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THE MODELLING OF THE INTERACTION OF THE HUMAN HAND WITH PRODUCTS

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ABSTRACT

Many products are designed to be hand operated in use. These extend from industrial machine tools to domestic appliances. In these the designer has to rely upon experience and ergonomic guidelines to ensure that the final product is comfortable, usable and not dangerous when in use. In order to aid in this problem a computer-based manikin has been created to investigate the posture of humans, which now incorporates the movements of the hand. This creates a number of difficulties, which extend from the large number of degrees of freedom to those of redundancy and interaction.

In representing such hand movements within a modelling environment it is necessary to firstly understand the natural motions and to then represent then in a realistic manner. Whilst some of the responses are required to form contact with surfaces, to affect a grip or reaction, others are the responses arising from the interaction between the fingers. Other more complex actions require both combinations and sequences of grip actions to achieve the desired action. Many of these actions have been explored in order that the hands of the manikin can be instructed to undertake a range of activities extending from simply that of pointing at an object through to gripping, such as occurs when a manually powered wheel chair is in use.

Keywords: Computer modelling, constraint resolution and rules, human interaction, inclusive design

1 INTRODUCTION

In order to design products and machines that interact with humans it is necessary to understand the form that these interactions take. These can be seen to be of many types extending from the passive observation to the complex manipulation [1,2]. However, the most difficult actions involve the hand and the product (or machinery controls)[3]. These interactions can extend from the pointing at, and touching of objects or buttons through the process of grasping, positioning, operating and restraining [4,5].

2 HUMAN REPRESENTATION

A human manikin has previously been constructed and used in studying the postures of humans in which the hand was only represented by a single profiled planar solid [6]. The posture of the complete manikin, required to meet a defined task, is determined through constraint resolution processes [7]. Here all necessary conditions that needed to be fulfilled in achieving the required task are defined as constraint rules, which extend from those of reaching through to complete body balance. The free variables of the manikin are then manipulated by direct search techniques in order to find a true state that solves the complete set of rules for the problem [8].

2.1 Manikin structure

In representing the posture of the whole body a minimum of sixteen imbedded model spaces, connected via 86 degrees-of-freedom, need to be manipulated and resolved. This is achieved by a dedicated search strategy employing sensitivity analysis to select the dominant variables and to order the progression of the search [9]. One hand alone adds an additional 19 model spaces to the manikin and, theoretically, over 60 additional degrees of freedoms. However in practice it is found that there are many constraints on the movements of the fingers with actions appearing to be dominated by a few, with the remainder providing ‘follow-up’ support and grip.

3 HAND STUDY

This current study was thus initiated to investigate the complexity of the human hand and to establish the minimum number of freedoms necessary to represent the majority of common tasks. In achieving this it was necessary to develop the constraint rules necessary to achieve defined sub-actions (and sequences) and the rules for the common interactions between combinations of fingers.

3.1 Finger model

The hand was developed initially through the investigation of a single finger. Here it was represented by four model spaces, representing a metacarpal and three phalanges (or finger bones) that are 'jointed' together using the 'embedding' and 'pivoting' commands in the constraint modeller[10] (figure 1). This first function ensures that the higher joints take on displacements and rotations that are imposed upon them from lower model spaces. In this manner rotation of a lower joint will effect a rotation on all higher bones. The pivoting command additionally ensures that the rotations all occur about the joint centres between each bone.

