INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008

THE EVALUATION OF THE ABILITY OF A CONSTRAINT-BASED MANIKIN TO REPRESENT NORMAL HUMAN TASKS

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Keywords: human modelling, constraint resolution, human tasks

1. Background

There is often a requirement to investigate the interaction of humans with machines, products and the environment. This arises in studying both the use of hand operated tools and the manual operations associated with process and machine tools used in a production environment. Figure 1 shows a typical set of steps employed in a processing plant. Here the machine has been designed with little consideration for the operator. The operator is required to climb to the top platform to carry out many separate activities including checking the flow down the line, adjusting the controls mounted over the line and loading or extracting packaging material from the plant. Such climbing is tiring and can lead to both loss of productivity and to safety issues.

Figure 1. Typical access steps to a processing machine

There is thus a need to create an environment beyond the normal human animation programs currently available to the investigation of such problems. This new environment should incorporate an understanding of human movement and its restrictions, together with the ability to define different human interactions and postures that fulfil the requirements of the set tasks. This has been achieved by incorporating an anthropomorphic model within a constraint modelling approach.

A constraint resolution environment has been created and used extensively to model, resolve and optimise many machinery problems. Within the packaging and process industry there is increasing concern and legislation to insure the safe interaction between humans and machines. This has stimulated a requirement to create an integrated environment in which the machinery and human operator can be studied together.

2. Constraint modelling

Research has been undertaken for many years into applying the constraint resolution approach to the modelling of machine and mechanism operations [Leigh 1989], [Medland,2000]. This approach employs the use of direct search techniques to resolve a set of rules defined for the chosen problem. Within the modelling environment parametric models can be created and their declared variables manipulated. These rules are assembled into functions in which these variables are manipulated, by the search technique, in an attempt to determine a state in which all the declared rules are true.

This approach has been used extensively in the modelling and optimisation of machines, particularly for the packaging industry. For example the model shown in Figure 2 was used during the development and optimisation of a standardised drive unit for a machine system. All the components were described parametrically and entered into separate model spaces within the constraint modeller. The assembly was then described as a set of rules that determined which features aligned or associated with others (such a follower points on the cams). This collection of rules was then used to produce the kinematics of the machine.

Further rules were developed to describe the form of optimisation required. In this case out of alignment values were calculated and minimised to reduce the forces acting down the mechanism chains. This resulted in a number of the mounting points being repositioned and the geometry of the individual links being changed. A significant improvement in machine performance was thereby achieved.

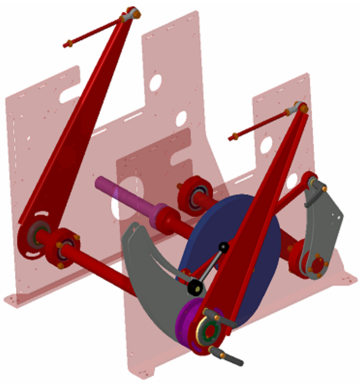

Figure 2. Original cam unit before optimisation in the constraint modeller

3. Human modelling

Many human modelling programs exist that allow manikins to be manipulated and positioned in a working environment and the simulation of activities built up [Porter, 1999], [AnyBody, 2007]. Whilst these provide a good visualisation of human activities they do not ensure that limits of movement or potentially dangerous situation are not arising, other than by inspection by the programme user. An approach based upon constraint processes has thus been investigated.

When modelling humans the skeletal structure must firstly be constructed. The skeleton is defined within the modelling environment as a pivoted set of links embedded within a hierarchal set of spaces. In order to provide the most versatile spatial arrangement (whilst not representing any normal posture) the hierarchy commences at the trunk and moves out towards the extremities. Within the constraint modeller the connectivity and constraints are achieved by employing a combination of embedding one space within another and applying a pivoting command to fix all the possible translations between these adjoining spaces.

3.1 Restrictions

The movement of the joints are further restricted or fixed to represent real human movements as some rotations do not exist (such as the eye does not rotate around the axis of viewing). Similarly no limb rotation can complete a full 360 degrees of movement. Thus all allowable motions have both upper and lower rotation limits imposed upon them through a set of implied constraints.
These restrictions are further complicated as rarely are some limbs taken to their available limits (whilst some are). These 'natural' limits are often imposed by the task being undertaken or by social conditions of acceptability. The limits imposed upon the motion of limbs, both singularly and in combination, is thus complex and need to be changeable to reflect the capability, disability, age and circumstances within which event is to take place.

3.2 Task rules

Here the rules that relate the human to the environment, or the postures required, are determined and used within the modelling environment to search for appropriate postures. Such rules relate the conditions required between geometric entities which define elements of the task. For example the rules of 'looking' require the rays cast from both eye balls to converge upon the defined object, whilst the difference in eye angles is minimised and within the range set in relation to the head. If this is not achievable then additional movement of the head, neck and torso may need to be applied (together with their limits).
It is this subtle combination of explicit rules that define the task elements and the implicit rules defining the acceptable limits to motion that provides the movement or posture that is most humanlike.

