3D Adaptive Reconstruction of Human Motion From Multi-Sensors

Ying-Xun Lai*, Lei Shu†, Athanasios Vasilakos‡, Joel J. P. C. Rodrigues§, Chin-Feng Lai*and Yueh-Min Huang*
*Department of Engineering Science, National Cheng Kung University, Tainan, Taiwan
Email: eetaddy@gmail.com; cinfon@ieee.org; huang@mail.ncku.edu.tw
†Nishio Lab., Department of Multimedia Engineering, Graduate School of Information Science and Technology, Osaka University, Japan
Email: lei.shu@ieee.org
‡Department of Computer and Telecommunications Engineering, University of Western Macedonia, Greece
Email: vasilako@ath.forthnet.gr
§Instituto de Telecomunicações, University of Beira Interior, Portugal
Email: joeljr@ieee.org

***Abstract*—In wireless body sensor networks, sensors may be installed on various body limbs to wirelessly collect body information for homecare services. The orientations and accelerations on each limb are different for various motion states. For example, each limb has different acceleration when walking versus running, and orientation when standing versus lying. According to the above information, the body motion state may be decided. Furthermore, each person has unique body characteristics such as height, foot pitch, and motion habit to effect the body reconstruction. Therefore, it is a challenging issue how to present human motions through 3D skeleton system simulation, and achieve an adaptive reconstruction of human motion according to the different body characteristics of each person. In this study, we proposed a novel scheme to utilize multiple triple axis accelerometer and gyroscopes to measure limb accelerations, then calculated the locations of limbs and try to employ kinematic theory to reconstruct human body skeleton, called 3D Adaptive human Motion Reconstruction (AMR). And we applied Body Correction Algorithm (BCA) to correct human body characteristics and fighted the error of transmission noise. This system was tested and validated with success.**

***Index Terms*—body sensor network, multiple triple axis accelerometer, body reconstruction**

I. INTRODUCTION

In recent years, homecare services were widely discussed and researched. One of the interesting topics is human posture detection, which usually uses image [1-2] or single accelerometer [3-5] for detection. However, image detection may violate users privacy and is limited to specific area. While single accelerometer has not enough information to accurately detect human motion. Therefore, the study tried to propose a scheme named 3D Adaptive human Motion Reconstruction (AMR), which uses multiple accelerometers and gyroscopes to measure accelerations and angular accelerations. Due to the information, we can calculate the locations of measured parts. But there are still several challenges for 3D AMR scheme. First, Human motions are usually irregular. The second issue is wireless interference. Different to image detection with fine image data, the noise of wireless transmission will make the error of reconstruction. Irregular human motions and wireless interference form the fuzzy detection between noise and irregular motion. Thus, it is considerable to calculate accurate body motion state in according to information collected from each limb. Finally, each person has different body characteristics, e.g. height, foot pitch and leg length. We need more complex scheme to present human motion simulation based on body posture information. In contrast to above challenges, this paper has follow contributions:

1) **Body skeleton modeling: Applied on Kinematics theories of body skeleton, we can model the detailed human body model.**
2) **An accurate body motion characteristic collection: the study proposed Body Correction Algorithm (BCA) to revise the length of each limb and the ratio of the upper and lower body parts accurately according to the motion habit of arms and foot.**
3) **3D human motion reconstruction: In the study, we integrate the multiple sensors, kinematic theory, and BCA to 3D skeleton simulation system to present a current motion reconstruction.**

The remainder of this paper is organized as follows. Section II elaborates on related works and background about the topic. Section III presents the system structure, including the leg length ratio calculation, posture detection, and a 3D skeleton system. Section IV discusses the experimental results and Section V gives the main conclusions of this paper.

II. RELATED WORK AND BACKGROUND

Human posture detection and reconstruction with sensors are intended to present body motions and posture changes with emerging sensor technology. Those researches can be divided to two typical technologies: one is optical sensor technology and other is on-body sensor technology.

