Personal Rehabilitation Exercise Assistant with Kinect and Dynamic Time Warping

Chuan-Jun Su

***Abstract*—Constant rehabilitation exercises at home are usually required for complimenting prescribed exercises executed in a hospital setting and for expediting a patient's physical recovery. One of the main issues is to provide technological support for making home-based rehabilitation offering similar outcomes to hospital-based rehabilitation with an occupational physician presented. This paper presents our development of a Kinect-based system for ensuring home-based rehabilitation (KHRD) using Dynamic Time Warping (DTW) algorithm and fuzzy logic. The ultimate goal is to offer assistance for patients to conduct home-based rehabilitation without the presence of a physician and to avoid adverse events.**

***Index Terms*—Home-based rehabilitation, kinect, dynamic time warping (DTW) algorithm, fuzzy logic.**

I. Introduction

A. Research Background and Motivation

In the current medical fields, Rehabilitation medicine has been rapidly developed and become an important part of medical field which is apposition to preventive medicine and therapeutic medicine. The concept of home-based rehabilitation is not new. The aim of Home-based rehabilitation is to provide an in-home alternative to in-hospital rehabilitation. Home-based rehabilitation allows for great flexibility so that patients can tailor their program of rehabilitation and conform to individual schedules. In the case of rehabilitation, a traditional therapy process generally conducted in a hospital setting and requires direct supervision of a skilled caregiver. The aim of home-based rehabilitation is to provide an in-home alternative to in-hospital rehabilitation. Home-based rehabilitation allows for great flexibility so that patients can tailor their program of rehabilitation and conform to individual schedules. Governments in many countries nowadays provide home-based rehabilitation service. Because of Patients may not have enough time to go to the clinic or lack transportation. For many patients, the frequent traveling to the clinic adds economic burden. In addition, rehabilitation participated at the clinic only in not enough for the patient's recovery; they need to practice the rehabilitation activity at home as well. However, they don't necessary follow the physician's order to do that at home. Therefore, rehabilitation treatment effects are not as good as expected. In order to solve these problems, the concept of home-based rehabilitation has evolved. But, practicing home-based rehabilitation exercise without the presence of a professional may cause adverse event or lead to secondary injury. In this paper, we describe our development of a Kinect-based system - KHRD using Dynamic Time Warping (DTW) algorithm and fuzzy logic for ensuring home-based rehabilitation. The KHRD allows a patient perform a prescribed exercise with the presence of a professional. The exercise performed will then be recorded as a base for evaluating the patient's rehabilitation exercise at home. The outcomes of the evaluation can be used as a reference for the patient to validate his/her exercise and to prevent adverse events. A summary report of the outcomes may also be uploaded to a cloud setting for physicians to monitor the patient's progress and adjust the prescription.

Manuscript received March 8, 2013; revised June 24, 2013.

Chuan-Jun Su is with the Department of Industrial Engineering & Management, Yuan Ze University, Taiwan, ROC (e-mail: iecjsu@satuen.yzu.edu.tw).

B. Kinect

A new and low cost device named Kinect which was launched on November 2010. Based around a webcam-style add-on peripheral for the Xbox 360 console, it enables users to interact and control with the Xbox 360 without using a physical controller through a natural user interface using gestures, voice or images [1], [2]. Kinect started as a sensor for the Xbox 360 game system about one year ago, but almost immediately many software developers began to use it for other applications. Thus Kinect is considered to be designed in as part of a rehabilitation tool. As time passed, people started using Kinect in ways Microsoft never imagined after Kinect can connect to the PC. From helping children with autism to helping doctors in the operating room, people are talking about Kinect beyond games [3]. The Kinect for Windows SDK provides the location information of up to two players standing in front of the Kinect sensor array, with detailed position and orientation information. The data is provided to application code as a set of points, called skeleton positions, that composes a skeleton. In the past, it is difficult to track human skeleton information using camera without body sensors. The above Kinect features and low cost are very applicable to develop home-based rehabilitation tool which can ensure the correct and safe rehabilitation activity.