3.3 Simple human actions

This constraint-based approach has been created specifically to investigate simple human actions and specifically the interaction of operators with products or equipment (and in particular to study manufacturing machines) by the modelling of both within a constraint environment.

3.4 Anthropomorphic representation

A close relationship with the Technical University of Delft led to an investigation of their ADAPS human model [Hockstra,1996]. This has now been successfully incorporated into the structures set up within the RASOR constraint environment for human modeling [Mitchell,2003]. Delft has provided access to data on existing models in the form of their geometry, their limb restrictions and wireframe representations of the body shape. This has been the basis of all the human representations that have since been used in the constraint environment.
The RASOR constraint resolution approach used in this human study employs a sensitivity search to select the dominant variables which have the major influence upon the selected rule [Medland,2004]. The selected combination is then applied through the use of bounded direct search techniques that seek to establish a set of solution variables that make all of the specified design rules simultaneously true. The rules can be formed into clusters, sequences or nested within the environment by switching on and off the rules within the set which describe different aspects of the task being resolved.
The kinematic representation of the human form now used contains a minimum of 21 linkages, 57 degrees of freedom and 172 bounding constraints in the resolution of problems containing possibly 21 requirement rules. Differing approaches have been used to investigate specific problems that have included problem reduction techniques, constraint nets and sensitivity analysis. All of these approaches have been initially applied in human model studies before being used to advance the use of the constraint modeller in other areas of research.

4. Standing

In order to evaluate the effectiveness of the approach described above an initial investigation was conducted into the modelling of standing. This was considered as one of the most common postures that needed to be represented and one of the most complex when merged with other tasks, such a operating a production machine.

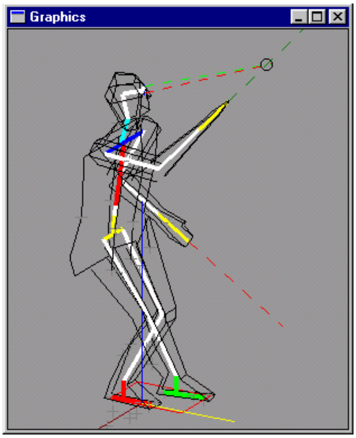

Figure 3. Man standing and pointing (whilst looking) at an object

In order to represent standing realistically both balance and natural posture had to be considered as well as taking into account the desired action. Figure 3 shows such an action. The position of the centre of mass has been calculated and its position shown on the floor. Similarly a bounding box has been constructed around the feet to show where balance may be achieved. Whilst the bounding box does not guarantee balance, it is used in the constraint approach to determine whether the manikin is initially 'unbalanced'. With the vector outside of the bounding box there is a necessity for the resolver to make some correction. The more accurate calculation requires the generation of the convex hull shown in Figure 4 (where the zone of balance is seen to be within the region encompassed by the extremities of all of the contact points).

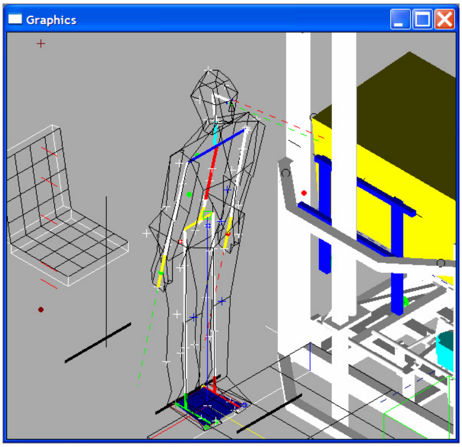

Figure 4. The convex hull of balance when standing with feet close together overlaying the bounding box

Balance is thus not just a simple test of whether the vector is inside the box or not. On many occasions the full convex hull may be required. If for example the man is sitting, the projected hull will need to encompass the buttocks or if leaning his weight upon a handrail then the convex hull needs to include such contact and support points. Additionally the hull may reduce during an analysis as the manikin may need to lean forward as shown in Figure 5. Here the manikin is attempting to balance upon the rear foot with the other raised. This results in the heal breaking contact with the ground so that the convex hull only encompasses the three points still in contact with the ground (that of a point in the centre of the foot and two toes).

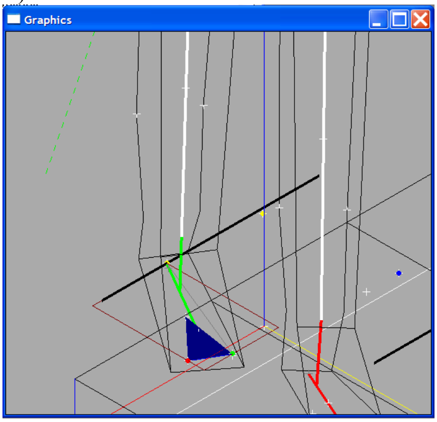

Figure 5. Convex hull when man is leaning forwards onto the toes of one foot

The balance condition is thus seen to be a complex, interactive condition that can change both with the applied condition and postures found during the search for a suitable solution.

5. Sitting

In a similar manner to standing, sitting can also be complex. There are many postures that fulfil the requirements that may be further modified depending on the actions required.

