Simulation of Digital Human Hand Postures of Car Controls Using a Data Based Approach

Georges Beurier[1], Nicolas Chevalot[1], Gilles Monnier[2], Jules Trasbot[3], and Xuguang Wang[1]

[1] INRETS - LBMH, 25 avenue François Mitterrand, Case 24, 69675 Bron, France
[2] Altran Technologies, 58, Bd. Gouvion St Cyr, 75017 Paris
[3] Ergonomie 64270 - 1 Avenue du Golf 78288 GUYANCOURT Cedex
Georges.beurier@inrets.fr

Abstract. This paper introduces a data-based approach to simulate with digital human models hand postures for grasping car control objects, which takes into account hand anthropometry, grasp type and object size. This paper presents more the experimental approach part than the simulation part itself. The simulation part is essentially done by the RPx software. This paper presents mainly a protocol in order to obtain data for the simulation.

Keywords: hand, data based approach, car controls, digital human.

1 Introduction

This study was motivated by the fact that only a limited number of hand postures are generally available in a digital human model. In addition, it is difficult to adapt a pre-defined hand posture for different hand and object size due to the complexity of the hand. In general, a hand is modeled with more than 20 degrees of freedom. It is not easy to define a desired hand posture by direct manipulation of each joint axis. This is particularly true for the users of digital human models who are most often design engineers and are not hand specialist.

The simulation of hand posture can take many forms. Often, only simulations are used, and the problem is how to be certain that the obtained posture is realist. The simulation can be only cinematic or dynamic like [1]. Here only the kinematical way is considered. In some work specific hand model are used for the hand posture simulation [2]. In our work, a constraint is to compute the posture for a specific commercial digital Human.

In order to constitute a data base of hand postures for car interior design, an experiment was carried out to capture hand postures when grasping different car control commands using an optoelectronic system (VICON). Five voluntary subjects with differently sized hand participated in the experiment. Ten imposed hand postures for each subject were captured when grasping steering wheel, interior mirror, parking brake, push button, two different rotating knobs, gearshift and glove box. These objects were chosen because they have a great diversity of grasping posture, which can be dividing in two main categories: force and precision posture. Prior to the

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experiment, the hand anthropometric dimensions were measured. In addition, several photographs of the hand with markers attached were taken in a calibrated space in order to determine the local coordinates of the markers in the hand model.

In this paper, we will at first present the method used for posture reconstruction.

In order to modify a pre-defined posture by an inverse kinematic algorithm, the geometric interaction between hand and object was investigated, especially the contact zones between the fingers and the object. From the reconstructed posture these contact zones are identified for each object, by taking the maximum depth of penetration of the fingers in the object. This is due to the fact that the used digital manikin has a rigid body model with regard to its environment. So, using some rules, for each object, it will be possible to determine the object contact zones by taking into account the hand anthropometry, and to determine the relative fingers contact zones. Postural adaptation to a differently sized hand and a differently sized object is ensured by modifying a captured posture so that hand contact points match with those of the object.

The emphasis of the present paper will be put on the whole process of posture data construction and its use for simulation. One example will be shown. Limitations and perspectives of the proposed approach will also be discussed, especially how to associate the hand grasping posture with the arm when simulating a whole body reach posture.

2 Experiments

2.1 Participants

The experiment was done with 5 voluntary subjects (2 women and 3 men) with no sign of neurological or joint impairment. They have been chosen for their anthropometric dimension. For this experimentation, subjects were chosen using the hand length criteria such that the subjects selection is broadest possible. The Fig. 1 shows the definition of our direct hand dimension measurement. For this experiment, and for this paper, only the right hand was considered.

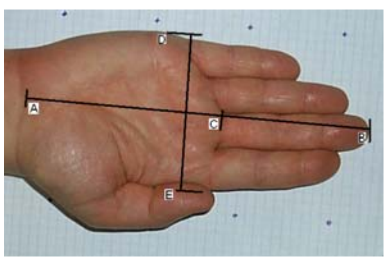

Fig. 1. Hand measurement

The direct hand measurement was:

- The hand length AB
- The palm length AC
- The palm width DE

The following table gives the hand dimensions of the selected subjects (for the first line M means Men and W means women).