- **Optical sensor technology: The researches of optical sensors can be further divided into two methods for motion reconstruction. One is the visual marker method [6-9] and the other is marker-free method [10-16]. For the visual marker method, main challenge is to make sensors to clearly recognize markers, wherever the researches that take light markers on limbs to detect. In addition, to accurately detect and reconstruct motion posture, studies installed markers with different shapes and color. However, it may detect errors when markers are on colorful clothes or covered. For this reason, the marker-free method is an achievable motion reconstruction by recognizing the distance of human** movement, proposed to improve the disadvantage. But, the drawback is to need complicated calculations for motion reconstruction.

- On-body sensor technology: Studies on Human posture detection with on-body sensors have mainly focused on position sensors, e.g., goniometry, pressure sensors, accelerometers, gyroscopes sensors [17-21], and magnetic sensors [22-26]. The advantages of those studies are that sensors are so small to portable and users dont have to stay a specific location. But the disadvantage is that sensor data are usually short of a integrative scheme. Therefore, the applications are usually focused to sample human motion detection. The paper tries to provide a feasible solution for this issue.

III. The Proposed 3D AMR Scheme

A. System Scenario and Architecture

The proposed system scenario may be seen in Fig. 1. In order to collecting accurate body information, we install one wireless transmitter module, one triple axis accelerometer, and one gyroscope on six parts of the human body including neck, wrists of both hands, waist, and legs. The triple axis accelerometer and gyroscope separately calculate the acceleration and angular acceleration of different parts and transfer the data through wireless transmitter modules. Then we simulate the human module with 3D function library and employ 3D AMR scheme to reconstruct human motion skeleton.

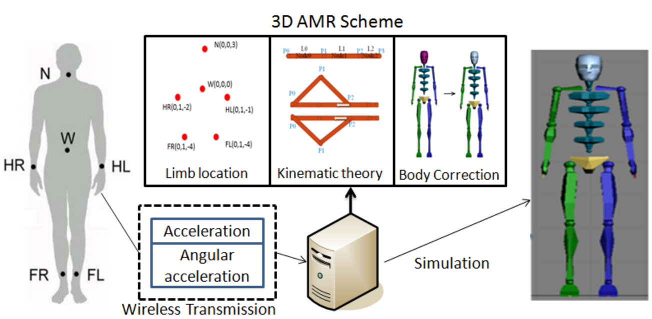

Fig. 1. System Scenarios.

The four steps of proposed 3D AMR scheme below as Fig. 2 are described.

Step.1 The wireless transmitter modules transmit sensor data measured from triple axis accelerometers and gyroscopes to the server for calculation. The acceleration and angular acceleration of each body parts are recorded and computed for the locations of body parts.

Step.2 The locations of body parts were just only modeled the simple shape. In the study, we model the joint movement calculated with kinematic theory which finds the position of the endpoint and all the points inbetween relative to the base.

Step.3 Everyone has different body characteristics such as body height and limb length. In order to calculating leg length proportion, we utilize BCA to compute leg length in according to recorded information of main body parts. Then we can calculate the body limb proportions based on leg length and body height.

Step.4 When to sharp body structure, an accuracy body skeleton can be mapped with 3D function library, e.g. OpenGL/DirectX. Therefore, a 3D skeleton motion reconstruction can be presented by 3D skeleton simulator.

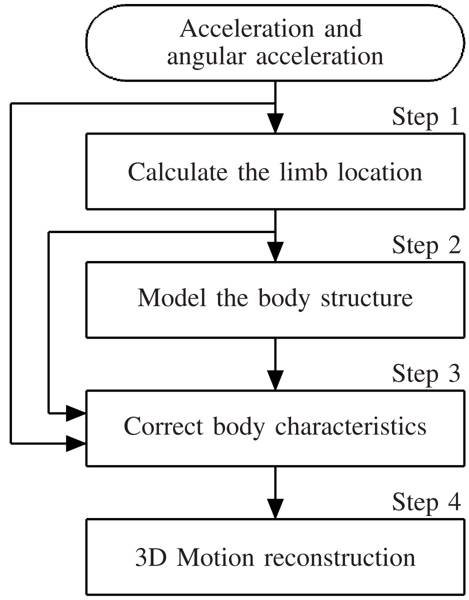

Fig. 2. Flow Diagram of 3D AMR Scheme.

