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AN IMPROVED HUMAN MODEL FOR USE IN THE STUDY OF SITTING POSTURES

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1. Introduction

The ADAPS human representation program, developed at the Technical University of Delft [ADAPS 1990], has been incorporated into the constraint modelling environment, created at the University of Bath, to allow the study of human interaction with products to be undertaken [Molenbroek et al., 2000],[Medland, 2008]. To allow realistic human movements and postures to be created, the detailed representation of the manikin has had to be extended, and new analysis techniques incorporated [Medland et al., 2009]. This paper presents further work undertaken to include a three segment spine (whilst the original was rigid) to allow better representations of bending and sitting postures to be found. The constraint modelling environment, whilst used extensively with the human modelling techniques, was created as a general purpose problem solving environment in which the issues to be addressed are defined in terms of rules. These are then solved, by direct search techniques, where a true state of the solution is defined as when the square root of the sum of all of the rules is, or approaching, zero. This technique has been used widely, by the Constraint Modelling Group at Bath, in the design and optimisation of machines and process equipment [Hicks et al., 2006],[Medland et al.,2009].

2. Background

During the development of these techniques practical human studies have been undertaken. These have included that of simple standing postures through to complex reaching, whilst balancing. Various more complex tasks have been investigated that have included that of stairclimbing and more extensively that of wheel chair posture and operation. The latter was undertaken in conjunction with the University of Canterbury, New Zealand, and has entailed both the modelling of human hands to model driving wheel grip [Medland, 2009] and a continuing extensive experimental program into the capabilities of subjects with both paraplegic and teraplegic conditions [Gooch et al., 2007].

2.1 Research aims

Whilst there are a significant number of people living with tetraplegia, gathering experimental data is difficult because the population of available tetraplegic sujects is geographically dispursed. Testing is generally conducted in a hospital environment supervised by medical practicioners. Hence transport arrangements must be made for the subjects and consultation times scheduled with physiotherapists. These factors limit the number of tests that can be practically completed within an acceptable timeframe. The aim of the constraint modelling manikin program is to explore the possibilities of determining the appropriate rules necessary to represent and reproduce the various states of chosen recognised postures. The constraint rules used in the approach define the basic requirements of the

posture, or action to be achieved, which are independent of the physical stature of the subject. In this approach the manikin geometry can be changed and new postures found from the original rules. It is then possible to observe and quickly measure the subjects before applying the chosen set of rules derived for that posture or state.
The initial study of the interactions, between subject and product, can thus proceed on that basis before a derived solution is presented to, and evaluated with, the subject. Such solutions can be approached as being either generally applicable, or designed to address the needs of an individual.
In order to extend and verify the approach a large number of investigations into different aspects of the modelling of humans have needed to be conducted by many researchers into a wide range of human activities.

2.2 Anthropomorphic representation

The data and representation of the human body, and its limits of movements, is drawn from the original ergonomic research and modelling undertaken at the Technical University of Delft [ADAPS, 1990]. Here a manikin was created, within a CAD environment, that could be manipulated to create postures appropriate to represent chosen tasks. Simple models of products and equipment could then be entered into this environment and the manikin manipulated, interactively, to determine appropriate interactions and postures.

2.3 Constraint modeller

The University of Bath constraint modeller was initially created simply to investigate direct search approaches to solving problems in which the solution conditions were defined by explicit rules. Its initial intention, and its use for many years, was primarily in the design and analysis of mechanisms. Here it was used extensively as a tool to aid in the design of process machines and mechanisms, and to optimise the performance of these machines to perform predetermined tasks, especially in the manufacturing, processing and packaging industries [Hicks et al., 2007].

