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PROGRESSES ON THE WAY TO A DYNAMIC MODEL

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Anthropometric human models are useful especially when treating static layout problems. Animation tools normally are used to visualize working processes, but not for changing the hardware design of a working place. Questions about forces applied by humans can presently be answered only by the help of paper and pencil procedures. Even if such procedures exist in a software version, they remain appendages to the existing geometrical orientated modeling programs. Within the research project "RAMSIS-dynamic", which was supported by BMW, new models have been developed for force, posture, and motion prediction based on experimental data. The procedure predicting the maximum forces uses calculated torque-ellipsoids. Dependencies of posture, gender and age are also considered in this model. For the posture prediction model the assumption is made that people try to minimize the ratio between necessary and maximum torque over all joints of their body. The resulting torque can be measured using a specially designed device. Additionally a model simulating target orientated motions of the limbs with low dynamic forces has been developed. This model considers some important factors like visual behavior, obstacle avoidance and different grasping modes. The three models were evaluated by comparison with real observed forces, postures and movements.

NECESSARY ABILITIES OF SOFT DUMMIES

After a difficult way of development presently only three important human models are operating on the market: JACK from USA, SAFEWORK from Canada and the models of the European RAMSIS-group. The following research project was carried out for the tool RAMSIS, but the ideas are independent of a particular computer based human model.

The present layout of RAMSIS offers the following features: Starting from a selected anthropometric model a set of restrictions is chosen, depending on the analyzed condition. In the next step the most probable posture is calculated by using an optimization algorithm, which finds the points of most probability for all body joints. The presently summoned up forces can be judged by applying the Siemens-Burandt (1978) procedure. This procedure, however, is an independent system developed for the purpose of general force judgements in working situations. It is not a generic part of the RAMSIS-system and therefore it can only offer rough judgements, not compatible to the high demands of a CAD-system. The same applies to the body movements: As matters stand at the moment, only determination of the moving space is possible on the base of a certain posture (e.g. gripping distances, moving space of the feet area and similarities), but not a real simulation of a complex movement. A further limitation is set by the posture calculation itself: At the present time correct posture calculations are possible only for driver working places but not for general situations.

These deficiencies define the contents of the research project RAMSIS-dynamic: In the future the CAD-tool RAMSIS shall be able to make predictions of the maximum forces for arbitrary populations, to calculate the posture in every situation by only defining the corresponding restrictions, and to simulate car-specific movement behavior. A research program was initiated to collect the necessary data. This program had three essential aspects: Investigation of human body forces, development of a general posture prediction model and development of a movement prediction procedure.

BASIC RESEARCH ON FORCE PREDICTION

The main idea of the force prediction procedure is to define for each joint a 3-D-body describing the maximum force moments, which can be activated in the actual posture to the different room directions (Schwarz, 1997). We call these 3-D-bodies *"moment potatoes"* as they look quite similar to this vegetable. In order to collect the necessary data for this model a measurement equipment had to be developed. It was not possible to use one apparatus for all joints, but we had to design different machines, separately for each joint. In most cases devices generally used in the body building scene could be modified for our purpose. For the measurement of three dimensional joints like the shoulder or the hand joint special devices had to be constructed to separately record the 3-d-forces in an adequate way. So we gained step by step different moment potatoes for defined joint angles or joint positions. The moment potatoes for realistic positions now can be calculated during the CAD-application using a specially developed interpolation algorithm.

In this application the corresponding moment potatoes can be selected, respectively interpolated, depending on the posture, which is defined in the RAMSIS-specific way by restrictions. If in a certain situation a specific force is to be applied, the moment vector for every joint can be calculated corresponding to the mechanical laws. Now it can be examined, if the load vector in every joint is within the corresponding moment potato or not, i.e. if the calculated forces are lower then the possible maximum forces. Then it can be decided if the force, which is mostly determined by technical reasons, is permissible or not. So the designer has already in the CAD-situation the opportunity to change necessary technical parameters.

The measurement expenditure for developing these moment potatoes is immense. A large amount of partly not very comfortable measurements are necessary for every subject. That means that it is impossible to measure a sufficient amount of subjects, although a similar number of values should be available as in the geometric-anthropometric area. In order to avoid this problem we generated the idea of the synthetic distribution. For this procedure we could use the force values received in a huge research program. In this field study carried out by our institute in co-operation with others (Rühmann and Schmidtke, 1992), the maximum forces of 2000 to 6000 subjects were investigated under different conditions. So it was possible to find the force distributions of typical industrial worker tasks (e.g. lifting of weight from the surface, working a pedal, pushing a lever etc.). If we assume that the distribution found in this field project can be valid for the distribution of our moment potatoes, we have only to determine the force percentile values of the subjects in a task corresponding to that of the field study. So, depending on the task, a number of 10 to 30 subjects was sufficient to create a base for the RAMSIS force prediction model.