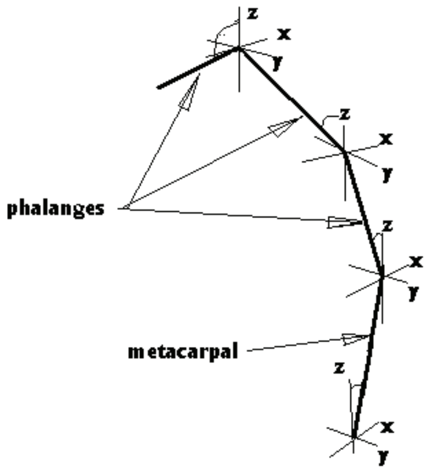

Figure 1 Construction of a single finger

These implicit constraints guarantee that the fingers remain correctly assembled but additional constraints need to be imposed explicitly to ensure that the fingers only bends in the allowable directions. The main movements are achieved by restricting the joints so that all rotate in a single plane (rotation in y-axis in Figure 1). The rotations in the other two directions are thus fixed by a constraint command, resulting in only three rotations being active out of the original full 36 degrees-of-freedoms allowable in the constraint modelling environment. However, in order to allow the fingers to spread when the hand is opened, an additional rotation is allowed in the plane of the palm at the base of the metacarpals (as in the x-axis of figure 1).
The movement of the thumb also undertakes an additional rotation out of the plane of the hand to provide it with its full dexterity. This results in the hand being represented by a total of 21 degree-of-freedom out of the original 114.

3.2 Limits on joint rotations

Within the constraint modelling environment these joint rotations can be restricted in range, by a 'bounding' command that limits the individual rotations to lie between set values defined for each joint. This ensures that whilst the fingers can close in to form a fist or to grip an object, they cannot spread backward beyond the flat position. These limits are implicitly applied as rules throughout the resolution activity and individually set for each finger from a generated list.

3.3 Facetted finger representation

The individual fingers are themselves embedded into a hand space that, in turn, is embedded into the wrists. All five fingers are first represented by lines for each bone, as shown in Figure 2.

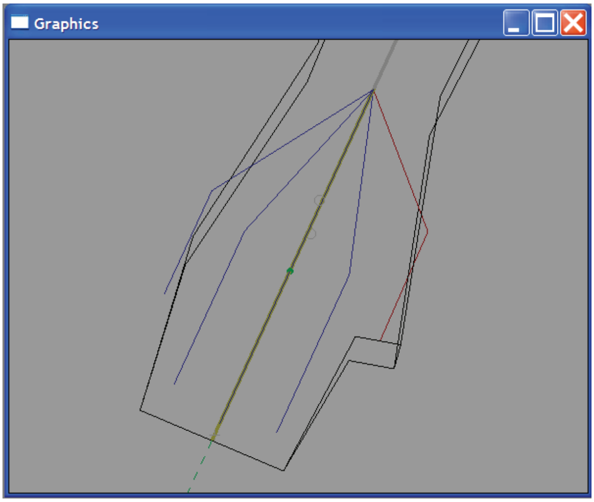

Figure 2 Lines showing individual fingers drawn within simple outline of the hand

The embedding of geometric solids into the individual finger bone spaces completes the finger representation. This has been done by using a number of different spatial models to give different levels of visual images, but is handled in this study by the assembly of spheres (at the joints) and conics in between. This provides an adequate level of visualisation and surface description, without excessively increasing the number of geometric entities in the model, as shown in figure 3.

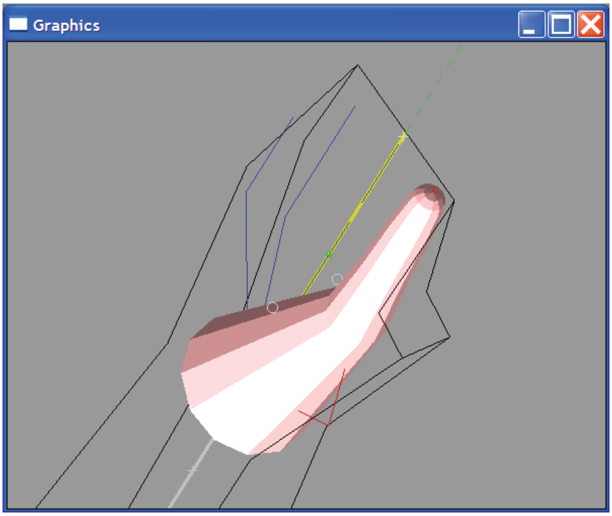

Figure 3 Surface descriptions of fingers using facetted spherical and conic models

An additional benefit gained from the facetted representation is that any of the model nodes can be used to represent the points of contact on the fingers. Points can thus be selected to represent different contact conditions arising in various problems. Points can be selected on the tip of the end sphere for such activities as pointing contact, through to those on the inside of the conics for gripping actions (as can be seen in Figure 3).