2.4 Human modelling

The integration of the constraint modelling approach with the human representation presented a number of problems that needed to be addressed.
The primary one was to determine the hierarchial relationships between the individual model spaces (used to represent the body parts). The arrangement of the hierarchy from ground (feet) up through to the head and hands whilst operating conveniently with all standing postures, created considerable difficulties when sitting or interacting with a grounded product with either hands or feet. As the ‘grounding’ of the manikin could change throughout the task being studied (such as when climbing up stairs) it was decided to select an origin for the hierarchy as close to the centre of mass of the model as possible, in order to simplify the calculation of balance during standing, and to reduce to levels of embedding necessary in the complete model.
The next major problem to be addressed arose from the total number of possible degrees of freedom that could be active in the manikin for any action and how they could change during successive actions. Without including the 104 separate freedoms occurring in the joints of pairs of hands, the number of body parts can be reduced, in a simplified representation to that of 22. This can then result in dealing with only a possible 52 separate variables if the maximum level of restriction is imposed. Here restrictions are imposed on eliminating the side flexing of joints or the spinning of eyes. Although this results in a large reduction in the number of freedoms to be handled, it still leave a high number to be sorted and handled [Medland, 2009].
Further more, all of these freedoms are themselves individually bounded as no human joint can continuously rotate, as in a machine. Each has its maximum and minimum angular position from its relaxed state. The analysis techniques need to be able to handle such bounded conditions. This is further complicated as, whilst some limits may be hard and physical, others may only be preferred or even just conforming to normal social practices. Various arrays of joint limits have had to be included and the program allowed to switch between them as the problem demands.