A GENERAL MODEL FOR POSTURE PREDICTION

The maximum force prediction model is an essential precondition for a general model for posture prediction. In such a posture model the following influencing factors must be considered (Marach, 1999):

- Active forces, which the subject wants to apply to a technical equipment (e.g. pushing down the hood of the trunk),
- passive forces, which are necessary to balance the influence of gravity and, in dynamic applications, additionally needed as inertia forces,
- the equilibrium conditions,
- the knowledge of the partial body masses, and
- restrictions similar to those in the RAMSIS posture prediction tool.

The basic idea of the general posture prediction model is: The human body tries to find an optimum over all joints, where the general effort of his forces is minimized. The effort of the forces - or using the expressions of this model of the moments - can be described as a sum of two terms. One is called "joint moment" M_{joint} describing the position of a totally relaxed state of the muscles and the other "relative moment" $M_{relative}$ determined by the restrictions and other outside conditions such as active and passive forces. The sum of these moments has to be related to the maximum possible moment $M_{maxiumum}$, which is calculated by the force prediction system described above. So we get a relative load value $L_{relative}$, which is a function of this ratio:

$$L_{relative} = f\left(\frac{M_{joint} + M_{relative}}{M_{maximum}}\right)$$

The usual shape of these load functions is shown in Figure 1 (it has to be mentioned that the functions normally are three-dimensional). For the functions, which must be available for every joint, the same optimization algorithm can be applied as it is done in the RAMSIS posture prediction system. The various joints do not contribute to the same extent to the posture. The different contribution weights are defined by different inclinations of the pot-like load functions.

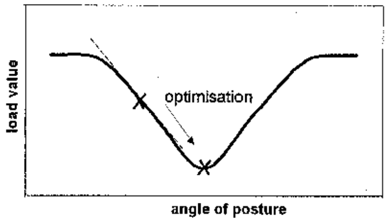

Fig. 1: Relative load and posture angle

When setting up the load function the values of the relative joint moments M_{joint} describing the relaxed state are not known so far. In order to determine these values a special experimental apparatus called *"balanced stand"* was created. In this stand the weight of every body part can be balanced over specially designed reels by an opposite weight. So the body can be kept in a quasi weightless state (see Figure 2).

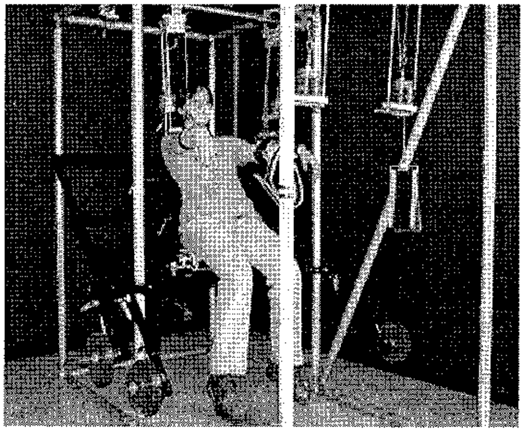

Fig. 2: Balanced stand

Using this apparatus it was possible to measure the moments in every joint depending on the joint angle. To get the anthropometric data of the subjects the RAMSIS-measurement tool was used. As by this method the volume of every body part is available, the body partial masses could be calculated. The posture of the subject was also objectified in every experimental situation using the superimpose technique of the RAMSIS posture measurement method. This costly procedure was done for 15 subjects.

We assumed - and our assumption was confirmed by the measurements - that the distribution of the joint moments is not as widespread as that of the maximum moments which can be influenced to a large extent by the way of living and by training. So at the moment we neglect the dispersion and use the average values as common valid joint moments.

SIMULATION OF MOTION

In order to realize movement predictions we have to distinguish between animation and simulation (Arlt, 1999):

- As *animation* we understand the ability of a man model to change the angles of the body elements. When we replay a sequence of several animated postures, the impression of a movement is generated in the same manner as it is done by presenting a movie. The difference to a movie is, that the viewing position (the so-called camera position) may be chosen freely by the user.
- *Simulation* means the realistic prediction of the human behavior during a movement action. This includes that environmental conditions have to be considered as well as the influence of the moving aim and in the last consequence also the dynamic conditions. If the user of a CAD-system would have at his disposal 'movement simulation', he might be able to investigate the influence of changed environment conditions on the moving behavior and, if this tool would be combined with a judgement procedure of comfort, he might evaluate the chosen design of a new equipment.