Table 1. Subject hand dimension

Subject #	M00	M01	W02	M03	W04	Mean	Std dev
Hand length (mm)	174	198	185	180	159	179.2	14.3
Palm width (mm)	78	89	76	81	68	78.4	7.6
Palm length (mm)	94	109	102.5	101	86	98.5	8.8

2.2 Apparatus

This study take place in the car industry context, thus we have used a physical mock-up, already used in other experiments. This allows us to place the subjects in a driving posture, and to present the object to grasp in their reach spaces.

Fig. 2. Parametric physical mock-up

The objects used were selected from these which can be found in a car. They are fixed on a movable small beam, and they are located with small markers. The following Fig. 3 illustrates these objects.

2.3 Procedures

This part describes the experimental path followed by all subjects. The first step after the hand measurement done during the selection phases was to photocopy the both side of the hand in order to be able to determine the phalanges length.

The second step was the placement of the makers. The makers were located on the five metacarpo-phalangeal joints (MCP), on the ten inter-phalangeal joints, on the five nails and two on the wrist like in the following figure (Fig. 4). Some markers were placed on the arm but they weren't used.

In the third step, the subject takes place in the mock-up and places his right hand in a calibration tools (see Fig. 5) with a flat hand posture. During an acquisition with the optoelectronic system, some photographs were taken from orthogonal point of view.

