Chapter 2

Using Constraints in the Understanding of the Interactions Between Products and Humans

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2.1 Introduction

The acceptability of consumer products often relies upon ease of successful use. Here there is a crossover between the functionality and how the user can derive the actions required. The form of these relationships can encompass the complexity of the physical actions that are required, the experience and capability of the user, and the social context in which the use takes place.

For example, in early work on vending machines it became obvious that differing approaches occurred or emerged between novice and experienced users. The new user was cautious, sometimes in the extreme. In work on the development of automatic petrol stations new users would read all instructions carefully and walk around the site before venturing in to part with their money and putting petrol in their tank. They were often looking for clues or familiar patterns that helped them recognise the tasks that would need to be performed.

The more experienced user would boldly approach the vending equipment making assumptions on how it operated, based upon previous experience (which could be helpful if it was the same type of station or very unhelpful if it was an alternate design).

The successful design of such products that rely upon close human interaction, where the operator is self taught, requires an understanding of both the approach of the human and of the product or machine operation. Clearly when the sequence and timing of the machine has been laid down it is not possible for the operator to change them. Instructions and feedback must thus be provided to allow the operator to understand the desired sequence of operations and most importantly what comes next. However, the derivation and inclusivity (with respect to user experience, capability and physical characteristics) of such instructions is, in general, fundamentally limited for all but the simplest of interactions.

One means to overcome such barriers is to explore user-product interactions during the early stages of the design of a product. However, achieving this is all but prevented by a lack of computational means capable of predicting the changes in user interaction that arise as a consequence of changes in the design of the product.

2.2 Modelling User-product Interaction

A considerable number of computing tools have been created to help different aspects of designing. In the area of product design these extend from styling packages through the classic geometric modellers to those handling manufacturing issues. To these can be added analysis tools such as ergonomics that allow certain aspects of the human interface to be evaluated. Two common ergonomic analysis tools are Sammie CAD (Sammie CAD Ltd., 2007) and Jack (Siemens AG, 2007).

However, these computer techniques can, in general, only be used sequentially, moving down from the concept through the detailing and on into the manufacturing. If, however, problems of an ergonomic nature are found at a late stage, much of the previous work may have to be revisited and changed.

Whilst considerable effort can be put into creating both computer-based and practical ergonomic studies neither provides the ability to assess and automatically correct errors during the early stages of design. Some areas of possible danger may only be identified accidentally or even after completion. An approach that integrates these different aspects of design creation and evaluation is thus required. The contribution of this paper is to report the creation of a constraint modelling approach for understanding human-product interaction.

2.3 Constraint Modelling

The constraint modelling approach seeks solutions to problems not by creating explicit equations but by undertaking searches across the problem space for conditions where all the constraints (rules) are true. For example, in the context of mechanical systems design, if two parts are required to assemble, then the rules of the fit are defined (such as a shaft must fit in a hole). This then defines the relationship between the diameter of the shaft and the hole. Either diameter (or even both) can be changed to obtain the required fit.

Within the constraint modelling approach the rules are first created (*i.e.* that which needs to be true) and the ‘free’ variables, for the search, selected. Direct search techniques are then applied to seek a true solution. Within such an approach there are no guarantees that a true solution actually exists or that a number of rules, although true, are not in conflict. The approach thus attempts to minimise the error in the total truth of the problem to an acceptable level.

The combination of rules and errors may indicate that no true or acceptable state can be generated. It is here that different strategies need to be applied. Some of the rules may not be solvable with the declared variables. Either the rules need to be redefined or new variables selected (or both). Such conflicts or trade-offs are common as the understanding of a problem increases and the design process evolves. In fact, the ability to creatively explore the problem space is central to generating understanding, particularly, where new or ill-understood problems are considered.