B. The 3D Loaction of Each Patrs

First, the accelerations recorded from triple axis accelerometer are defined as ($\overrightarrow{a_x}$, $\overrightarrow{a_y}$, $\overrightarrow{a_z}$) which show as below Fig 3A.

$$\overrightarrow{a_{sum}} = \overrightarrow{a_x} + \overrightarrow{a_y} + \overrightarrow{a_z} \quad (1)$$

To consider in real situations the affect of gravitational forces on the triple axis accelerometer, the $\overrightarrow{a_{sum}}$ is the total acceleration sum which includes the gravitational force $\vec{g}$ and the speed acceleration $\overrightarrow{a_{real}}$ of the real-world absolute space, hence to get the absolute space displacement distance we will need to find

$$\overrightarrow{a_{real}} = \overrightarrow{a_{sum}} + \overrightarrow{g} \quad (2)$$

When $\overrightarrow{a_{real}}$ is found then the real space displacement Δd can be calculated.

$$\Delta d = V_0 \Delta t + \frac{1}{2} \overrightarrow{a_{real}} \Delta t^2 \quad (3)$$

Where the value V_0 is the initial speed, Δt is the time span. But the body posture is not always horizontal and may have precession, nutation and spin. Therefore, the human reconstruction has inaccuracy only based on values of triple axis accelerometers. To improve the inaccuracy, this study combined gyroscope which can record angular change of triple axis. The Euler angular space

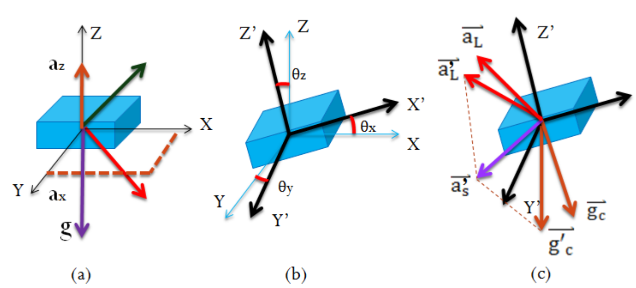

Fig. 3. The Accelerometer System Displacement.

rotational axis, the gyroscope sensor receives the acceleration (Θ, Ψ, Φ), format mainly uses Euler angles. After receiving the angular acceleration data can then find the triple axis sensor angular rotation A, where the θ_x represents the angular rotation of the X axis, θ_y the angular rotation for Y axis, and θ_z for the Z axis.

$$A = \omega_0 \Delta t + \frac{1}{2}\alpha \Delta t^2 \tag{4}$$

Where ω_0 is the initial angular speed and α is the respective angular acceleration. Although in the real world the triple axis accelerometer will move along with the human limb creating a offset error between the coordinate system of said device and the world coordinate system as shown in Fig 3B. Also the triple axis accelerometer coordinate each has an angular offset error (θ_x, θ_y, θ_z) with respect to the world coordinate, so will also need to change the reading values with respect to the world coordinate. According to the angular offset, we can revise gravitational acceleration $\overrightarrow{g_c}$ and $\overrightarrow{a_L}$ show as Fig. 3C.

$$\overrightarrow{g_c'} = \overrightarrow{g_c} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_x) & -\sin(-\theta_x) \\ 0 & \sin(-\theta_x) & \cos(-\theta_x) \end{bmatrix} \begin{bmatrix} \cos(-\theta_y) & 0 & \sin(-\theta_y) \\ 0 & 1 & 0 \\ -\sin(-\theta_y) & 0 & \cos(-\theta_y) \end{bmatrix} \begin{bmatrix} \cos(-\theta_z) & -\sin(-\theta_z) & 0 \\ \sin(-\theta_z) & \cos(-\theta_z) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$$\overrightarrow{a_L'} = \overrightarrow{a_L} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_x) & -\sin(-\theta_x) \\ 0 & \sin(-\theta_x) & \cos(-\theta_x) \end{bmatrix} \begin{bmatrix} \cos(-\theta_y) & 0 & \sin(-\theta_y) \\ 0 & 1 & 0 \\ -\sin(-\theta_y) & 0 & \cos(-\theta_y) \end{bmatrix} \begin{bmatrix} \cos(-\theta_z) & -\sin(-\theta_z) & 0 \\ \sin(-\theta_z) & \cos(-\theta_z) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$\overrightarrow{g_c'}$ is the direction of the gravitational force of the sensor device, and $\overrightarrow{a_L'}$ is the acceleration value of the triple axis accelerometer with respect to the world coordinate system. Hence then can immediate find the actual acceleration value. $\overrightarrow{a_s'} = \overrightarrow{a_L'} - \overrightarrow{g_c'}$. Then we can calculate the location of each parts by equation (3).