In the study, illustrated in Figure 6, the seating position of a man was investigated in order that he was able to see and point at different parts of the machine. Many different postures were found but few that allowed the man to look at all of the required points. Some had to be abandoned as they were at the lower back and could only be seen by moving off the chair.

The sitting posture shown in the figure is one of many found that both satisfy the rules of sitting (with feet on the floor, buttock points on seat and back points on seat back) and comply with the limits of natural motion and posture. By comparing the positions taken up, the one with minimum changes to the other reqired pointing actions, can be selected and the position/orientation of the chair rationalised.

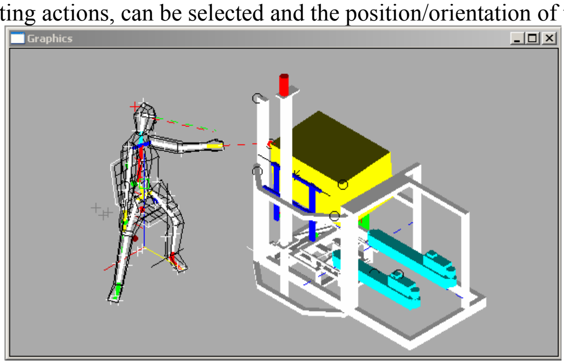

Figure 6. A study of a man sitting by a machine

The study could thus be used to find the optimum position for the chair and could be used to reposition or group the controls on the machine.

6. Stair climbing

Another major investigation has now been initiated into the complexities of stair climbing. (That of descending however will await the completion of climbing due to the increased chance of instability that occurs when coming down.) This study has shown the interdependency of the various actions as the stairs are climbed. If the manikin starts at different positions relative to the first stair, the treads are of different height and widths with different initial postures, the actions of moving from one step to another will change considerably. Further changes will occur if the person is carrying a load or using a handrail (figure 7). Here the posture is seen to be distorted by the action of holding a point on the machine but without putting any weight upon it.

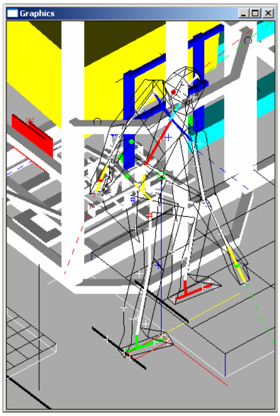

Figure 7. Man using a hold point on the machine whilst climbing a step

Whilst the main action is always visualised in stair climbing as moving the foot from one step to the next, as shown in Figure 8, nine intermediate actions occur between repeated actions of moving up a series of steps. The first two actions prepare the person for moving into the stair climbing mode. The person is positioned, balanced and looking in the right direction. Stair climbing can then commence.

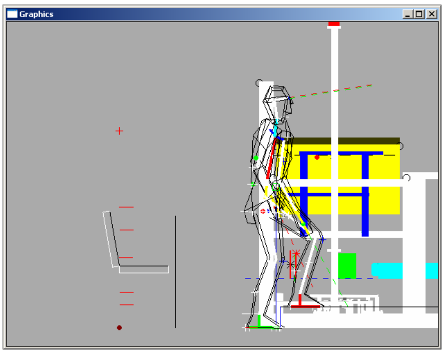

Figure 8. The posture in moving from one step to another

The next moves the load off one foot and thus balances the person on the other. The foot can be first lifted, then brought forward over the step, and then placed in contact with that step, whilst maintaining balance on the rear foot. It is only then that the centre of mass can move through the convex hull encompassing both feet, that it is possible to be transferred to the forward foot. Once all the mass is

within the convex hull of the single forward foot then the operation of lifting the rear foot can commence. There again a sequence of actions commences, this time with the rear foot, to lift it, pass it over the step edge and place it beside the other. This must be completed again whilst balance is maintained upon the other. It is only when both feet are together on the step can balance and a standing posture be resumed.
This process is further complicated in climbing a staircase as do we rarely climb one step at a time and pause, usually with only very heavy loads. The more normal action is to change the second and subsequent actions by not standing with the first foot but by passing directly to the one above, with only a single step rising again occurring at the end to result in a final standing (or walking) position at the top.

7. Further studies

The programme of research into the constraint modelling of humans has undertaken further studies into different tasks to be evaluated within the constraint evaluation approach. These have included initial studies of cleaning the floor and getting into a bath. A major study is now underway into the design and optimisation of wheelchairs for paraplegics.

8. Conclusions

The studies into different normal human tasks has been undertaken to provide a basic understanding of the form of the constraint rules necessary to describe them and to evaluate the capability of the constraint resolution approach to represent them realistically.

These studies have shown the complexity of even the simplest human posture when applied to more complex tasks and the need to be able to evaluate alternative configurations. However they have shown that the constraint modelling approach has the capability to undertake such tasks and handle large numbers of rules, such as the complexity of balance, sitting and stair climbing that can be incorporated into other task requirements.

This has provided a basic understanding that has allowed the approach to be further refined and applied to other human modelling studies.

Acknowledgement

The authors wish to thank their respective academic institutions (the University of Bath, UK and the University of Canterbury, NZ) for their continuing support of this collaborative programme of research into human modelling.

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