In our approach to do basic research work for such a simulation tool we found in a literature study (Sivak, 1992) that for every movement there exists a "leading body element" (e.g. hand, finger, foot or thorax etc.). Following this, we had to define "dynamic restrictions" for this leading body element. Then the postures of the other body parts may be calculated by the static body posture prediction model. One of the tasks of this part of the RAMSIS-dynamic-project was to show up if and to what extend this procedure works.

With respect to this basic idea we distinguished between four classes of movements:

1. A *"Guided Movement"* is given, when the leading body element is quasi fixed to an object, whose movement is determined by technical parameters (e.g. pedal, lever, or steering wheel).
2. A *"Simple Perfect Movement"* is given, when the movement path can be determined completely self-paced. It is characterized by the release from one object to the approach of an aimed object (e.g. moving of the hand from the steering wheel to the gear lever).
3. *"Modified Movements"* are "Simple Perfect Movements", which are obstructed by an obstacle.
4. *"Complex Movements"* are determined by the correct coordination in time of simple perfect and modified movements. An example is the climbing-in procedure into a car.

At the present time we are only able to offer experiments, algorithms, and data for the classes 1 to 3.

The dynamic restrictions had to be defined more exactly. Again in literature studies (Spada, 1992, Bullock & Grossberg, 1989) we found, that three control components determining the coordination of movement elements have to be considered for simulation (see also Figure 3):

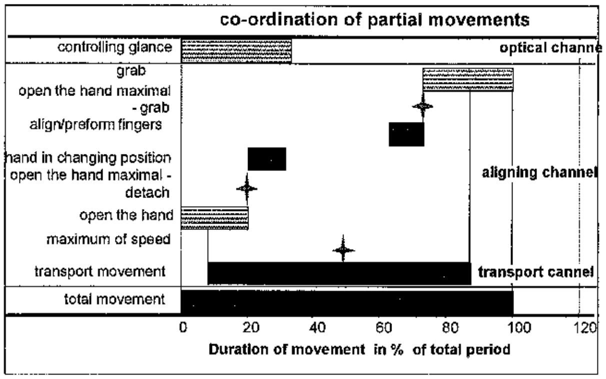

Fig. 3: The three control components of the dynamic restrictions and their coordination explained by an example

- The *transportation component* determines the course in space and time between the start-point and aim-point (Gentilucci et al, 1991; Marteniuk et.al., 1987; MacKenzie et al., 1987).
- The *aligning component* effects the alignment of the leading body element (usually the hand) depending on the task and especially of the starting and aiming conditions (Jeannerod, 1986; Linscheid et al., 1979).
- The *optical component* refers information about the spatial destination and position as well as of the form of the aimed object (Paillard, 1990; MacKenzie et al., 1987; Jeannerod, 1986) It can be neglected in the case of skill based behavior.

Our model supports the situation of an adequate coupling between these components: Under the *aspect of time* we distinguish between:

- Partial movements of duration depending on the situation: E.g. for distances larger than 15 mm the transport component depends on the special distance and a general intention of velocity ("fast", "normal", "slow") and additionally on the size of the aimed object (Fitt's law).
- Partial movements of constant duration: E.g. opening and closing of the hand,
- Movements of minimal duration: E.g. controlling glance,
- Fixed coupling elements, which are given by the necessity that two events must meet at the same time: E.g. the beginning of the controlling glance fits with the beginning of the alignment process.

In order to consider the spatial aspect, a plane is drawn between start-point and aim-point. As our experiments have shown, the moving path remains with great exactness totally within this plane. The detaching vector and the approaching vector depend only on the kind of gripping and therefore on the form of the corresponding objects, i.e. the releasing object and the aiming object. The connection between start-vector and aim-vector can be described with high accuracy by a parabola in this plane.

As already mentioned a lot of experiments have been carried out in order to determine the details for the above described model of the moving behavior and to support it with the necessary data. For example in a specific experimental situation the subjects, starting from a defined point, had to grasp five differently formed bodies which were mounted in various positions in the space in front of the subject. In order to get general results, the experiments were carried out in a neutral environment (chair and gripping space in front of the subject) and in a car mock-up, in which the subject had to perform a simulated driving task.

All these mentioned experiments provided data for the case of *Simple Perfect Movements*. A lot of experiments were additionally performed in a second variation with wooden slats as obstacles. So data were acquired for the case of *Modified Movements*. In this case we found that both movement path and the corresponding coordination of body parts movements are very similar to the *Simple Perfect Movement*. A small modification is caused by the obstacle itself. The subjects seemed to keep certain safety distances around the different parts of their body. We found out that this safety distance depends firstly on the kind of the body part (e.g. in the case of hands and feet it can be rather small; the safety distance for the head is more extended) and secondly on the importance of the movement (e.g. in the case of emergency the distance will be diminished).