C. The Body Structure Modeling

For the 3D body skeleton model, 3ds Max software was applied to present skeleton data and the intensity of the skeleton files could be set or adjusted through 3ds Max. In the study, only six sets of triple axis accelerometers and gyroscopes are installed onto each part of the main body to reduce inconvenience. But it is not enough to present detail skeleton in according to sensors data.

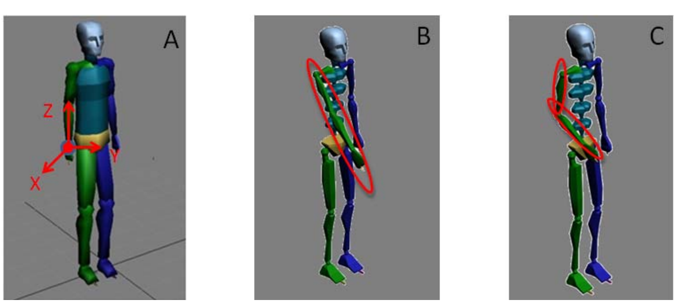

Fig. 4. 3D Skeleton Posture Modeling.

Taking Figure 4 as example, while server get the acceleration of right hand by sensors and compute motion reconstruct (4A), it just only can present the general motion posture (4B), whatever it is too hard to present complete the motion of hand (4C).

The kinematic theories of 3D skeleton are used to calculate the motion of limbs with the sensors data of six parts on the human body. In figure 5, Bone 0, Bone 1 and Bone 2 are interconnected. In which Bone 1 is sub-node of Bone 0, and Bone 2 is sub-node of Bone 1. L1 is the length of Bone 1, L2 is the length of Bone 2. In the kinematic theories, the movements of bones can be categorized into two types: Forward Kinematics (FK) and Inverse Kinematics (IK).

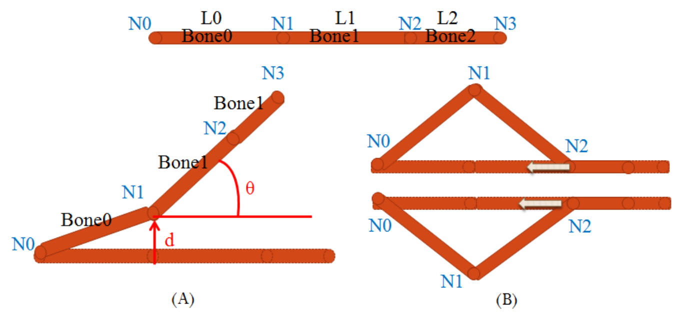

Fig. 5. The Kinematics Theory: Forward Kinematics (A) and Inverse Kinematics (B).

The FK theory is shown as figure 5A. The displacement of Node 1 is d, the rotation is θ, and the location is (x_1, y_1, z_1) . We can calculate the location of N2 by equation (7). In which d_x, d_y, and d_z are the vectors of d in the x, y and z axis. θ_x, θ_y, and θ_z are the rotation vectors of θ in the x, y, and z axis.

$$N2 = \begin{bmatrix} x_2 \\ y_2 \\ z_2 \\ 0 \end{bmatrix} = N1 + (N2 - N1) \cdot ROT(A_1) \cdot Trans(D_1)$$
$$= \begin{bmatrix} x_1 \\ y_1 \\ z_1 \\ 1 \end{bmatrix} + \begin{bmatrix} x_2 - x_1 \\ y_2 - y_1 \\ z_2 - z_1 \\ 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_x & -\sin\theta_x & 0 \\ 0 & \sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_y & 0 & \sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_y & 0 & \cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_z & -\sin\theta_z & 0 & 0 \\ \sin\theta_z & \cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & d_x \\ 0 & 1 & 0 & d_y \\ 0 & 0 & 1 & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

