of evaluative criteria and thus some judgement can be made as to the suitability of the design.

Virtual fitting trials simply involve the use of the multivariate database of 'individuals' by accessing it during computer design work so that the percentage accommodated can be predicted based upon criteria for task success set by the designer (i.e. access, vision, reach, mobility and strength). A computer approach using an enhanced version of the SAMMIE human modelling system [28] is used to automatically 'test' each individual dataset and identify those individuals who cannot achieve one of the criteria for successful interaction with the design. The designer is then able to call up the data for these 'designed out' people and to simulate their problems by modelling their body dimensions and physical capabilities.

2.5. Validation case studies

A highly adjustable rig is to be constructed to simulate a variety of workstation configurations that will also be created virtually within the computer model. This will allow direct comparisons between the computer predictions of an individual's ability to perform a task requiring multivariate accommodation (e.g. being able to gain access, see, reach and operate) with the same individual attempting to perform the task with the same workstation configuration in the laboratory.

3. SAMMIE COMPUTER AIDED ERGONOMICS DESIGN SYSTEM

The evaluation of the ergonomic aspects of design by the use of computer-aided design techniques is a well-established methodology and many computer systems are available [23]. SAMMIE, **S**ystem for **A**iding **M**an-**M**achine **I**nteraction **E**valuation is a long-established and typical example that has been used in a wide variety of applications [29] and forms the basis of the work described here. Human modellers are frequently similar to more general kinematic modellers used for the simulation and evaluation of mechanisms such as industrial robots. Thus the major articulation points of the body are represented by pin-joints constrained to maintain motion within the ranges of human joint extensions. The joints are connected by rigid links as an approximation to the long bones of the body, and these are enfleshed to give a visual representation of human shape. Anthropometric control through manipulation of the joint-to-joint dimensions and flesh shape and size is provided so that the model can be made representative of the product user population. The complexity and variability of the human body has dictated that an approximate symbolic representation of shape is generally used (for example by the use of primitives in a boundary representation solid modelling scheme).

Figure 1 shows a typical example of SAMMIE used in a recent project carried out on behalf of the UK Department of the Environment. The work was concerned with updating British Standards BS5810 and BS5619 [30,31], which specify public access standards for people with disabilities with respect to physical space, interface design, accessibility issues and ease of use. One aspect of the work concerned the determination of space requirements for disabled people in a car park. SAMMIE was useful in being able to demonstrate how the requirement for space around different types of vehicles, for people with varying levels of disability and with and without an assistant varies and how the needs for one set of circumstances might conflict with those of another. For example a driver who transfers himself from a wheel chair to a car requires sufficient space to allow the car door to be fully opened, whereas an adapted vehicle with a side ramp requires a significantly wider space.

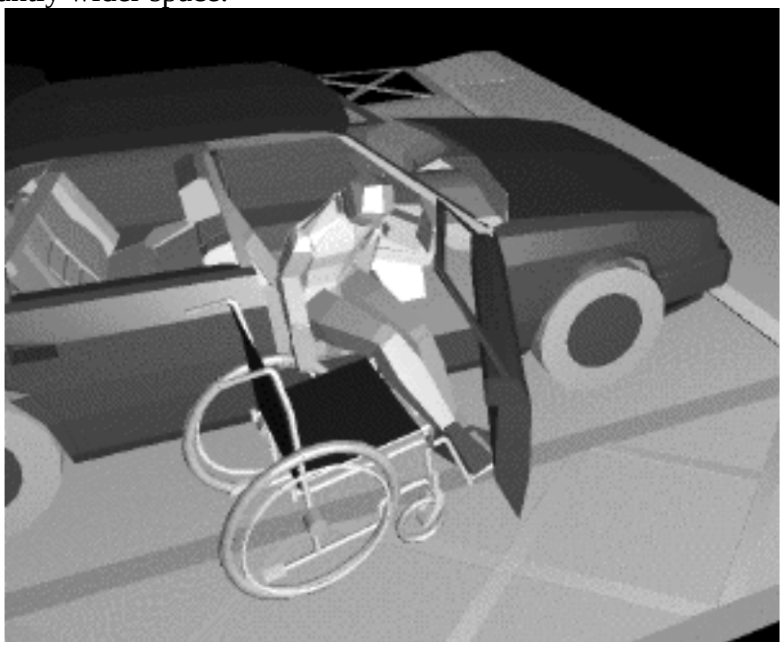

Figure 1. Evaluation of wheelchair access to vehicles using SAMMIE

SAMMIE proved useful and effective for this application, but the success of the work relied upon the designer's use of the system in an appropriate fashion. Consideration of the anthropometry to use with the model (percentiles and dimensional relationships between different aspects of the model) and assessment of the value of the solutions were subjective judgements of the designer (albeit based upon extensive experience).