C. Dynamic Time Warping Algorithm

Euclidean distance is a simple method to compare two sequences. But each patient may complete the same activity with different time length. Euclidean distance cannot compare two sequential movements which have different time lengths and it is very sensitive to small distortions in the time axis. Therefore we need a method which doesn't have above defect as Euclidean distance in order to determine the similarity between the standard and the patient activity. A distance measure called Dynamic Time Warping (DTW) which has been widely applied in speech processing can be used for addressing the issue of distortion in time axis [4]–[6]. DTW algorithm has earned its popularity by being extremely

DOI: 10.7763/IJIET.2013.V3.316

efficient as the time-series similarity measure which minimizes the effects of shifting and distortion in time by allowing elastic transformation of time series in order to detect similar shapes. We utilize benefit of DTW algorithm to solve comparing two sequences which have different time length in order to determine the similarity between the standard and the patient exercise.

D. Fuzzy Logic

When physicians evaluate trajectory and speed of rehabilitation exercise mainly based on their experience and subjective evaluation without utilizing more precise and measurable computer value. Therefore, we cannot set a value of trajectory and speed to evaluate result using traditional logic theory. In contrast with traditional logic theory, where traditional binary sets have two-valued logic: true or false, fuzzy logic variables may have a truth value that ranges between 0 and 1. We will collect subjective evaluation of the physician and the data of trajectory and speed with DTW algorithm help in order to build fuzzy inference of physician's subjective evaluation.

II. Relatend Works

A. Home-Based Rehabilitation

Home-based rehabilitation has evolved in recent years as a viable alternative to in-patient rehabilitation for suitable patients. The aim of home rehabilitation is to provide an in-home alternative to in-hospital rehabilitation. This concept is a new and developing health service in Taiwan.

The therapy services of home-based rehabilitation include:

- Muscle strength and Endurance Training
- Therapeutic Exercises
- Balance Training
- Ambulation Training
- Physiotherapy
- Rehabilitation Medicine

No matter which of the above services, it helps people with disabilities achieve and maintain their optimal physical, psychological and social functions. The primary aims of the specialty are to empower the disabled person, to assist them in reducing the impact of their disability and to promote their full inclusion into society.

B. Rehabilitation with Device Help

Many researches use industrial motion sensors and Nintendo Wii Remote to assist physicians and patients [6], [7]. No matter that divert patient's uncomfortable and boring feeling with video games or VR environment in rehabilitation process, or physicians use the rehabilitation data which provided by devices to know patient's rehabilitation process. These researches show that motion sensors are useful as physical rehabilitation tools and confirm feasibility of device help. A new device named Kinect was launched on November 2010, it provides full-body control of animated virtual characters and users need not be bothered with body sensors. In the past, game manufacturers also developed sports and fitness games with Kinect [8]. These Kinect games can let users to do exercise in their home, but it cannot correctly evaluate user's exercise or it just check final pose in the all exercise process. The wrong exercise leads to sports injuries. Nevertheless, these games show the possibility of exercise application using Kinect. A lot of applications and researches talking Kinect beyond games after Kinect can connect to the PC. Kinect may become a new rehabilitation tool because of its advantages.

C. Kinect Applications

Due to Kinect is a low-cost device which can trajectory human skeleton and has depth camera, more and more researches of Kinect be published. Real-time gesture classification and motion recognition system are also popular researches with Kinect [9], [10]. Some researches show possible using Kinect in rehabilitation area. Reference [11] builds rehabilitation system for young adults with motor disabilities using Kinect. In addition, scholars develop an interactive game-based rehabilitation tool for balance training of adults with neurological injury using Kinect [12]. Reference [13] establishes a motion matching model of View-Invariant. Wu calculates the frame of key pose of the 3D coordinates distances between 15 joints of live motion skeleton and the best sample skeleton, and recognizes human motion using human skeleton by Kinect and OpenNI software [14]. This method is not applicable for rehabilitation exercise, because we hope to compare all frames of rehabilitation exercise to avoid wrong rehabilitation process. In our research we also use the skeleton information to evaluate the exercise. In order to compare all frames between patient's rehabilitation exercise and physician's rehabilitation exercise, we will use DTW algorithm.