3.4 Constraint rules

The fingers are then manipulated by constraint rules to allow differing activities to be represented. In a pointing action points within the finger, and on the top of the end sphere, need to lie upon a ray passing down the finger onto the object being pointed at. This is achieved with the constraint rule:

Rule(point(n) on ray(m)) (1)

where the point is defined as point(n) and the line as ray(m).

In the touching condition of finger to finger the rule is:

Rule(point(n) on *point(m))* (2)

Any number of such rules can be switched on and assembled into clusters to form specific actions. These are then automatically resolved by constraint direct search techniques. In this search all of the freedoms of the hand are used to find a configuration that makes all of the assembled rules true.
Such an approach can be further extended to allow groups of rules to be switched on and resolved, as a sequence, to represent the preconditions, intermediate approach and the finial positioning found in many actions.

3.5 Hand assembly

The individual fingers have then been embedded within the wrist space of the manikin and their interrelationships defined by rules. A realistic amount spreading is allowed by providing upper and lower bounded values between each pair of fingers, as shown in figure 4.

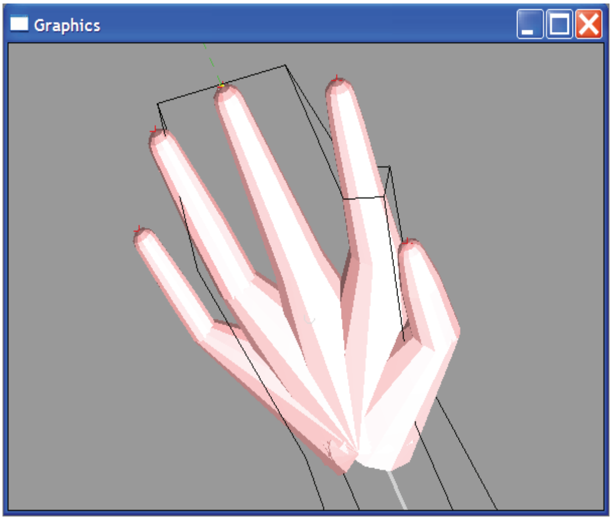

Figure 4 Hand shown flat but with fingers fully spread

For many actions not all fingers are undertaking primary or significant roles. For example, when touching, only the first finger is active by being in contact with the touched object. All other fingers are closed up out of the way. In many of these actions only the first joint of the first 'redundant' finger needs to be considered and an angle of rotation chosen. This finger posture can be represented realistically by setting all of the other joints to the same angle. The remaining fingers in the hand can similarly be represented naturally by allowing the subsequent fingers to take on reduced angles, until the little finger is reached. Observation of real hand gestures has shown that this reduction in finger angle is approximately half between each successive finger.

However, these simple rules can be overridden if the chosen tack require it, and demands specific actions from discrete fingers. This can be seen in the examples illustrated in the following section.

3.6 Hand to arm relationship

The hands can be seen as dexterous appendages at the extremes of the arms. As such they contribute little to the positioning of the arm but mainly extend the reach slightly beyond that of the wrist. However, the ability of the hand to grasp, point etc, is greatly affected by the positioning of the wrist and its orientation. The final action must thus be arranged to allow some limited arm movement in order that the correct grasping attitude can be performed.

In carrying out such tasks the hand must firstly be opened in a manner that allows the task to be ultimately achieved and a point selected as the arm action centre. For example when a pushing action is required the hand is initially formed to provide a pointing finger, with the others closed and out of the way. An action point is then selected on the tip of the pointing finger that can be used when positioning the arm. If a hold is required then the hand is opened into a spread state (from which the grasp can be performed) and an action point chosen near its center.