During all experiments the postures of the subjects were observed by the RAMSIS posture measurement system which allows to parameterize totally the actual posture using the superimposing technique. Then we tried to predict the moving postures by applying the static posture prediction CAD-tool, whereby the time depending position of the leading body element on the moving path was defined as an additional restriction (a so-called *"Dynamic Restriction"*). Arriving at the parameterized real posture we could compare this with the predicted posture. Using the relative angle deviation and the absolute spatial deviation of the different body elements as yardsticks for this comparison we found values of 8 % for the mean relative angle deviation and 18 mm for the mean absolute deviation. In order to evaluate these results we compared them with the accuracy of repeated movements of the subjects during the same experimental courses. We found the prediction accuracy more reliable than the accuracy of the repeated motions. So we are sure that the new developed moving model is able to support sufficient aids for practical use.

CONCLUSION

Of course no development is ever completely finished. As a next step *Complex Movements* should be taken into consideration. As the ultimate aim of our efforts in modeling the moving behavior we want to be able to simulate such complex and difficult movements of the whole body like climbing into a car, dependent of a lot of environmental parameters as inclination of the A-column, position of the B-column, size of the door, level of the doorstep and so on. Certainly we cannot expect to find only one leading body element during such a complex movement and therefore we have to develop new algorithms for the simulation process.

Also the posture prediction model has to be completed. Here the missing comfort evaluation can be seen as a very important gap. When using the RAMSIS CAD-tool, a comfort evaluation is presently only possible for drivers in a sitting position. That has to be enhanced for arbitrary positions.

The force prediction model in connection with the posture prediction model and the enlarged comfort model will lead to a further feature: In a force implying situation RAMSIS will than change itself the posture in order to minimize the force, respectively moment load, in each joint and reduce simultaneously the discomfort feeling in the same manner as it would be done by a real person.

LITERATURE

Arlt, F. (1999): Untersuchung zielgerichteter Bewegungen zur Simulation mit einem CAD-Menschmodell. Dissertation, Technische Universität München.

Bullock, D. & Grossberg, S. (1989): Vite and Flete: Neuronal modules for trajectory formation and postural control. In: Wayne, A. (Hrsg.): Volitional action conation and control, Herschberger, Amsterdam, pp. 253 – 297.

Burandt, U. (1978): Ergonomie für Design und Entwicklung, Verlag Dr. Otto Schmidt KG, Köln.

Gentilucci, M., Castiello, U., Corrandi, M.L., Scarpa, M., Umilta, C., Rizzolatti, G. (1991): Influence of different types of grasping on the transport component of prehension movements. Neuropsychologia, 29, 5, 361 – 378.

Jeannerod, M. (1984): The timing of natural prehension movements. J. Motor Behavior, Vol. 16, 235 – 254.

Linscheid, R.L., An, K.N., Chao, E.Y., Cooney, W.P. (1979): Normative module of human hand for biomechanical analysis. Journal of biomechanics, 12, 775 – 788.

MacKenzie, C.L., Marteniuk, R.G., Dugas, C., Liske, D., Eickmeier, B. (1987): Threedimensional movement trajectories in Fitt's task: Implications for control. The Quarterly Journal of Experimental Psychology, 39A, 629 – 647.

Marach, A. (1999): CAD-fähiges Prognosemodell für statische Körperhaltungen des Menschen. Dissertation, Technische Universität München.

Marteniuk, R.G., MacKenzie, C.L., Jeannerod, M., Athenes, S., Dugas, C. (1987): Constraints on human arm movement trajectories. Canadian journal of psychology, 41(3), 365–378.

Paillard, J (1990): Basic neurophysiological structures of eye-hand coordination. In: Bard, C. (Ed.): Development of eye-hand coordination across the life span, Columbia SC, 27 – 74.

Rühmann, H.; Schmidtke, H. (1992): Körperkräfte des Menschen. O.Schmidt-Verlag, Köln.

Schwarz, W. (1997): 3D-Video-Belastungsanalyse – Ein neuer Ansatz zur Kraft- und Haltungsanalyse; Fortschr.-Ber. VDI Reihe 17 Nr. 1666, Düsseldorf: VDI Verlag.

Sivak, B.(1992): The contributions of Peripheral and Central Vision in prehension. In: Proteau, L., Elliott, D. (Hrsg.): Vision and motor control. pp. 233 – 259, North-Holland, Amsterdam, London, New York, Tokyo.

Spada, H. (1992): Lehrbuch allgemeine Psychologie. Huber Verlag Bern, 497 - 557.