The fundamental need for designers to be able to redefine, revise, evolve and explore the constraint set (problem space) as understanding increases is one of the key benefits of using a constraint approach. The ability of constraint-based approaches to support the representation and exploration of the interactions between machines and materials, processing systems and products, and machines and operators has been demonstrated (Molenbroek and Medland, 2000; Hicks *et al.*, 2006a, 2006b).

2.4 Human Modelling Using Constraints

This constraint resolution approach has been developed over the last thirty years and been used extensively in the design and optimisation of manufacturing machines as well as other devices. In the last decade a human model was created based up on the anthropometric design assessment program system (ADAPS) model generated at the Technical University of Delft (Ruiter, 1999).

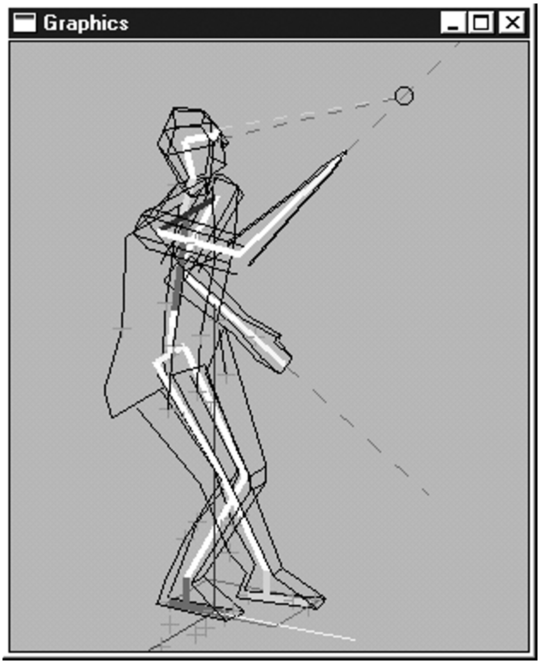

Figure 2.1. The underlying structure of the constraint-based manikin

Figure 2.2 shows a manikin attempting to work (touch) a specified point on a machine whilst also looking at that point, keeping both feet on the ground and maintaining balance (balance is defined by a rule that calculates the centre of gravity which the search routine attempts to keep within the base of support of the feet).