Figure 2 shows a small part of an ergonomics evaluation of the train that takes passengers from the recently completed Hong Kong airport into the city. The study was conducted in a similar fashion to the previously described project except that it was taken through the further stages of mock-up and prototype. This enabled the conclusions of the synthesised computer evaluation to be confirmed through 'fitting trials' with real people. To more fully investigate these fitting trials during the computer simulation there is a need to develop the underlying computer tool, and this is the subject of the next section.

Figure 2. Wheelchair access in the Hong Kong Airport Train

4. AN ENHANCED COMPUTER TOOL

To date the work performed in the area of Virtual Fitting Trials has concentrated on various aspects of macro programming for the SAMMIE computer aided ergonomics system. This has evolved from some simple tasks using the tool and macro language into a basis for a generic design analysis macro with supporting data input and storage. This is being carried out in parallel with the survey and data collection aspects identified above and thus synthesised data is being used to develop the methodology.

The database simply consists of data files which describe *individuals* in terms of anthropometric data, joint constraints, reach / grip related hand length, handedness and a range of descriptive data related to the individual's name, age, sex, etc. This is to be contrasted with the more traditional method of recording and using *population data*.

The task and its evaluation criteria are defined within an analysis set-up / configuration file. The file specifies which individuals to include in the analysis, the main alignment object for approach or initial orientation, vision checks to perform, reach checks to perform, the order of these checks and also details about the checks such as the desired reach type (fingertip, thumbtip, etc.), the acceptable vision distances and whether an item needs to be viewed in its entirety or only at its central point.

The analysis performs a loop that cycles through the individuals and the checks as specified in the set-up. The analysis is self contained such that it does not require user input unless a system problem occurs due to incorrect setting up of the evaluation. The output consists of a list of the check results for each individual and a rough metric of the success of each check.

In order to try to maximise the information provided by the various checks the macro performs some simple logic and operator manipulation in order to achieve success. This is an attempt to replicate the process by which a human designer would approach the task. Thus when considering a reach test, a standard SAMMIE reach check to a desired object is augmented by some further analysis. The system is interrogated for the location of the operator and the object and their respective orientations and on failure of the reach test performs one of a number of options related to pointing the shoulder and checking again, or actually rotating, extending, or abducting the torso. The macro assesses the situation for each check and determines ultimately whether the check is possible and what has had to be done to achieve it. A similar situation is also provided for vision checks whereby the eyes, head, neck, and torso are again moved to try to achieve success.

A host of issues relate to the current work and the process the macro embodies. The key areas are the development of a generic analysis in which the system is not locked to one set of data / individuals, one analysis routine, or one design to be analysed. These concerns are also highly dependent on the designer being facilitated in the set-up of the analysis, the inputting of data, and the extraction of results. These issues are being addressed by the development of the analysis tool in the three main areas of data input and manipulation, task description and analysis, and result reporting and analysis feedback.

With the data input and manipulation interface the aim is to develop a user friendly and highly visual template for inputting of operator data. This interface can then be used to aid the process of inputting the project data when collected in addition to providing an ideal test of the interface.

For the task description and analysis system the proposal is to develop a task description language so that a designer may put together a readable description of the analysis to be performed in a manner that reflects how the design is to be used. The aim is to use the familiar verb-noun /object syntax to describe the major interactions with objects in the design e.g. 'grasp steering wheel'.

Result reporting, ranking and re-evaluation / analysis feedback is important in terms of providing the designer with usable and appropriate methods. In addition to providing percentage accommodated, the tool should be able to provide a result tolerance or degree of failure on individual elements of the task such that the information provided is not a binary pass/fail but rather a failed by x%. This then automatically provides a starting point when attempting to identify and rectify any causes of design failure.

5. A CASE STUDY

As a working model, a common automated teller machine (ATM) design has been used as a basis for the development of generic task analysis elements. The aims were to explore the possibilities for automating a number of the manual activities associated with the assessment of such a design. Activities include: input of the human model data, placement of the human model with respect to the ATM, the description of the task, and most significantly how the system reacts to a negative result in one of the task elements. The approach utilises the SAMMIE system's macro control language, adopting a number of human readable setup and input files for specifying the data to be used and the task to be performed. The system then interrogates these files for the analysis without the need for further user interaction. In order to try to maximise the information provided by the results from the analysis the macro performs some simple logic and human model manipulation in order to overcome a failure. This is an attempt to replicate the process by which a human operator would approach the task. The macro assesses the situation for each task element and determines ultimately whether the task is possible and what has had to be done to achieve it. Further work is investigating object oriented methods for encoding model objects with information on how they are to be interacted with (grip locations, operational parameters etc.), formalisation of the task description, and modularisation of the analysis elements for generic application to any task.

