Smart Capture System coupled with a Subject/Patient Avatar for the Supervision of the Human Motion

Benjamin Admont*, Kevin Lepetit*, Adrien Letocart*, Arselle Saizonou*, Zilong Zhang*
Tien Tuan Dao, Marie-Christine Ho Ba Tho
Sorbonne University, Université de technologie de Compiègne, CNRS, UMR 7338 Biomechanics and Bioengineering, Compiègne, France
{benjamin.admont, kevin.lepetit, adrien.letocart, arselle.saizonou, zilong.zhang}@etu.utc.fr
{tien-tuan.dao, hobatho}@utc.fr
*equal contribution

Abstract – Numerical avatar is necessary to represent the human body in enhanced virtual reality systems for functional rehabilitation purposes. However, current avatars are simplified leading to inappropriate representation of complex human body. We proposed in this present work a smart capture system to create subject- or patient-specific avatar. A generic geometrical model was created from medical images. Then, a morphing process was developed to scale the generic model into a subject- or patient-specific avatar. A visualization module was developed using portable device to facilitate the capture task. A prototype allowed to perform a demonstration of our smart capture system.. A validation study revealed a maximal deviation of 6 % for our scaling method. Our proposed solution is of great interest to create a subject- or patient-specific avatar in an accurate and efficient manner.

Keywords: Smart capture system, patient/subject specific avatar, human motion, scaling, image processing, medical images, percentile model.

I. INTRODUCTION

The motion of the musculoskeletal system is complex and it relates to a coordination mechanism of skeletal muscles and bones. Recently, some virtual reality systems have been developed to monitor such complex motion [1-4]. Simplified avatar representation has been commonly created for these systems. According to biological complexity of the human body, this simplification is inappropriate for representing the biological interaction between involved organs and tissues, especially when simulating musculoskeletal disorders. Thus, the objective of this present work was to develop a smart capture system to create subject or patient specific avatar for the supervision of the motion of the human musculoskeletal system. We focused our first prototype on the lower limb structures.

II. MATERIALS AND METHODS

To reach the proposed objective, a flow chart development was proposed (Fig. 1). Our methodology was based on the following steps: 1) the development of a geometrical model of the multiple-joint system of the lower limb (hip, knee, ankle) from medical images, 2) the determination of simple morphological parameters could be used for capture system, 3) the development of a morphing method based on proposed morphological measurements to create and scale a subject- or patient- specific geometrical model from the generic geometrical model and 4) the implementation a visualization platform to manipulate the 3D generic geometrical model as well as to perform the morphing process.

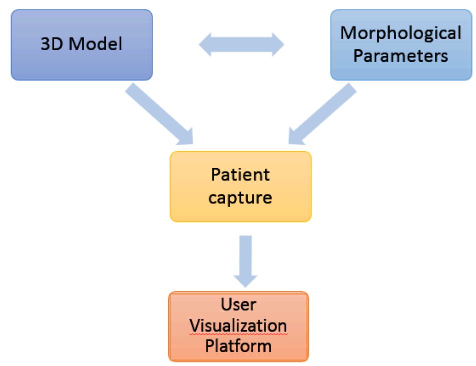

Figure 1. Flow chart of our proposed smart capture system

1) *Baseline morphological model development*

To serve as the generic model of the lower limb, our geometries were based on the CT images of the Visible Human Female (National Library of Medicine – USA) [5]. Axial CT slices were acquired with a slice thickness of 0.33 mm. The total number of images is 1730 with 512 x 512 matrix size. To create 3D STL-based geometrical model, the segmentation was done with ScanIP module (Simpleware, UK). To facilitate this task, different anatomical regions (thigh, leg, foot) were segmented separately. Each region was composed of the bone and the soft tissue. Several mesh refinement levels were proposed in order to choose the most appropriate for the visualization on the mobile platform. The association of the different regions was made with Créo software (PTC, France).

2) *Determination of morphing parameters*

To respect the quick capture time and a low cost process, two parameters (mid-thigh circumference and thigh length) were selected based on the database provide by McDowell et al [6]. Moreover, we proposed to adapt the database to our technical requirements (standing posture and camera-based capture) as follows: 1) the determination of the femur distal point as the middle point of patella in standing posture instead of above patella point in sitting posture, 2) the mid-thigh circumference was calculated from the width of mid-thigh by the formula of circular perimeter.