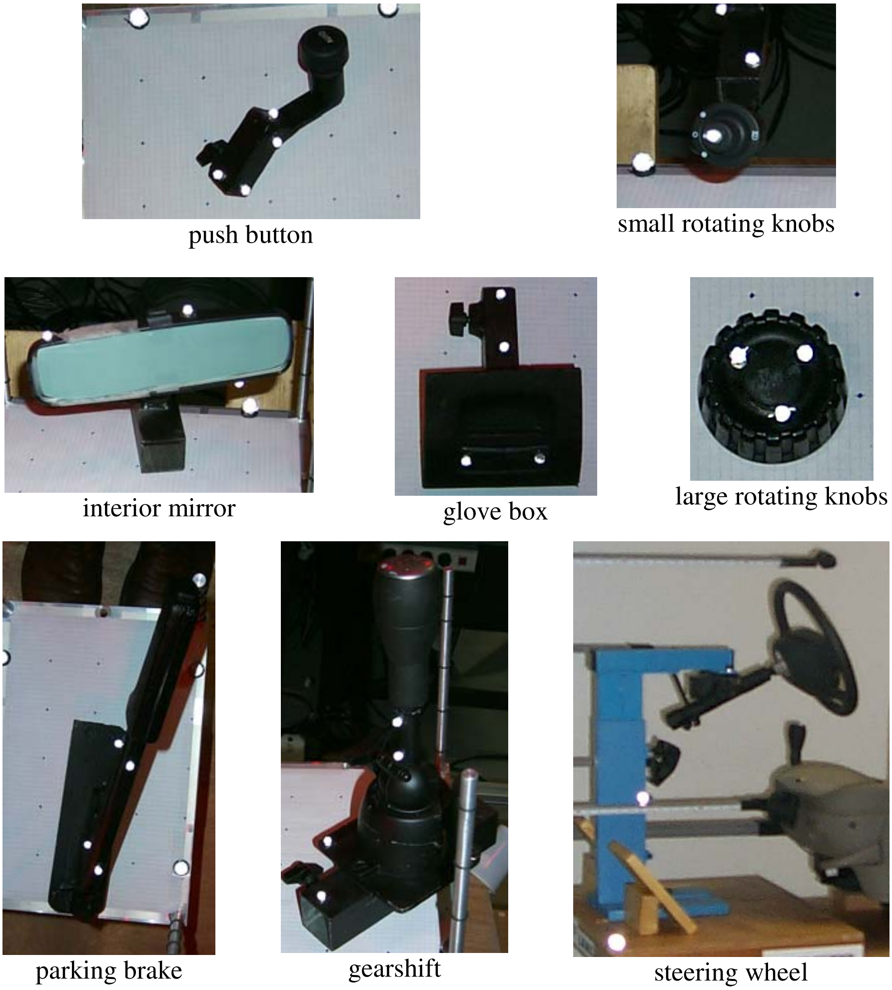

Fig. 3. Selected objects

Fig. 4. Marker placement on the hand

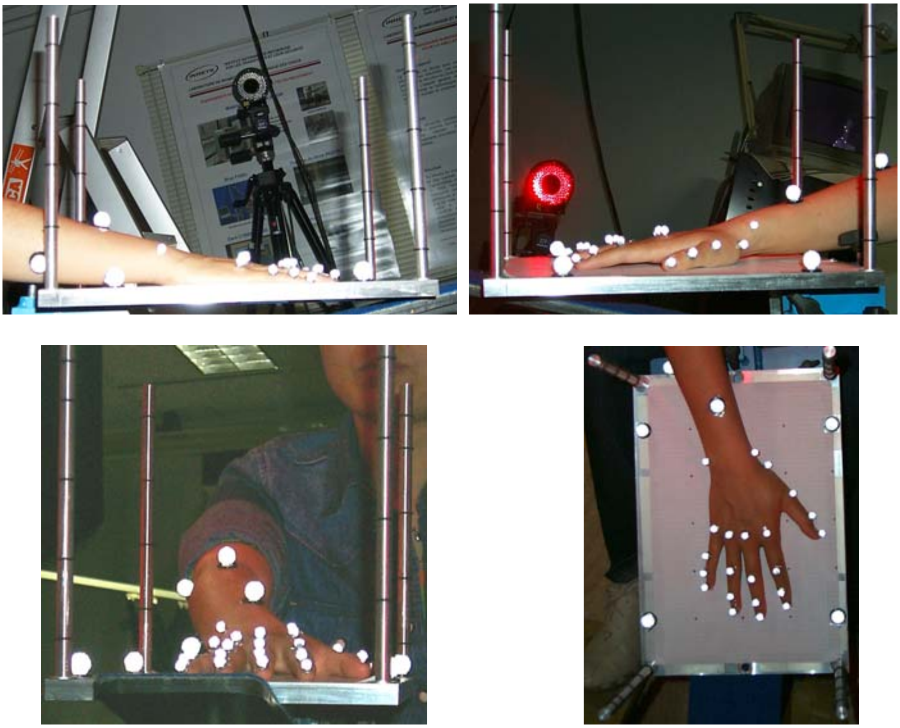

Fig. 5. Hand photographs and the calibration tool

The fourth step is the experiment itself, for each object each subject has to do three times the motion. An acquisition with the motion recorder was done for each motion. Generally, the motion consigns have three defined posture phases, the initial posture, the action postures (~10s), and finally the subject come back to the initial posture. The action postures are described bellow in italic for each asked motion. There can be several postures by objects.

- push button 1 finger
  10s with a contact without pushing + 10s with a maximum pushing contact force
- small rotating knobs 3 fingers
  10s contact + turning to the right + 10s contact
- interior mirror 5 fingers
  10s contact + pushing action + 10s contact
- steering wheel 5 fingers the thumb along the wheel
  10s contact + turning the wheel to the left + 10s contact
- steering wheel 5 fingers the thumb around the wheel
  10s contact + turning the wheel to the left + 10s contact
- parking brake 5 fingers the thumb along the parking brake
  10s contact + pulling the parking brake up + 10s contact

- gearshift 5 fingers the palm in contact with the top
  10s contact
- glove box 4 fingers
  10s contact + opening + 10s contact
- large rotating knobs 5 fingers the thumb around the knobs, the palm in contact
  10s contact (force posture)
- large rotating knobs 5 fingers all finger along the knobs
  10s contact (precision posture)

The 10s in contact means also without motion from the subjects.

2.4 Raw Data Processing – Motion Reconstruction

This first step is to dimension the numerical manikin hand. From the hand photocopies, the segment lengths of the hand are estimated. The photographs taken are calibrated with the DLT method [3] (Direct Linear Transformation) with the aim of making coincide the photographs and the numerical environment (Fig. 6). Then, in the second step, the joint angles of the digital manikin hand are modified in order to acquire the hand posture, using a superposition of its image and the DLT calibrated photographs. In the same, the hand dimensions are checked and eventually adjusted (Fig. 7). The photographs were taken during an acquisition with the motion recorder, so we have the coordinates of each marker in a laboratory frame in which the digital manikin is defined. Once the individual hand model is well defined, the second step is to 'attach' the markers on the hand model, i.e. attach each marker to the corresponding body of the hand, and to calculate the local coordinates of the markers in the relative frame.