IK is opposite to FK as it is initialized by the slave bone, Bone 2, to generate effects similar to pressing in order to drive the master bone, Bone 1. It is noted that, FK can only lead to one result, while IK may have different results as shown as figure 5B. We can calculate the location of P1 by the motion of P2.

$$\hat{q} = f^{-1}(P) \tag{8}$$

$\hat{q}$ is the location of P1 and f^{-1} is Jacobian matrix.

$$J_f(\hat{q}) = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \cdots & \frac{\partial f_1}{\partial q_n} \\ \cdots & \ddots & \cdots \\ \frac{\partial f_6}{\partial q_1} & \cdots & \frac{\partial f_6}{\partial q_n} \end{bmatrix} \tag{9}$$

D. The Body Correction Algorithm

For different body characteristic, it is hard to model the fitted body structure only with acceleration and angle data, therefore this study apply Body Correction Algorithm (BCA) to calculate the correlation between angular acceleration and length. BCA shown in figure 6 is similar to the Back Propagation Network algorithm. The system takes the acceleration and angular acceleration as input. And the hidden layer is the body characteristic like as the length of body, hand and foot. First, the body characteristic is system default. Then the system takes the kinematic theory and body characteristic to model the body skeleton. However, the system logs the acceleration and angular acceleration at the working state that considers the stability of the system. Finally, the BCA revises the body characteristic according to the logged values.

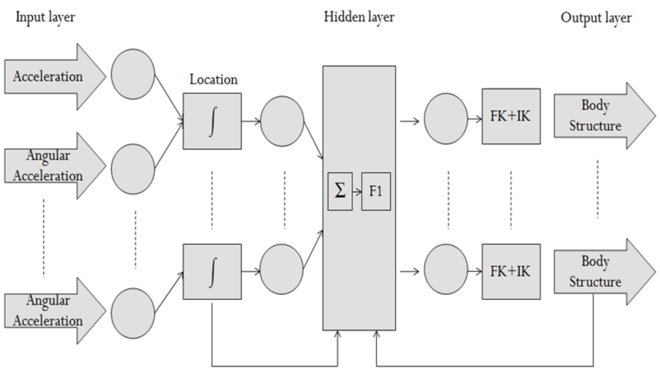

Fig. 6. The Body Correction Algorithm.

This BCA first carries out training on samples by several groups of known accelerations and angular accelerations of each part. After calculating the location of parts, it used activation function f, with the equation as below:

$$f(x) = \frac{1}{1 + \exp(-\alpha x)} \tag{10}$$

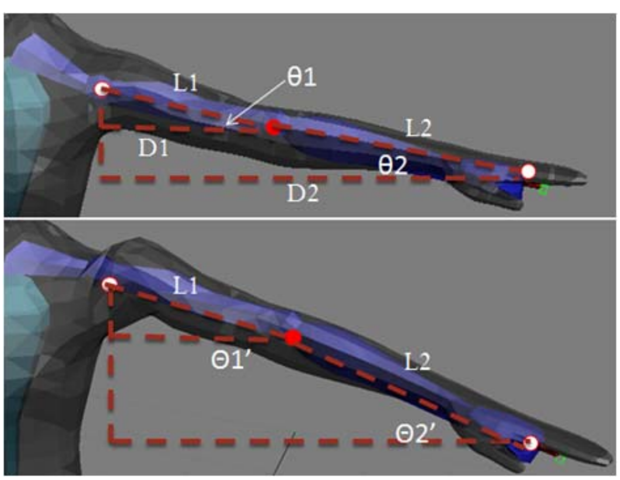

Fig. 7. The Modification with the Length and Angle of Skeleton.

Where the input parameters are the locations of parts. After getting the body characteristic, the system models the body by the kinematic theory. Then the system returns the results of body skeleton to modify. The modification with the length and angle of skeleton is shown as figure 7. When we get the body angle θ, the length L of skeleton can be calculated, which D is the horizontal displacement. With the training, the system can get a body module which adapts to the individual body characteristics of different people.

IV. Experiment and Result

In this section, we will present the implementation system related about 3D human motion reconstruction and test for the accuracy of the motion reconstruction on different methods.