3) Patient capture and measure using image processing

To measure patient morphological features (mid-thigh circumference and upper leg length) from the camera device, we developed a capture protocol with the following steps: 1) set up of standing position in the frontal plane, 2) set up of 15mm diameter circular markers on the proximal hip head, middle thigh, and distal femoral head of the subject under investigation, 3) set up of a A4 size chess board as reference frame for calibration purposes and 4) image capture using a smart phone camera. It is important to note that the smart phone camera has to be calibrated before doing the measurements. This calibration is done through intrinsic (focal, distortion coefficient or center point) and extrinsic (distance between the camera and the pictured object) camera parameters. Intrinsic parameters are measured based on the features extracted from the reference frame in various positions (20 pictures). A rigid support was also used to avoid any grid pattern distortions for the reference frame. The calibration was done using Matlab software [7]. Extrinsic parameters were iteratively measured at each picture. They are made of translation and rotation matrix aiming to move from the camera center referential to the top left corner of the reference frame. During the measurement process, selected morphological measurements (thigh width and length) are computed in pixel size and in millimeter based on the reference frame.

Once the captured picture is uploaded into Matlab software, a manual selection of the 2 morphological features ends is performed via the program. The thigh length ends are selected accurately with 2 markers placed at the right anatomical areas. For thigh width, one single marker, placed about equal distance to the 2 thigh length markers, is used to select the 2 width ends at the same level. Then, calculator returns in millimeter scale the thigh length, thigh width and thigh perimeter.

4) Morphing process

A statistical method was proposed for the scaling. Based on the two selected parameters (thigh length and mid-thigh circumference), a database of morphed models was generated from the baseline geometrical model. In order to cover the entire population, 9 deformation ratios were applied for the length and for the perimeter. The scaling was done by doing three homothetic transformations of the generic model along the three spatial axes.

5) Visualization platform

The visualization platform was developed on a smart phone. Interface for scaling was created. To visualize the 3D model, an available application named Graphite was selected as it is compatible with Android system which manages large files.

6) Validation

Firstly, it is important to check the generic character of our baseline model of lower limbs to ensure that there is no appearance of pathology or abnormal deformation. According to previous studies of bone's form, we have verified our model in term of: skeletal angle (Neck-shaft angle) which should be approximately 125° in adulthood; the ratio of upper leg to lower leg is normally 81.3% (Fig. 2), we also process the shape of bone, for example, with the relationship between inter-condylar notch and width of the femoral condyle being 0.255±0.028 [8].

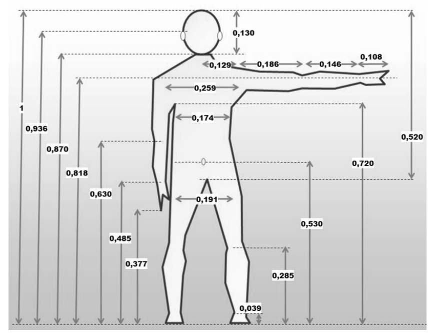

Figure 2 Proportional relationships of the human body

Secondly, to check the robustness of our system, we used our system to create subject specific avatar models of 5 healthy volunteers (4M&1F, average age 24.6 yrs.). We compared our estimated values with the measured values for the thigh length and mid-thigh circumference parameters.

III. Results

1) Morphological measurement determination

The neck-shaft angle of our model is 129° and the ratio of thigh to shank is 87.8. A difference of 8% was found. This is in agreement with results from anthropometry data [9].

2) 3D model development and scaling database

The generic model of the leg is composed of three regions which contain the soft tissues and the bones (Fig. 3). It is important to note that the main difficulty was the matching step in order to obtain an accurate model.

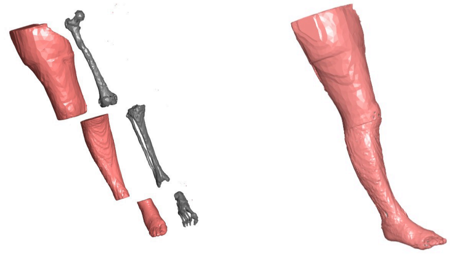

Figure 3. Generic model

The model database is currently made of 81 scaled models which represent 90% of the human male population. The generic model is the model number 40 (table 1.).