The third step is to reconstruct each hand posture acquired by minimizing distance between the model based marker positions and the measured marker positions. Unfortunately, during the acquisition, some markers disappear for a more or less long time. So a period, in the marker coordinates data file, was selected as large as possible with no motion from the subject, and a mean was done for each marker coordinate in order to obtain data corresponding to a unique mean posture. From the three acquisition trial, the best one was selected. The reconstruction method used is already described in [4] which is based on [5]. Fig. 8 illustrates the reconstruction phase.

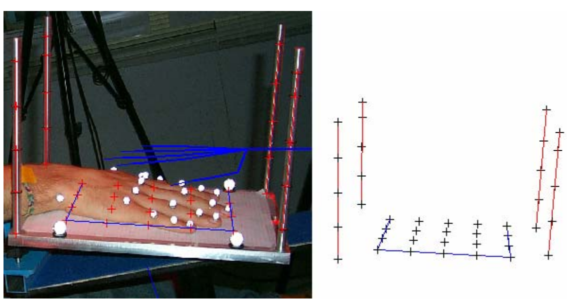

Fig. 6. DLT picture calibration

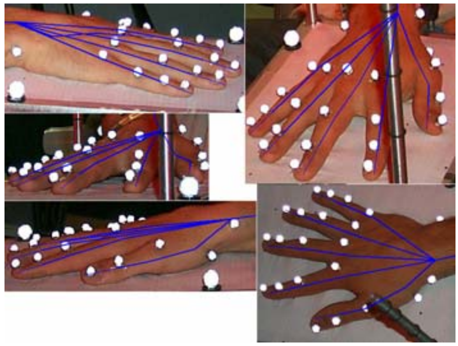

Fig. 7. Adjustment of the hand posture and the hand dimension

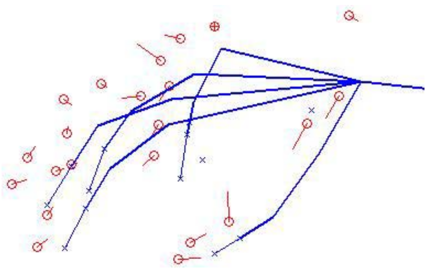

Fig. 8. Skeleton model of the hand with local and measured marker during the reconstruction step. The hand markers, defined in their manikin local frame, are represented by circles, the targets, from the measured data, are at the end of the segments.

3 Posture Simulations

Until here the procedure was identical for all the experiments, but for each object or grasping posture consign, the case is different. So in this part, only the large rotating knobs case with 5 fingers along the knobs (precision posture) will be considered. For each object or posture we have to consider their specific properties (i.e. for the kind of shape of the objects in the contact zone: cylindrical, spherical, planar …). In each case the contact zones have been reduced to one point, this allows to specify constraints to the simulation tool. But the constraints aren't always point to point, they can be point to line, point to plane …

In the used numerical manikin the envelope of the finger is defined by a succession of polygonal ring, which are used to draw the surface of the skin (Fig. 9). Each vertex of the polygon is called skin point. For the large rotating knobs case, the contact zones have been reduced to one point for each finger and for each subject. In this case the contact point was defined by the nearest skin point of the second ring of the distal phalange to the large rotating knobs axis. The following figure (Fig. 9) illustrates the definition of a contact point where the distal phalange axis is parallel to the knobs axis.

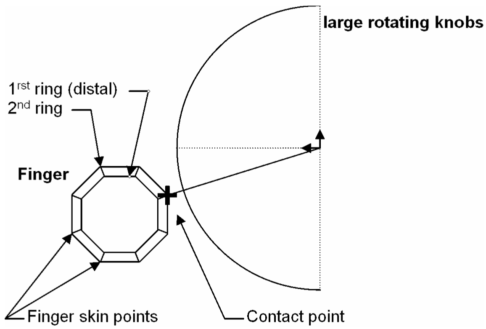

Fig. 9. Contact point definition

All subjects haven't grasped the knobs with the same manner. So for the simulation we have defined that the thumb contact point gives the zero angle for the orientation of the large rotating knobs towards the hand (see Fig. 10). Except for the middle finger, all contact zones of the other fingers are in a sphere of 1cm radius for each finger. For the simulation, with this fact, only the contact zones averages were considered (see Fig. 10), for the other objects the contact points can be dependent of the hand anthropometry.