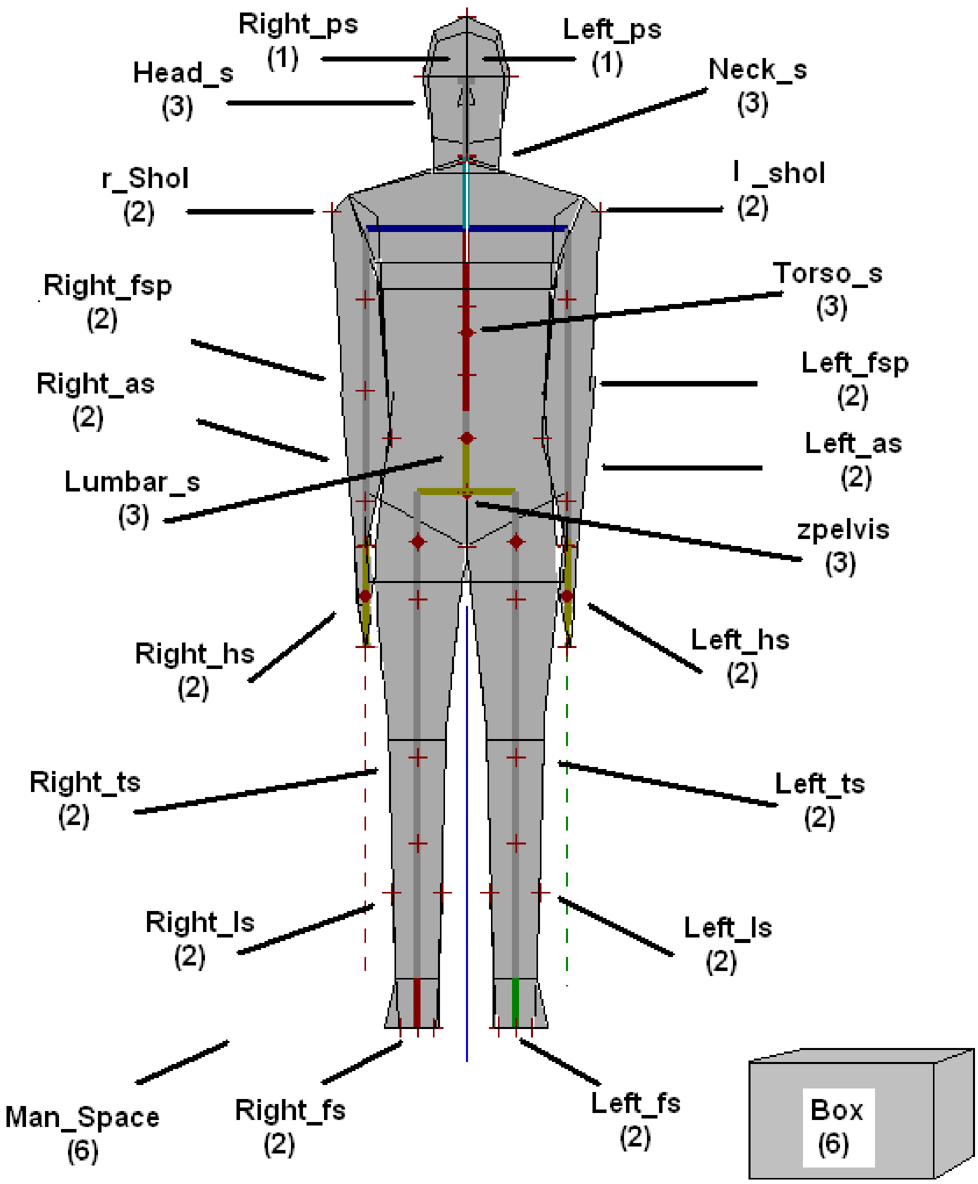

Figure 1. A manikin representation with the lowest number of practical body elements (22) and degrees-of-freedom (52)

2.4 Hand modelling additions

In order to create closer represention of humans, particularly for the study of their interaction with wheelchairs, a major modification was made to include the hands in the constraint based representation. Here the hands provide the most common form of interaction between the manikin and any product. The inclusion of them additionally required an extra 22 joints to the body but, fortunately, many of the resulting additional freedoms are restricted, and occur at the end of the hierarical chain of the arm. This allowed the initial positioning of the hand to be performed globally by a point at the end of the arm and then providing small degrees of iteration and correction to position the hand. The type of contact required between the fingers and the object could then be established by a further set of rules when the grasping attitude is itself considered.

A complete modelling study was undertaken of the hand and the movements involved [Medland, 2009]. This showed that normally only the thumb and first two fingers provided the primary grasping and contact operations (and thus establish the initial hand position), with the remainder providing further general support (or taking up a relaxed position). In many simple cases, such as pointing, very few joints are involved in establishing the primary action, with the majority taking up relaxed positions. In other cases, such grasping objects more fingers are involved and new rule conditions have needed to be developed.

Points have been included that lie between points on the fingers and the surface being contacted. These 'sticky' points are restricted to move anywhere on the surface and rules applied to maintain contact with the finger points. Within the rule sets, these are allowed, by changes in their weightings, to be variously highly to lightly associated with one another. This then provides conditions in the range from where the points are accurately fixed together, to being only lightly associated (hence the 'sticky' description).

Such hand models are shown in figure 2 where the first illustrates the resolution of a touching rule applied between the first finger and thumb, whilst the remainder take up 'relaxed' positions. Here the relaxed positions are defined by a sequence of rules that correspond to all the joints of a single finger sensibly taking up the same angles, whilst the joint angles between successive fingers reduce by approximately a half. This results in the observed condition that the little finger hardly moves unless it is actively required.

The second illustration is of the grasping of a rod where a number of finger points along the fingers are applied to 'sticky' points that can move across the surface of the rod. Due to the smallness of the rod chosen not all contact points can be achieved at any one time (so the resolution of the rules do no achieve a zero state but reach a higher minimum). The illustration shows here that the grasp is at the base of the thumb, fully wrapped on the first finger and on the tips of the middle and little fingers (with the ring finger playing no part).

This latter representation has been incorporated in the full representation of the manikin and wheel chair analysis (as shown in Figure 3) to allow the grasping of the driving rim to be represented.

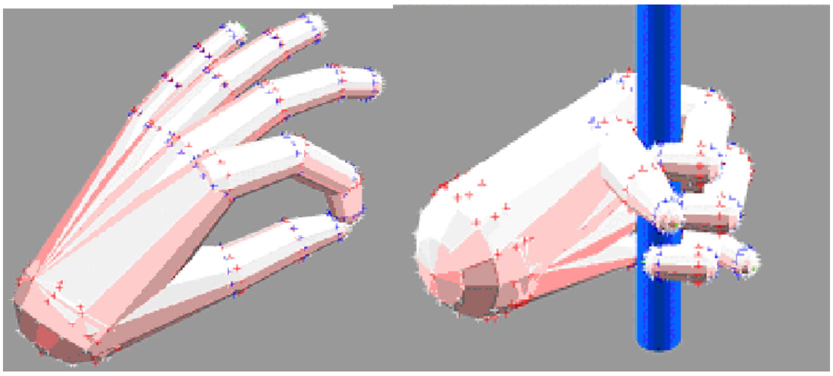

Figure 2.The representation of touching of finger and thumb and of grasping a rod