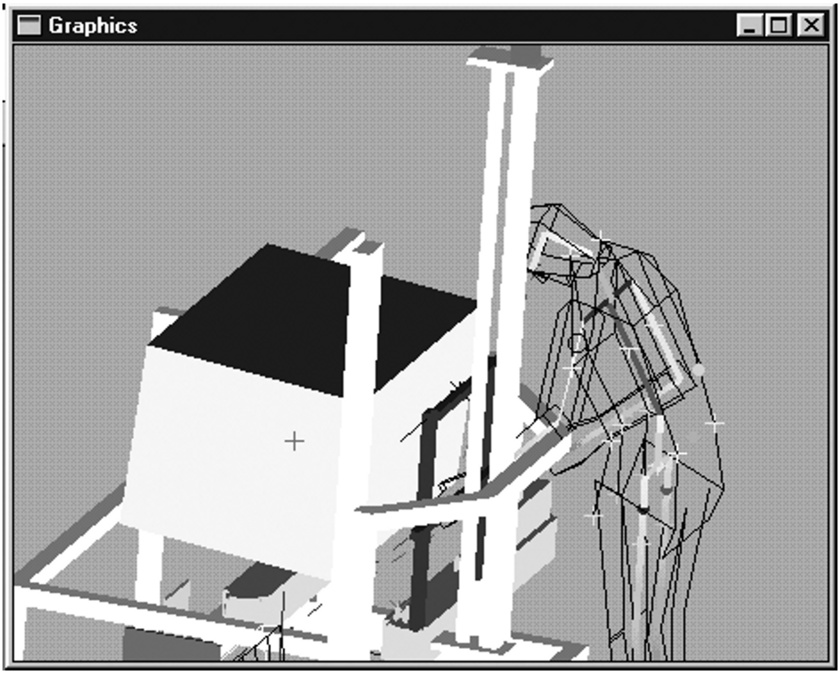

Figure 2.2. Human-machine interaction

Whilst the model of the manikin has more than eighty degrees of freedom, in practice, only a subset of these variables will control a particular posture or influence an interaction. In such studies the ‘free’ variables (joint rotations) of the manikin are automatically selected through the use of sensitivity analysis to identify the dominant variables and eliminate the insignificant ones. This process not only reduces the number of degrees of freedom, which improves computational efficiency, but also prevents the search from exploring redundant regions of the space. The latter of these is important to prevent the underlying numerical methods from unnecessarily altering variables which cannot subsequently be corrected as their contribution is negligible and hence cannot be measured. In this manner it is possible to predict human postures and movement patterns more accurately.

Should the manikin have difficulties in finding a satisfactory solution (even when all postures and positions around the machine have been explored) then new positions for the action point on the machine can be included. If for instance the point represents the position of a selected control, design work can be undertaken to find an alternative and better position for it. Thus a configuration satisfying both the human operator and the machine operation can be determined.

2.5 Predicting Postures Using Constraints

Many human studies commence with the model standing or sitting in a balanced state. These are often taken as a given condition but must be provided within any modelling environment. Within the constraint environment the position of the centre of gravity of the body at any instance can be calculated from masses associated with each part of the body. For the manikin to balance the centre of gravity must lie within the base of support, which can be calculated for standing as within the footprint or sitting as the seat-print.

In other more complex studies the centre of gravity will change as movements and new postures are demanded. One such activity is that of moving from sit to stand. Here the rules defining sitting and those for standing are different but must merge at an intermediate point where the force balance moves from being provided by the seat to being provided by the feet upon the ground. At this intermediate state both sets of rules are true unless momentum is used to 'throw' the body from one state to the other. The predicted movement pattern and intermediate posture for the sit-to-stand sequence is shown in Figure 2.3. The accuracy of the predicted movement pattern has been validated through practical studies and is reported elsewhere (Mitchell , 2007).

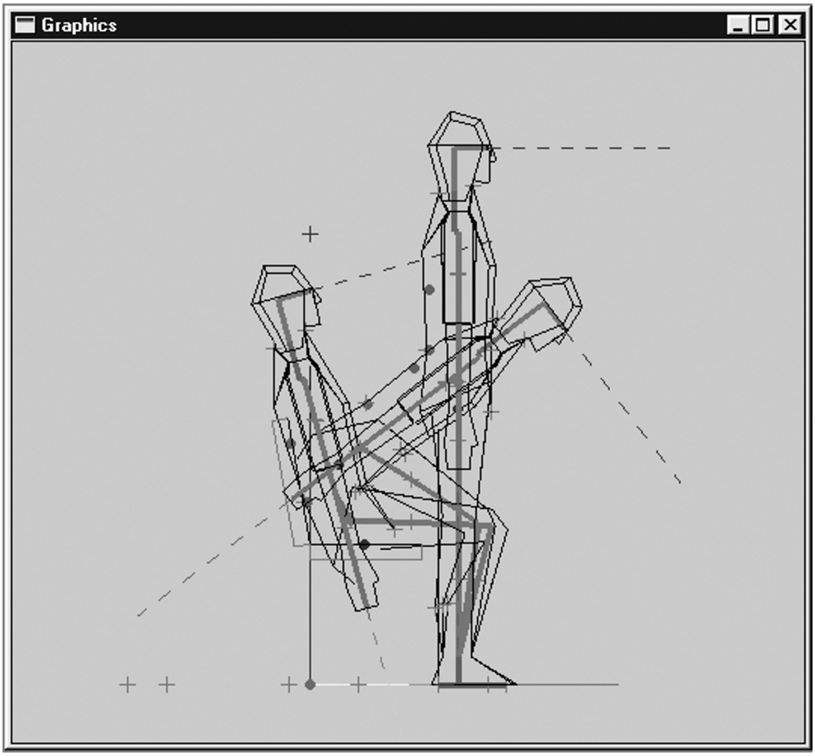

Figure 2.3. Simulating the sit-to-stand movement pattern and intermediate posture

2.6 Modelling the User-wheelchair Interaction for Improved Design

A study of the sitting posture of users in a wheelchair shows the close integration necessary between the individual and the designed product. The seating position must be comfortable allowing the person to sit in a relaxed ‘driving’ position with the feet on the support platform and the body leaning against the back rest. The user must also be capable of reaching the wheel push-rim over a range to be able to propel the wheelchair.