The complexity of the constraint processes is thus not increased significantly by the inclusion of the large number of extra degrees of freedom. An additional set of variables and a small group of rules are all that is needed to define the hand activities. A sequence of operations cycling between the positioning of the arm and the forming of the desired contact with the defined object are all that is required.

4 HAND TO CONTACT RELATIONSHIP

When the hand is set to touch or contact itself then the points on the facetted surfaces can be used to contact points on another through the use of Equation 2. However, when establishing the touching or grasping relationships between the hand and a chosen object, a number of special surface points have had to be defined within the constraint modeler.

These surface points are defined to 'float' across the chosen surface and, through the use of Equation 2, to align with the chosen contact points on the respective fingers. Each of these points are positioned within their own model space and positioned at the origin of the geometric space of the primitive solid chosen, with selected geometry fixed. For points moving on the surface of a flat plane, the z-axis is set in the surface plane and fixed to zero whilst the other two are declared as free variables in the search. The final x- and y-parameters thus become the point directly below the finger contact point. Similarly, a floating point can be defined for a cylinder by setting the origin of its model on the axis of the cylinder, and providing the contact point with an off-set equal to the radius of the cylinder. The contact point can thus be positioned on the surface and allowed to move under the finger point by including the variables of displacement along the axis and its angular position around the cylinder to be included in the search for a resolution.

Whilst additional surface points are necessary for other geometric primitives, the ones for flat and cylindrical objects (as well as that for self contact) are sufficient to allow the following contacts to be created.

4.1 Point-on-point

Selected points can be declared as in contact. The bringing of the required points together gives, for example, a pinching action (figure 5). In such a case the remaining, non-pinching fingers are positioned through rules of compatible positioning.

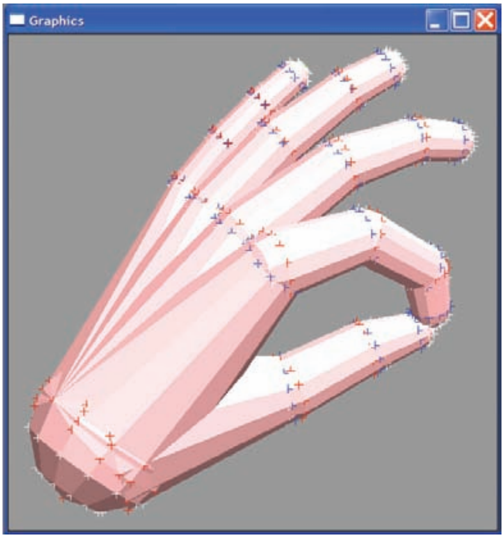

Figure5 Touching finger and thumb with other fingers relaxed

4.2 Point-on-surface

Rules have been generated to allow points to be placed at a zero height above a flat surface. When points are selected at different positions on the fingertips different types of touching conditions are generated (figure 6).

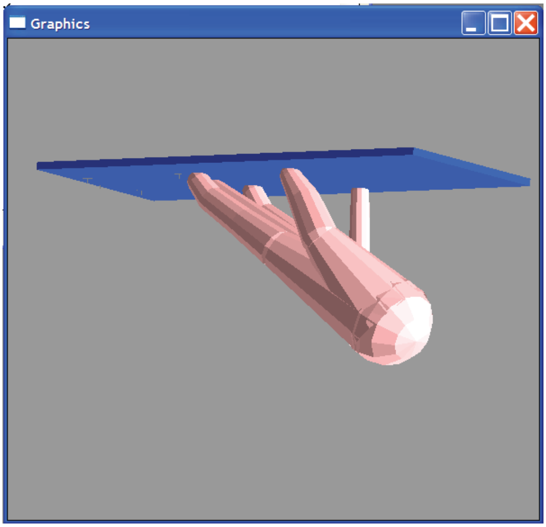

Figure 6 Fingers touching a surface

4.3 Point-on-cylinder

Points have been defined that 'float' across the surface of the cylinder. Selected contact points on the fingers are allowed to touch these surface points to provide a range of grip representations. With the same rules and a different size of cylinders the grip conditions are seen to be satisfied in a different manner (as seen in Figures 7 & 8).