Length	Mid-thigh circumference perimeter								
	444	465	478	498	533	572	597	614	646
356	1	2	3	4	5	6	7	8	9
367	10	11	12	13	14	15	16	17	18
375	19	20	21	22	23	24	25	26	27
386	28	29	30	31	32	33	34	35	36
408	37	38	39	40	41	42	43	44	45
429	46	47	48	49	50	51	52	53	54
440	55	56	57	58	59	60	61	62	63
447	64	65	66	67	68	69	70	71	72
459	73	74	75	76	77	78	79	80	81

Table 1. Scaling model database

By using the proposed capture protocol, the morphed leg models of different subjects were easily obtained from the database (Fig. 4). An example of 3D model visualization in smart phone platform is given in Fig. 5. The comparison between computed and measured values revealed a maximal of 6% deviation (Table 2). There are 3 factors for the measurement inaccuracy as follows: i) markers positioning, estimated at +/-5mm as the anatomical points of reference are used; ii) the manual selection of the markers, estimated at +/-5mm, which means one third of the 15mm markers diameter; and iii) measurement program accuracy, calculated lower than 0.5 pixel, which means lower than 0.2 mm using an average pixel - millimeter equivalence. As a consequence, the overall inaccuracy is +/-1cm, which means +/-2.5% by considering percentile 50, 40.8cm, of the thigh length. Moreover, automatic detection of the markers would reduce from +/-1cm to +/-0.5mm.

Figure 4. Leg model of different subjects: pictures with markers and reference frame.

Figure 5. Example of 3D model visualization

	real *(cm)*		calculated (cm)		mismeasurement (cm)	
	Thigh lenght	Thigh width	Thigh lenght	Thigh width	Thigh lenght	Thigh width
patient 1	38	17	38,5	17,4	-0,5	-0,4
patient 2	43,5	15,5	43,1	16	0,4	-0,5
patient 3	36,5	14	35,8	14,6	0,7	-0,6
patient 4	45	13,5	45,6	13,1	-0,6	0,4
patient 5	36	14	36,4	13,5	-0,4	0,5

Table 2. Accuracy analysis

IV. CONCLUSION AND PERSPECTIVES

A smart capture system was developed to create subject- or patient-specific avatar representation of the human body. Our propose system showed its robustness and ease-to-use characters. The accuracy is good enough for a rapid and efficient process. As perspectives, some improvements will be analyzed in a further study such as the consideration of soft tissue deformation into the morphing process or the automatic detection of the markers as well as the improvement of the graphical user interface.

ACKNOWLEDGMENT

This work was carried out in the framework of the Labex MS2T, which was funded by the French Government, through the program "Investments for the future" managed by the National Agency for Research (Reference ANR-11-IDEX-0004-02).

REFERENCES

[1] J.M.Z Ibarra, A.J. Tamayo, A.D. Sánchez, J.E. Delgado, L.E. Cheu, W.A. Arévalo. Development of a system based on 3D vision, interactive virtual environments, ergonometric signals and a humanoid for stroke rehabilitation. *Comput Methods Programs Biomed*, vol. 112, no. 2, pp. 239-249, 2013.

[2] D. González-Ortega, F.J. Díaz-Pernas, M. Martínez-Zarzuela, M. Antón-Rodríguez. A Kinect-based system for cognitive rehabilitation exercises monitoring. *Computer Methods and Programs in Biomedicine*, vol. 113, no. 2, pp. 620-631, 2014.

[3] G. Kurillo, T. Koritnik, T. Bajd, R. Bajcsy. Real-time 3D avatars for tele-rehabilitation in virtual reality. *Stud Health Technol Inform*., vol. 163, pp. 290-6, 2011.

[4] M.S. Cameirão, I.B.S. Bermúdez, O.E. Duarte, P.F. Verschure. The rehabilitation gaming system: a review. Stud Health Technol Inform., vol. 145, pp. 65-83, 2009.

[5] A.H. Vette, T. Yoshida, T.A. Thrasher, K. Masani, M.R. Popovic. A complete, non-lumped, and verifiable set of upper body segment parameters for three-dimensional dynamic modeling. *Medical Engineering and Physics*, vol. 33, no. 1, pp. 70-79, 2011.

[6] M.A. McDowell, J.P. Hughes, L.G. Borrud. Health characteristics of U.S. adults by body mass index category: results from NHANES 1999-2002. *Public Health Rep.,* vol. 121, pp. 67-73, 2006.

[7] J.Y. Bouguet, camera calibration toolbox for Matlab (http://www.vision.caltech.edu/bouguetj/calib_doc/)

[8] K.R. Smith, J.A. Bauer, J.H. Cauraugh, A.B. Falsetti, J.L. Pattishall. Differences in three intercondylar notch geometry indices between males and females: a cadaver study. The Knee, vol. 9, no. 1, pp. 41-46, 2002.

[9] E. Harless. Textbook of plastic anatomy, Part III (in German), Stuttgart, 1858.