These rules have been incorporated into the modelling environment and the manikin set to find a position in which all actions and postures are successfully carried out. Studies currently being undertaken by colleagues in Christchurch, New Zealand, have shown that such postures are similar to those found from real experimental studies of both able-bodied and disabled people. See Figure 2.4.

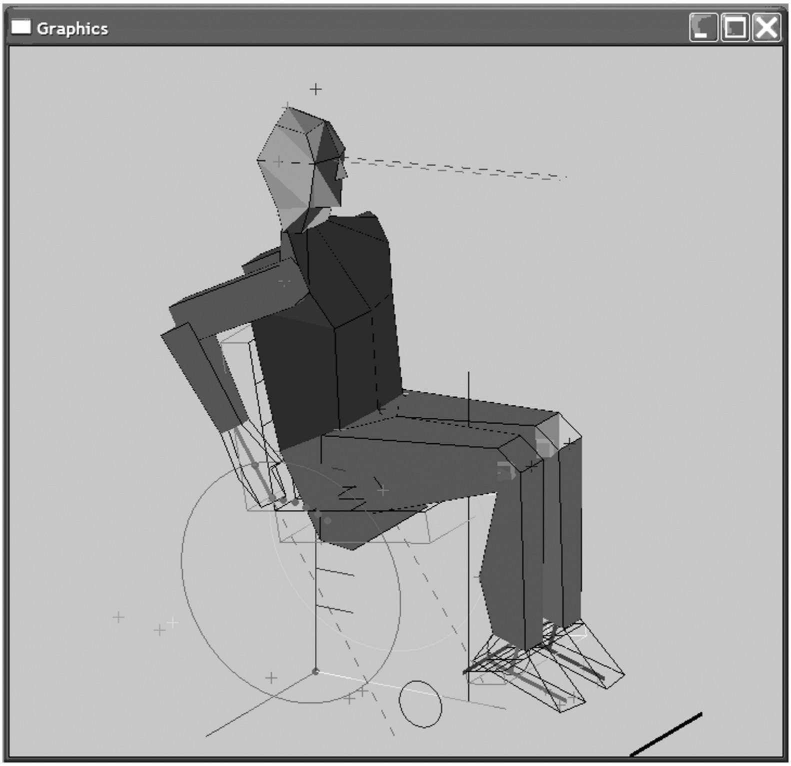

Figure 2.4. Simulating the seated posture in a wheelchair

The forces and power required under different conditions have been studied experimentally using a special purpose dynamometer in order that the effectiveness of the wheelchair design can be studied. It is intended that the limiting conditions will be compared directly with those provided by the constraint-based manikin.

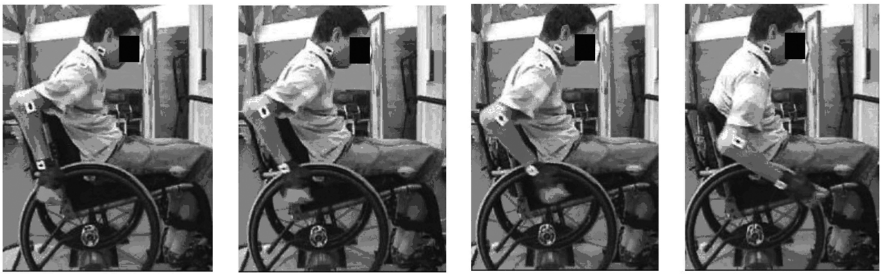

Figure 2.5. Study of wheelchair propulsion being undertaken in New Zealand (Gooch)

As the models in the constraint environment are all parametric, certain design parameters, such as wheel size, balance point and seating height can all be declared as free variables in an optimisation search. The best configuration to meet the chosen conditions can thus be sought to meet these limiting conditions. By changing the geometric parameters of the manikin an optimised wheelchair can be investigated to meet either the needs of an individual or those of a specified user group.