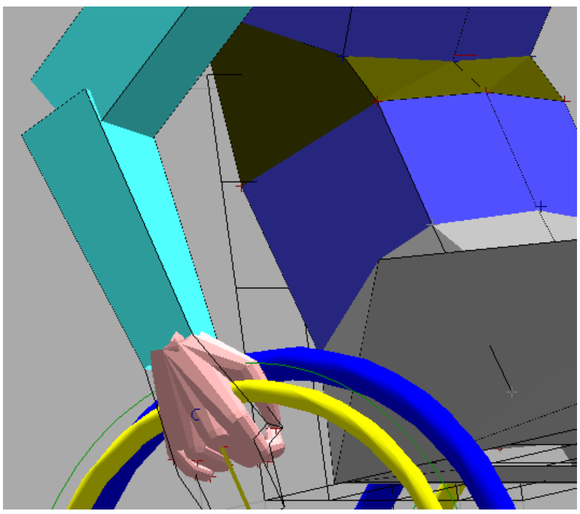

Figure 3. The light gripping of the wheelchair rim

3. Three segment spine model

The original ADAPS model was created with a single body part to represent the complete spine. When studying the sitting of paraplegics in wheelchairs this was found to be insufficient due to the wide range of different postures taken up by patients with injuries at different spinal positions. From a review of these injuries and the postures taken, it was decided to construct a new spine model composed of three jointed segments.

These three new segments extend from waist to shoulder and provide a maximum of 40 degrees of forward bend between each segment (as shown in Figure 4). As the search routines operates on the principle of minimum movement the total bend in the spine is both reduced to that necessary, below the upper limits, and distributed approximately equally between the segments. The inclusion of the three segment spine has allowed both greater movement to be achieved and resulted in more realistic postures being represented.

This bending action is also achieved whilst the manikin remains in balance. This is shown in figure 4 as the arms are moved to the rear and the balance vector can just be seen inside the convex hull and right at the toe.

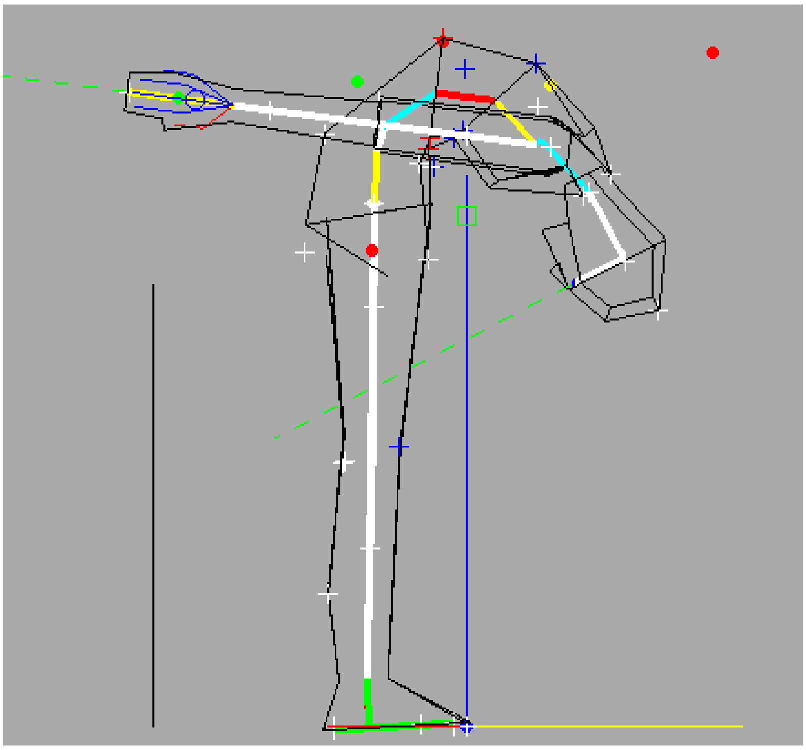

Figure 4. Manikin in a balanced position with all spine segments at their maximum

4. Human representation of paraplegics in sitting posture

The single spine element used in the original human representation resulted in a limited ability to represent the complex postures of sitting. To improve this represention and analysis of the postures adopted by paraplegics, when operating wheel chairs, it was necessary to incorporate this more complex representation.