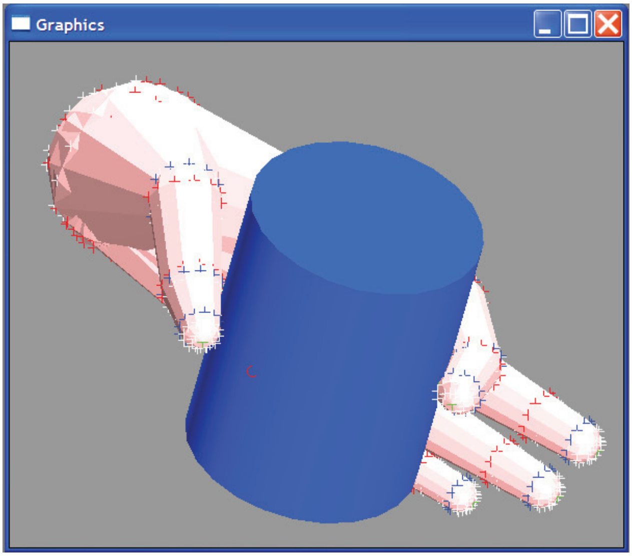

Figure7 Tip contacts around large cylinder generates cup-like grip.

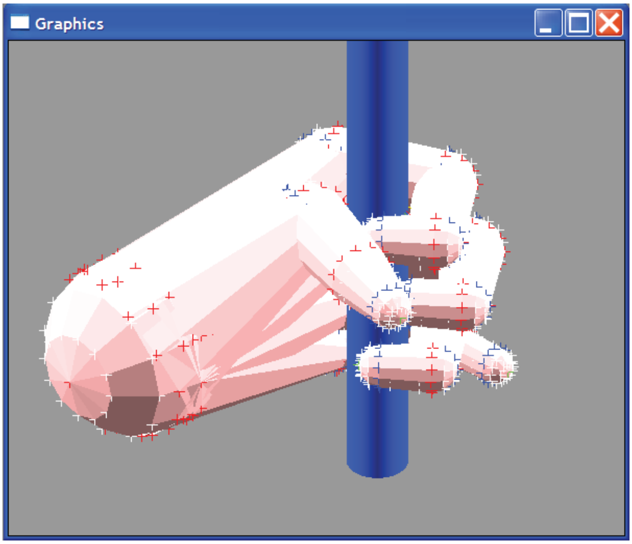

Figure 8 Multiple finger contacts around a smaller cylinder results in handrail type grip.

5 EXAMPLE OF COMPLETE MANIKIN MODELLING

The above hand modelling techniques have been applied in a preliminary study into the grasping approaches used when a hand-operated wheel chair is employed. Within the constraint modelling environment the rules are set up to allow a manikin to be seated in the wheel chair and for the centre of the arms to reach for the reaction point on the rim of the driving ring. When this sequence of event is run it leads to the sitting posture as shown on Figure 9.

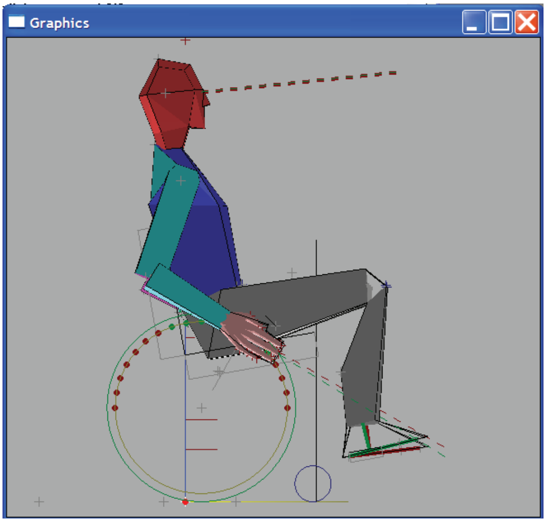

Figure 9 Natural sitting position for man in a wheel chair, created by constraint rules.