D. Dynamic Time Warping (DTW)

DTW has been applied to any data which can be turned into a linear representation can be analyzed with DTW. It is currently used in many areas: gestures recognition [15], handwriting [16], time series clustering and data mining used DTW to match an input signal to a deterministic sequence of states [17]–[20]. Reference [21] uses a three-axis accelerometer sensor with DTW-based algorithm to help Wolf Motor Function Test. Reference [22] utilize DTW algorithm to compare two videos which have different time lengths. The scholar builds a system which can do behavior matching that determines the similarity between a standard and a testing behavior. Reference [23], [24] shared how to use the DTW algorithm to adopt gesture recognition using skeleton positions in the Microsoft Kinect forum and CodePlex. The nonlinear dynamic time warped alignment allows a more intuitive distance measure to be calculated. We utilize benefit of DTW algorithm to solve comparing two sequences which have different time length in order to determine the similarity between the standard and the patient exercise.

E. Fuzzy Logic

Fuzzy set theory was first proposed by L.A. Zadeh [25]. An instance of granulation is the concept of linguistic variable which was introduced by L.A. Zadeh [26]. Today, the concept of linguistic variable is used in almost all applications of fuzzy logic [27]. The application of fuzzy set theory in engineering started from the E.H. Mamdani [28]. Reference [29] evaluate student performance in laboratory applications using fuzzy logic. And they think that fuzzy logic evaluation is flexible and provides many evaluation options, while the classical method adheres to constant mathematical calculation. Reference [30] presented the development and actual implementation of an interactive computer graphics environment that encompasses a fuzzy inference model of a lake. Reference [31] presented a fuzzy rule base approach to human exercise recognition. And experiment results have shown that the recognition rate for eight exercise classification is 84.63%. Reference [32] presented fuzzy rule-based human actions recognition for home care system. And the accuracy is close to 90 percent. Further, fuzzy set theory has the potential to be regarded as an efficient measurement for the subjective performance evaluation.

III. Methodology

A. Requirement Study and Data Preprocessing

In home-based rehabilitation, a physician generally prescribes tailored, low-impact exercises without aggravating the injury for the patient to practice at home by thoroughly assessing the patient's condition and limitations. The exercises are then demonstrated by the physician and recorded in videos for the patient to follow at home. In this paper, we describe the development of a Kinect-based KHRD system for ensuring home-based rehabilitation by providing real-time evaluation of the discrepancy between the recorded and patient's exercises. We assume that a tailored exercise is performed by the patient and recorded under the supervision of a physician by using the proposed KHRD system. The evaluation can then be achieved by exploring the differences derived from two factors:

- Trajectory disparity: the motional path created by each joint over time and
- Speed variation: the time consumption in completing a designated exercise.

The Kinect depth sensor consists of an IR emitter and an IR camera. The camera knows where the emitter is located, and can sense the similarity and difference pattern based on the overlap of the cameras viewing angle. As shown in Fig. 1.

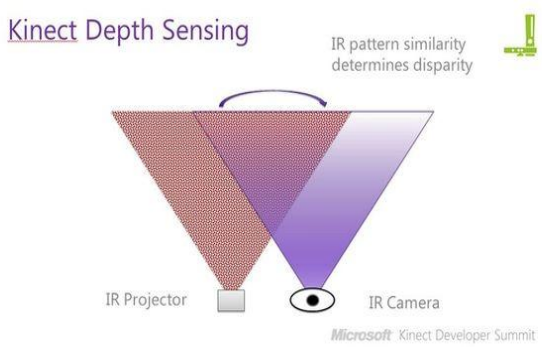

Fig. 1. Working principle of Kinect depth sensing.

Due to the limitation of Kinect, the user is required to act within a practical range defined by the Kinect as illustrated in Fig. 2. A data-preprocessing will be performed as an initiation of the KHRD, which transforms the Kinect's coordinate frame to a local coordinate frame centered at the "Hip-center" of the user's skeleton captured by the Kinect as depicted in Fig. 3. To ensure effective data capturing, the data of skeleton joint will be calibrated using homogeneous transformation as shown in Fig. 4.