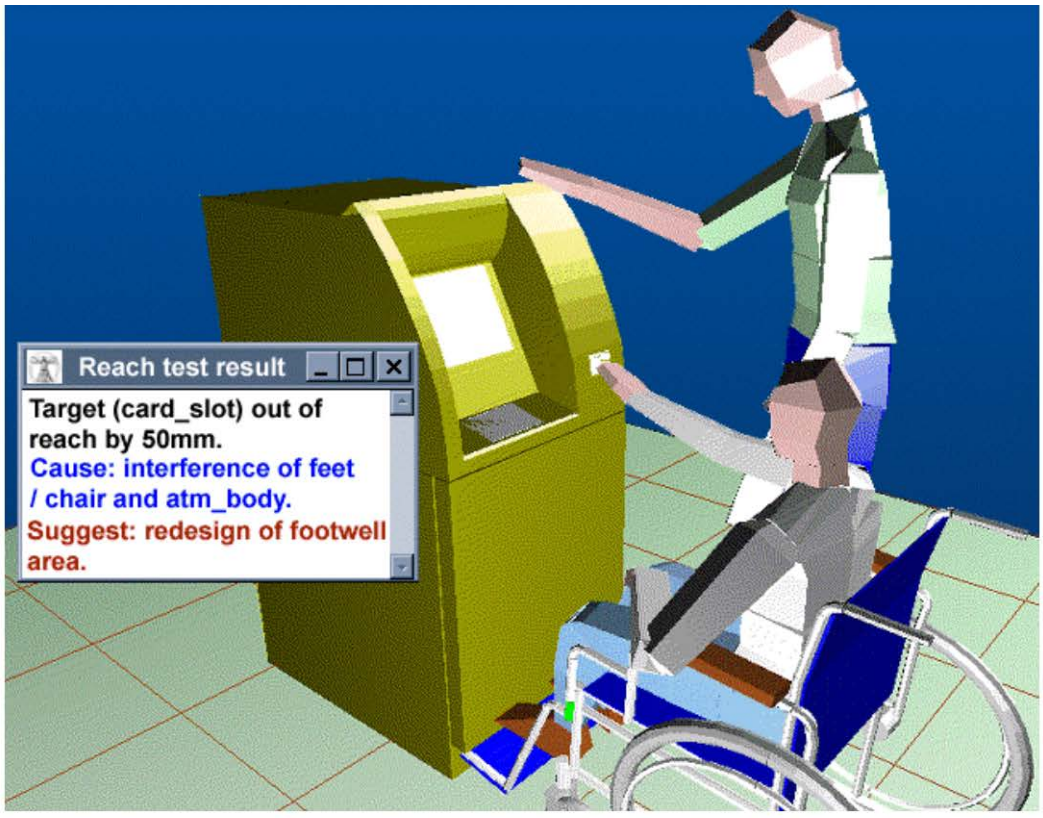

Figure 3. Automatic Teller Machine Evaluation using

Figure 3 illustrates a typical situation with wheelchair and able-bodied users of the ATM. The wheelchair user is 'designed out' through an inability to reach the card slot, and indeed there may be several other difficulties including viewing of the screen. The overall task has been

described within the SAMMIE macro language and a sub-element of this will have been the reach to the card slot. The out-of-reach condition has been generated by a standard reach-test within SAMMIE and the logic programming in the macro has attempted to alleviate the situation by improving the position of the ATM user. However, in approaching closer to the ATM another constraint has been encountered in that standard interference checking within SAMMIE has detected the clash between the ATM and the wheelchair. This leads to the suggestion (unimplemented in software at present) that some re-design of the footwell area may resolve the difficulty. The example amply illustrates the basic principles of (i) determining percentage accommodated by identifying those individuals that cannot perform the prescribed task, (ii) identifying the cause of the failure and (iii) suggesting means by which the percentage accommodated might be increased.

6. CONCLUSIONS

The research is in its early stages and so far only initial survey and software development work has been undertaken. The eventual collection of data and its use within a software tool to evaluate the percentage accommodated by a design will enable us to determine the full benefits of the research. It is expected that a prototype tool will be available for use by design professionals as part of a mechanism for disseminating the ideas of 'design for all'. Similarly it is expected that the education and research communities will benefit through the sharing of the data collected and the availability of an application tool that can potentially be extended into a wider range of application areas. Finally, it is our hope that older and disabled users themselves will benefit through a wider-spread and better understanding of their needs and capabilities resulting in improved quality in the design of products, systems and services.

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