A. The 3D Human Motion Reconstruction Simulation

For motion reconstruction testing, the acceleration and angle data on Z-axis and X-axis in walking motion are recoded and shown above as figure 8. In walking motion, the left and right leg will generate forward or backward, upward and downward acceleration. Whether the current state is walking can be identified according to the periodic acceleration and motion frequency. Because the data collected may not be able to present the motions accurately, the length of legs and hands are the default values for reconstructing the human motion shown as figure 9A.

After utilizing BCA to calculate the probable leg length, the proportions of the upper and lower body can be computed based on body height and leg length. The skeleton is adjusted according to the different limb characteristics of each person with BCA. Therefore, the accurate proportions of the upper and lower body are conducive to the reconstruction of human motion. The simulation results are shown in figure 9B. As seen, the simulation with BCA is more real presented than the one without BCA.

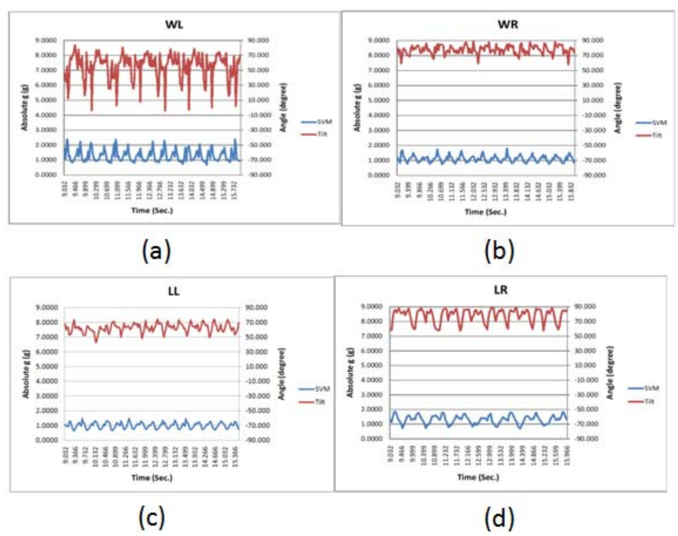

Fig. 8. Acceleration and Angle Data of Wrist (a)(b) and Leg (c)(d)in Walking.

B. The Accuracy Testing of Motion Reconstruction

In the study, this experiment chooses 12 subjects who is age at 18-57 for testing. For testing accuracy, the sequence and duration of each motion which are totally test for 600 times were different. The correct case is defined the difference degree between the simulation and real motion is less 10%.

The result shows below Table 1. The result compared to single sensor system which takes head for test part is more accuracy in different motion state. And the proposed scheme has higher recognition capabilities and error reduction with the influences of abnormal elements in compared with reconstruction without BCA.

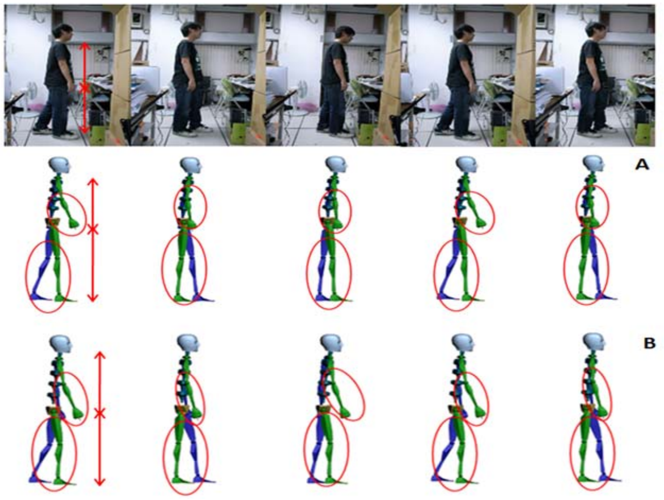

Fig. 9. 3D Skeleton Simulations without BPN Algorithm (A) and with BPN (B).

TABLE I
RESULT OF ACCURACY ON DIFFERENT MOTIONS STATE.