2.7 Modelling to Improve Designs

The application of a constraint-based approach to design problems, such as the wheelchair study, allows the various interactions between humans and products to be studied in an integrated manner. The full human model exists within the constraint environment and rules can be generated to define the relationships with any suitably modelled product. A wide range of product interactions can be represented, including all aspects of touching, looking and operating together with those of human posture and balance. The ability to represent a range of interactions between user and product, and predict the changes in human posture and movement patterns brought about by changes in the product design, provide a unique modelling environment. In particular, user-product interaction can be considered during the early stages of design to create more inclusive products or during the redesign of existing products to optimise their function for a particular user or group of users both of which are not readily available through existing ergonomics modelling tools.

2.8 Conclusions

The requirement to be able to model and reason about product-user interaction during the early stages of design has been discussed. It has also been argued that one of the major limitations of commercial tools, in the analysis of ergonomics, is their inability to predict the changes in interaction brought about by altering the product design. Such limitations are a particular issue where interactions are dependent upon locomotion. In these cases, the ability to reliably predict human postures and movement patterns arising from a change in the designed environment or a change in user capability, such as ageing or disability, poses a significant research challenge.

To begin to address this research challenge, a methodology for modelling human-product interaction based upon constraint-based techniques has been presented. The overall approach and underlying numerical techniques are summarised and a number of modelling scenarios discussed. The scenarios include the complex motion of sitting-to-standing and the modelling and reasoning about the interactions between the user and the wheelchair for its improved design. In particular, in the case of the wheelchair it is shown how the design can be optimised to meet the needs of either individuals or selected groups of the disabled.

Following the success of the reported studies the approach is being extended to consider the requirements for modelling the operation of consumer produts to operate consumer products. These include the rules necessary to carry out actions such as pushing (for vacuum cleaner *etc*.), carrying objects (say up stairs) and working with the product in such scenarios as at a desk or in the kitchen.

2.9 Acknowledgments

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2.10 References

Hicks BJ, Mullineux G, Medland AJ (2006a) The representation and handling of constraints for the design, analysis and optimisation of high speed machinery. Artificial Intelligence for Engineering Design, Analysis and Manufacture, (20)4: 313–328

Hicks BJ, Sirkett DM, Medland AJ, Mullineux G (2006b) Machine-material interaction and its impact upon the design of improved tooling. In: Proceedings of the 6th International Symposium on Tools and Methods of Competitive Engineering (TMCE 2006), Ljubljana, Slovenia

Mitchell RH, Medland AJ, Salo AIT (2007) Design methodology to create constraint-based human movement patterns for ergonomic analysis. Journal of Engineering Design, 18(4): 293–310

Molenbroek JFM, Medland AJ (2000) The application of constraint processes for the manipulation of human models to address ergonomic design problems. In: Proceedings of the 3rd International Symposium on Tools and Methods of Competitive Engineering (TMCE 2000), Delft, The Netherlands

Ruiter IA (1999) Anthropometric man-models, handle with care. In: Proceedings of the International Conference on Computer-Aided Ergonomics and Safety (CAES’99), Barcelona, Spain

Sammie CAD Ltd. (2007) The SAMMIE system a computer based human modelling tool. Available at: http://sammiecad.com (Accessed in October 2007)

Siemens AG (2007) Technomatix Jack – ergonomics and human factors product. Available at: www.ugs.com/en_us/products/tecnomatix/human_performance/jack/index.shtml (Accessed in October 2007)

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