As the spinal injuries occur at different levels in the spine, the subjects will undertake different postures in order to maintain their balance and still allow necessary arm movements to achieve the driving forces across the top of the main wheels to provide motion. Each chair has thus to be adjusted to allow the user the right combination of these sitting and driving positions.

In the studies undertaken at the University of Canterbury, in collaboration with the Spinal Unit at Burwood Hospital, a number of patients (now in excess of a twenty) have been investigated and their postures and movements recorded. These range from a large proportion of C6 injuries where some arm motion is just achievable, down to a single L1 injury which leaves the subject almost full upper body movement but no leg movement. A further group covers the range from C5 to C7 where some impairment occurs in both elbow and wrist extensors.

4.1 Manikin representation employed

The capability of the model to represent this range of disability was initially investigated to see the postures that could be undertaken as the head position was required to follow different positions of a viewed ball. In the analysis the ball was systematically moved from an initial starting position at 100cm in front of the wheelchair (and at a height of 80cm) back into the subjects lap (at only 25cm forward).

The manikin representation used contained five contact positions expressed by rules. These were chosen to give two on the base of the buttocks for sitting on the seat. The further three were chosen for leaning back and were positioned on the back of the buttocks, the middle back and then the shoulders. These contact points were initially positioned 9.4cm back from the spine centre to represent points on the skin surface plus the padding between skin and chair frame.

In this initial study the manikin rules required that it be positioned with only the lower two contact rules on the back being active. This resulted in the manikin sitting close into the lower portion of the chair but allowed the shoulders to move forward. In this group of studies the constraint resolution process was required to determine the complete manikin posture when, not only were the two lower back contact rules and the eyes focusing on the ball true, but the hands in the driving position, the buttocks on the seat, and both feet on the wheelchair foot rest. The constraint processes were thus required to manipulate a total of up to 38 degrees-of-freedoms in a search for this true state.

From this study it can be seen that with the ball, in the 100cm forward position, the manikin closely represents many of the C6 subjects (an example is reproduced in Figure 5 together with the manikin resolution). Others, such as in Figure 6, show the manikin sitting with the buttocks slightly further forward (by 2cm) and the shoulders held back (by 4cm) to be close to other C6 subjects, as shown in the same figure.

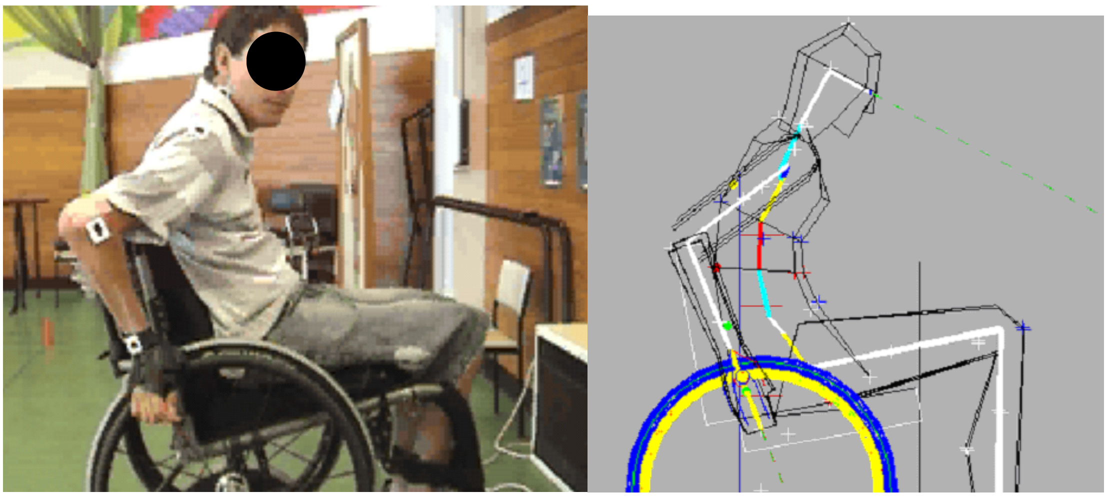

Figure 5. C6 subject sitting back in chair and manikin model

Other C6 subjects tended to take a more upright position with contact being made in all three regions resulting in the shoulders being held well back, as is shown in Figure 7, whilst a C5 subject, shown in Figure 8, took a very slumped position with head brought well forward.