Task	Standing	Sitting	Running	Walking	Total
Total test	150	150	150	150	600
Correction	150	150	131	142	573
Incorrection	0	0	19	8	27
Accuracy(%)	100	100	87	94	95.72
Accuracy with Single sensor(%)	None	81.3	74.1	76	None
Without BCA(%)	100	92.6	80.6	88	90.3

V. CONCLUSIONS AND FUTURE WORK

In this paper, the proposed 3D AMR scheme utilized six sets of triple axis accelerometers and gyroscopes installed onto different parts of body to measure accelerations and angular accelerations on the limbs. Combined with accelerations and angular information, the simple human motion evaluation is built. In human motion reconstruction, the more information collected from different parts of body, the more accuracy can be reconstructed. However, the sensor accuracy, cost and comfort for human are considered. It is a strike drawback of comfort while too many sensors are installed on the body. In order to reduce issue, sensors are worn or carried to affix onto the six parts of human body. Based on theories of skeleton FK and IK, the human body postures are really reconstructed in most cases. The proposed BCA which records the related data and revise the limb height and body ratio is employed to improve accuracy rate of human body reconstruction. During the reconstruction, some error may occur with irregular motion like swing. These could be improved in the future.

ACKNOWLEDGEMENTS

This paper is a partial result of project NO. 99 RC13 and NSC 99-2219-E-011-001 conducted by National Cheng Kung University and Nation Taiwan University of Science and Technology under the sponsorship of the National Science Council(NSC), ROC. Lei Shu's research work in this paper is supported by Grant-in-Aid for Scientific Research (S)(21220002) of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

REFERENCES

[1] Pollefeys M, Nister D, Frahm JM, and Akbarzadeh A, Detailed real-time urban 3D reconstruction from video, *International Journal of Computer Vision*, Vol. 78, No. 2-3, pp. 143-167, Oct. 2007.
[2] Saxena A, Sun M, and Ng AY, Make3D: Learning 3D scene structure from a single still image, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 31, No. 5, pp. 824-840, May 2009.
[3] Harms H, Amft O, Troster G, and Roggen D, SMASH: a distributed sensing and processing garment for the classification of upper body postures, *Proc. of the the Third International Conference on Body Area Networks*, Brussels, Belgium, pp. 1-8, Mar. 2008.
[4] Slyper R and Hodgins JK, Action capture with accelerometers, *Proc. of the 2008 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, Dublin, Ireland, pp. 193-199, Jul. 2008.
[5] Vlasic D, Adelsberger R, Vannucci G, Barnwell J, Gross M, Matusik W, Popovič J, Practical motion capture in everyday surroundings, *ACM Transactions on Graphics - Proceedings of ACM SIGGRAPH 2007 TOG Homepage*, Vol. 26, No. 3, Art. 35, Jul. 2007.
[6] Ballan L and Cortelazzo GM, Marker-less motion capture of skinned models in a four camera set-up using optical flow and silhouettes, *Proc. of the Fourth International Symposium on 3D Data Processing, Visualization and Transmission*, Atlanta, GA, Jun. 2008.
[7] Wan C, Yuan B, and Miao Z, Markerless human body motion capture using Markov random field and dynamic graph cuts, *The Visual Computer*, Vol. 24, No. 5, pp. 373-380, Jan. 2008.
[8] McNamara JE, Bruyant P, Johnson K, Feng B, Lehovich A, Gu S, Gennert MA, and King MA, An assessment of a low-cost Visual Tracking System (VTS) to detect and compensate for patient motion during SPECT, *IEEE Transactions on Nuclear Science*, Vol. 55, No. 3, pp. 992-998, Jun. 2008.
[9] Li B, Meng Q, and Holsteinc H, Articulated motion reconstruction from feature points, *Pattern Recognition*, Vol. 41, No. 1, pp. 418-431, Jan 2008.
[10] Ashutosh S, Sung HC, and Andrew YN, 3-D depth reconstruction from a single still image, *International Journal of Computer Vision*, Vol. 76, No. 1, pp. 53-69, Jan. 2008.
[11] Noah S, Steven MS, and Richard S, Modeling the world from internet photo collections, *International Journal of Computer Vision*, Vol. 80, No. 2, pp. 189-210, Nov. 2008.
[12] Santamaria J, Cordon O, Damas S, Garcia-Torres JM, and Quirin A, Performance evaluation of memetic approaches in 3D reconstruction of forensic objects, *Soft Computing - A Fusion of Foundations, Methodologies and Applications*, Vol. 13 No. 8-9, pp. 883-904, Jul. 2009.
[13] Zou B, Chen S, Shi C, and Providence UM, Automatic reconstruction of 3D human motion pose from uncalibrated monocular video sequences based on markerless human motion Tracking, *Pattern Recognition*, Vol. 42, No. 7, pp. 1559-1571, Jul. 2009.
[14] Jia H and Martinez AM, Low-rank matrix fitting based on subspace perturbation analysis with applications to structure from motion, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 31, No. 5, pp. 841-854, May 2009.
[15] Oliensis J and Hartley R, Iterative extensions of the sturm/triggs algorithm: convergence and nonconvergence, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 29, No. 12, pp. 2217-2233, Dec. 2007.
[16] Chen HT, Tien MC, Chen YW, Tsai WJ, and Lee SY, Physics-based ball tracking and 3D trajectory reconstruction with applications to shooting location estimation in basketball video, *Journal of Visual Communication and Image Representation*, Vol. 20, No. 3, pp. 204-216, Apr. 2009.
[17] Boonstra MC, van der Slikke RMA, Keijsers NLW, van Lummel RC, de Waal Malefijt MC, and Verdonschot N, The accuracy of measuring the kinematics of rising from a chair with accelerometers and gyroscopes, *Journal of Biomechanics*, Vol. 39, No. 2, pp. 354V358, 2006.
[18] Dong Z, Wejinya UC, Zhou S, Shan Q, and Li WJ, Real-time written-character recognition using MEMS motion sensors: calibration and experimental results, *Proc. of IEEE International Conference*