For the simulation, with a digital manikin with any anthropometry, the algorithm will use only the defined contact zone as constraint and the angle joints will be initialized with the posture corresponding to the closer subject in term of hand size. The inverse kinematic solver is differential based as initially proposed by Liegois [5].

$$\Delta\theta = J^{+}\Delta X + \left(I - J^{+}J\right)\left(\theta - \theta_{ref}\right)$$ with:

ΔX the incremental marker displacement,

$\Delta\theta$ the incremental joint angle change

J called the Jacobian and relates linearly ΔX and $\Delta\theta$

J^{+} the pseudo inverse of J

θ the joint angle posture

θ_{ref} the referential posture

The first term of this equation tends to minimize the distance between the object contact points and the model-determined corresponding skin points and is given high priority. Whereas the second term minimizes the distance between the actual posture and the selected referential (and also the initial) posture and is given a low priority. So in terms of angle joint, the posture solution does not tend to move away from the reference posture.

For the posture simulation with similar object, with a different diameter, with a similar grasp, the chosen solution is to keep constant the distance between the contact points and the object surface, by taking into account a constant angular distribution of the contact points around the knob from the knob axis. The following figure shows an example of simulation (Fig. 11).

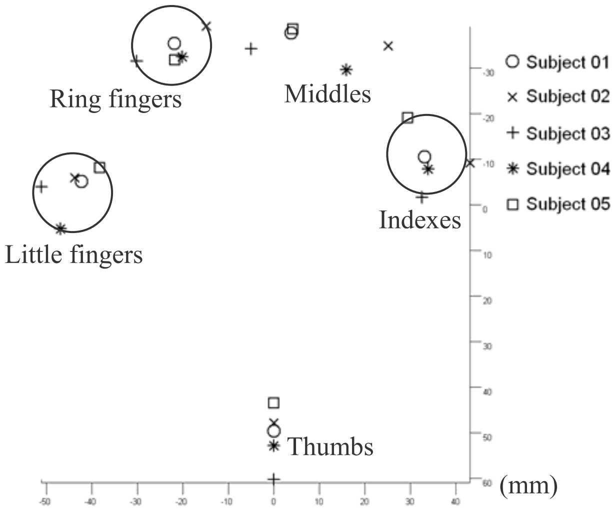

Fig. 10. Contact points projection distribution for the rotating knobs. Indexes are on the right.

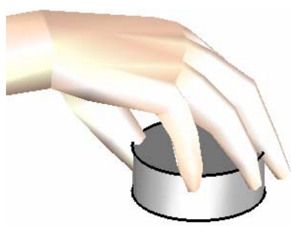

Fig. 11. Simulation result

4 Conclusions

This paper presents an experimental approach for the simulation of grasp posture. This approach is based on databases, and is adapted for a digital manikin. The simulation gives a realistic representation of the posture with a limited number of inputs for the users instead of a joint axis handling. One of the limitations can be the number of postures in the database; but in our car interior design context, only few postures are used. The hand manikin model definition can be another critical point. The digital manikin is defined with skin points which aren't dependent of the contact, so some fingers can shallowly penetrate in the object structure. This point often is not so important because the manikin is generally globally considered. For digital manikin used in classical CAD software, the hand model definition (commonly 250-500 skin points for one hand) is not enough accurate for studies which require a great precision.

Another point of difficulty is the manikin hand model kinematic definition. In this study the manikin hand model has some limitations: the palm is always flat, the joint angle limits aren't always well defined, the kinematic structure of the palm shows some symmetry… To get better results, a more complete model can be envisaged [6], but in this case, it will be not compatible with the chosen manikin. Another point of development, is how to associate the simulation of hand posture grasping with the reach of a global posture. In this case a first response element is to cumulate the constraints, but users have to take care of the constraints compatibility.

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