The final groups studied were at the extremes of positioning. An L1 subject took up an attitude in which he leaned well forward from the waist with the head and shoulders down low towards the lap (Figure 9). In that figure the manikin representation is also shown taking up the same attitude due to the middle contact point being released and the high back point being driven well forward.

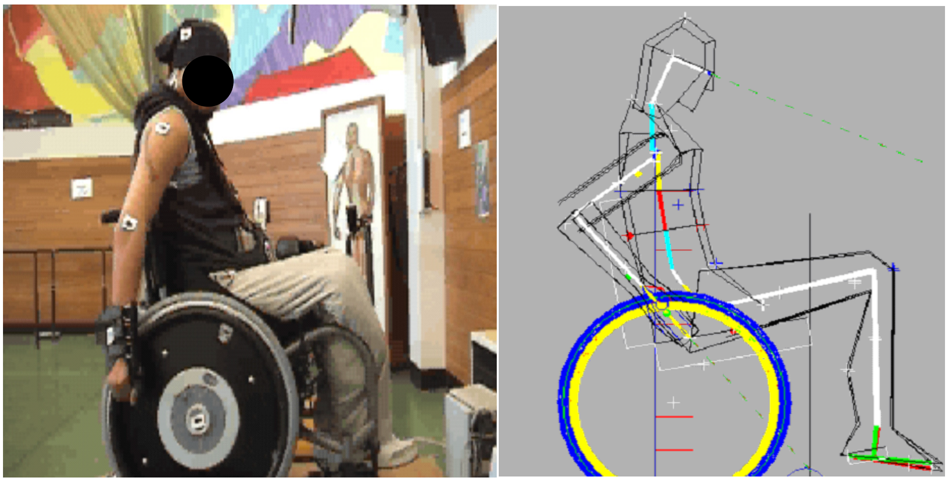

Figure 6. C6 subject with buttocks forward and manikin model

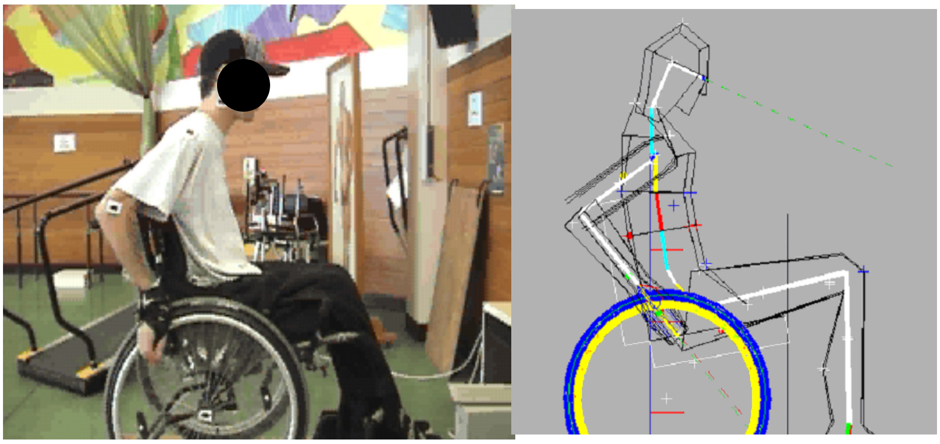

Figure 7. C6 subject taking a very upright posture and manikin model

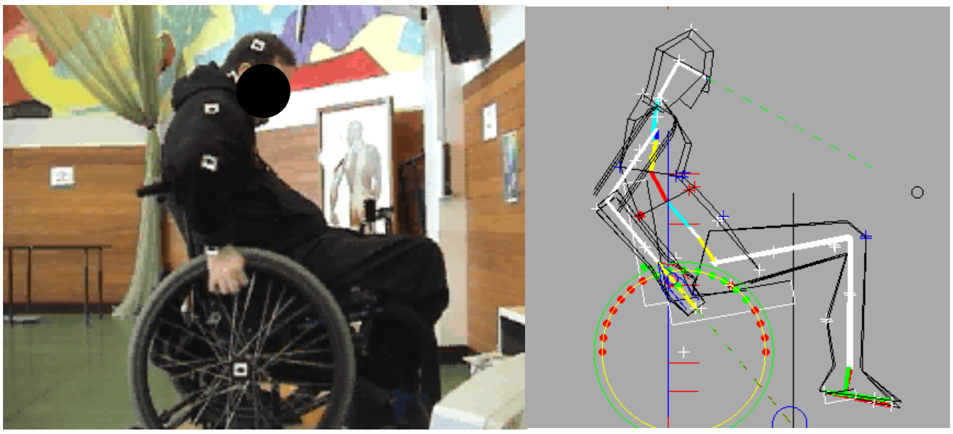

Figure 8. C5 subject sitting well forward and manikin representation

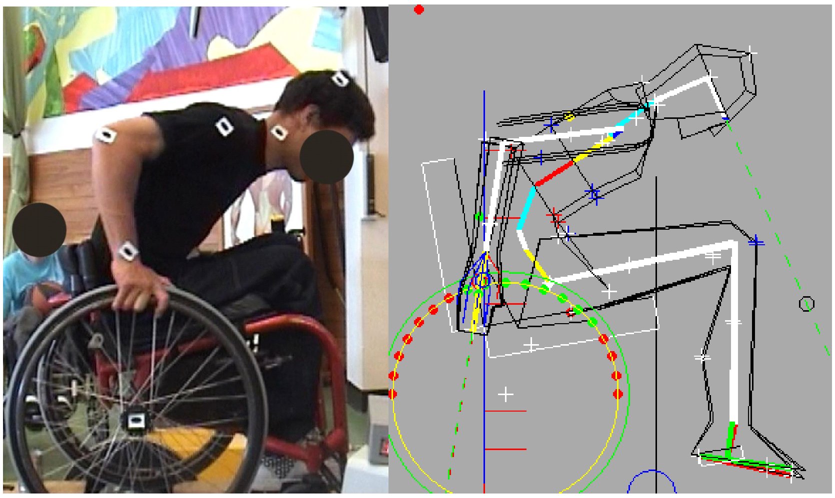

Figure 9. L1 subject bending from the lower waist and manikin model

5. Use of models in analysis and design

The subjects studied and modelled in the manikin constraint environment, provided a full range of the postures observed. These groups could then be used to determine the necessary positions and attitudes for the seating and foot rest for each individual case and the suitability of the overall wheelchair design evaluated. These preferred postures can then be selected for each case and the chair adjusted to meet the requirements of each subject.

It is intended to use this approach to make a selection of which type of posture is most suitable in each case, and to then modify the detail by undertaking specific measurements to fit it to the individual. This will allow a wheelchair to be customised to meet a particular set of requirements without the necessity for extensive measurement and evaluation of the subject. This will also provide the basic information to allow individual wheelchairs to be designed from scratch.

6. Conclusions

The study and modelling of humans included in the paper show some small aspect of the ongoing research that has been undertaken into human/product interaction and, in particular, that being undertaken in the area of paraplegics. The extension and modifications undertaken in both the areas of human modelling and constraint resolution processes has made it possible to provide accurate representations of paraplegics and their postures when operating wheelchairs.

The additional features of grasping hands and a three segment spine has allowed rules to be generated for the constraint resolution processes for various sitting postures. These have provided representations of a full range of postures that represent the different attitudes taken by subjects with different levels of spinal injuries.

These different representations can now be used to reduce the experimental measurements necessary to model individual subjects and their postures. They can be used to identify the changes necessary to modify a wheelchair to meet the needs of the individual and will lead to techniques to create designs to meet such needs.

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