on Robotics and Biomimetics, Bangkok, Thailand, pp. 688-691, Feb. 2009.

[19] Tseng YC, Wu CH, Wu FJ, Huang CF, King CT, Lin CY, Sheu JP, Chen CY, Lo CY, Yang CW, and Deng CW, A wireless human motion capturing system for home rehabilitation, *Proc. of Tenth International Conference on Mobile Data Management: Systems, Services and Middleware*, Taipei, Taiwan, pp. 359-360, May 2009.

[20] Liang X, Li Q, Zhang X, Zhang S, and Geng W, Performance-driven motion choreographing with accelerometers, *Computer Animation and Virtual Worlds*, Vol. 20, No. 2-3, pp. 89-99, Jun. 2009.

[21] Amasay T, Zodrow K, Kincl L, Hess J, and Karduna A, Validation of tri-axial accelerometer for the calculation of elevation angles. *International Journal of Industrial Ergonomics*, Vol. 39, No.5, pp. 783-789, May. 2009.

[22] Huang Q, Bian GB, Duan XG, Zhao HH, and Liang P, An ultrasound-directed robotic system for microwave ablation of liver cancer, *Robotica*, Vol. 28, No. 2, pp. 209-214, Mar. 2010.

[23] Isola AA, Ziegler A, Schäfer D, Köhler T, Niessen WJ, and Grass M, Motion compensated iterative reconstruction of a region of interest in cardiac cone-beam CT, *Computerized Medical Imaging and Graphics*, Vol. 34, No. 2, pp. 149-159, Mar. 2010.

[24] Catapano I, Crocco L, D'Urso M, and Isernia T, 3D Microwave Imaging via Preliminary Support Reconstruction: Testing on the Fresnel 2008 database. *Inverse Problems*, Vol. 25, No. 2, pp.1-23, Feb. 2009.

[25] Garcia J, Besada JA, Soto A, and Miguel GD, Opportunity trajectory reconstruction techniques for evaluation of ATC systems. *International Journal of Microwave and Wireless Technologies*, Vol. 1, No. 3, pp. 231-238, Jun. 2009.

[26] Flores-Tapia D, Thomas G, and Pistorius S, Wavefront reconstruction of elevation circular synthetic aperture radar imagery using a cylindrical green's function. *EURASIP Journal on Advances in Signal Processing*, Vol. 2010, No. 9, pp. 1-12, Jan. 2010.