In this solution the hand are kept against the outer edge of the rim and so provides a representation of the position taken up when pushing via the palms. Figure 10 shows the full palm pushing mode when the fingers are raised clear of the wheel and rim. This is again resolved by the use of additional constraint rules.

In Figure 11 the hands are changed to undertake on a grasping action, with the fingers attempting to encircle the small section of rim (represented by a short length of cylinder within the complete torius rim).

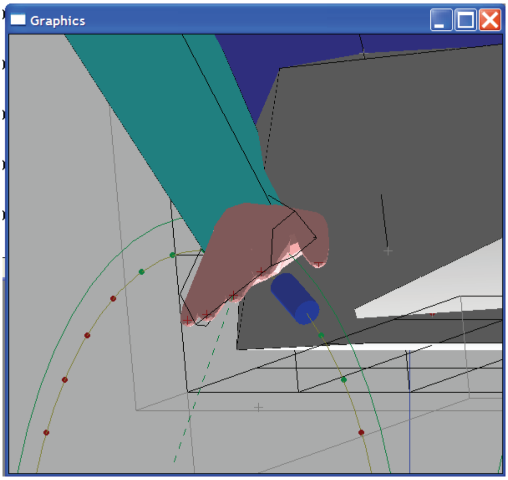

Figure 10 Hand moved into a palm pushing format onto a small section of rim.

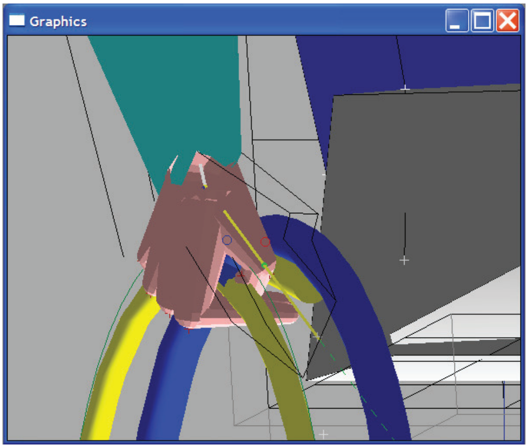

Figure 11 Grasping action used to hold onto the rim.

The final hand position illustrated, in Figure 12, is that used by some wheel chair users. Here the interaction between the hand and the rim is through the use of the palm with the hand turned outwards.

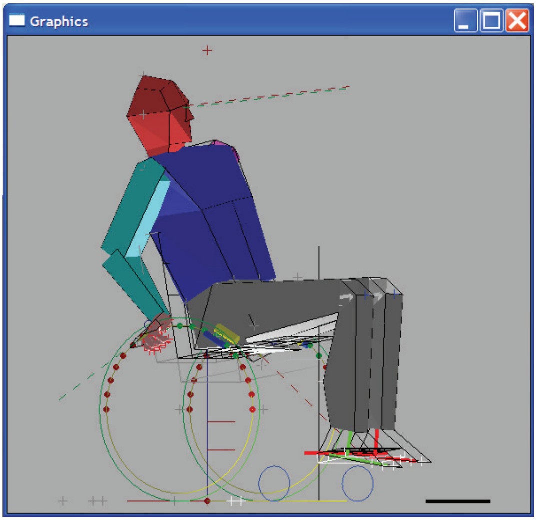

Figure 12 Manikin pushing wheel chair with the ball of the hand

6 CONCLUSIONS

These initial sets of contact rules have been sufficient to allow different types of human to product interactions to be considered. For example, by using the full manikin representation, it has enabled a study into the interaction between a user and wheelchair to be commenced. As both manikin and wheelchair are parametric representations, the aim of the study is to allow both the manikin and the wheelchair design to be manipulated to determine the most appropriate configurations and postures to be employed in different circumstances.

The generic nature of the various forms of contact and grasping investigated has provided the basis for the representation of many other forms of human to product/machine to be studied.

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