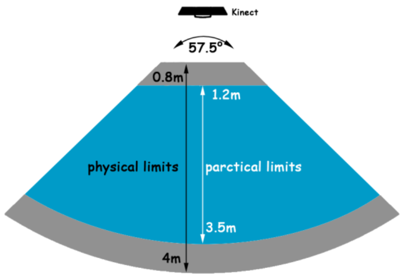

Fig. 2. The limited range of Kinect.

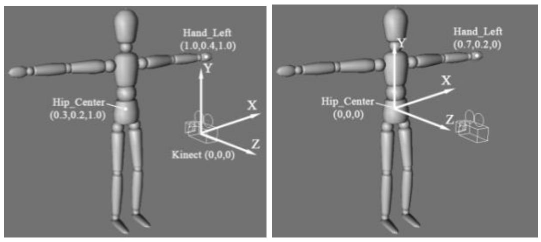

Fig. 3. The coordinate frame transformation.

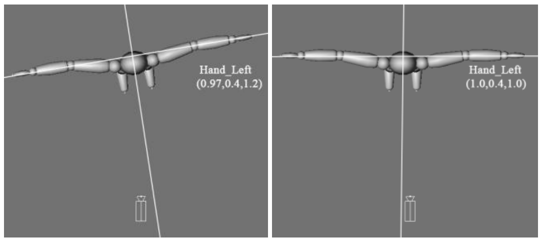

Fig. 4. The calibration of the data captured using homogeneous transformation.

B. The KHRD Architecture

KHRD can be architecturally divided into two main modules as shown in Fig. 5:

- The Kinect-based rehabilitation management module provides full functionality for users to practice rehabilitation exercise with Kinect at home.
- The Data Repositories module encapsulates the Exercise Database and User Profile.

The architecture of KHRD is detailed in the following sections:

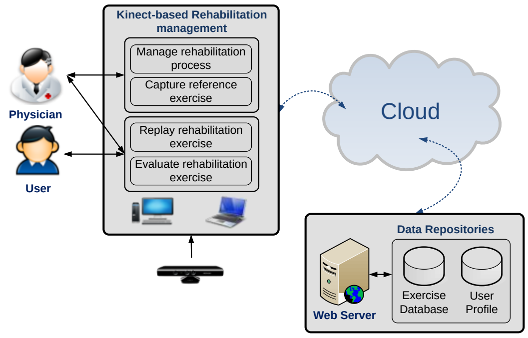

Fig. 5. The architecture of KHRD system.

C. Kinect-Based Rehabilitation Management Module

The module of Kinect-based rehabilitation management in KHRD system comprises four main functions: 1) capture user performed exercise under supervision of a professional, 2) replay the exercise for user to execute at home, and 3) evaluate the performance of the exercise.

D. The Capture Reference Exercise Function

This function enables the capture/recording of a user's execution of prescribed exercise under the supervision of a professional by using Kinect camera with 30 frames per second. It captures the user's 3D joint position by performing skeletal tracking and stores captured data to a file for future reference. The implementation was made using Kinect for Windows SDK version 1.5 with Windows Presentation Foundation (WPF) running under the environment of Visual Studio 2010. KHRD system captures position information of each reference joint and stores these data to a file in order to display for patients. Fig. 6 shows the skeleton-space coordinate system of Kinect for Windows SDK. An example of captured positional data of "Hand_right" and "Hand_left" joints is illustrated in Table I.

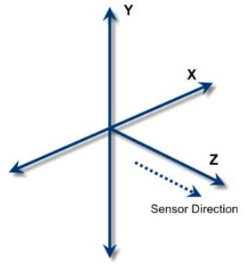

Fig. 6. Skeleton-space coordinate system for the sensor array.

TABLE I: EXAMPLE OF THE POSITION DATA: "HAND_RIGHT" AND "HAND_LEFT" JOINTS

Hand Right	Frame1	Frame2	Frame3	Frame4	Frame5
X-axis	-1.03271	-1.01393	-1.00279	-1.07700	-1.07722
Y-axis	-1.61344	-1.62983	-1.65032	-1.63272	-1.62548
Z-axis	-0.48157	-0.46476	-0.45619	-0.51384	-0.51594
Hand Left	Frame1	Frame2	Frame3	Frame4	Frame5
X-axis	1.12096	1.10549	1.11624	1.12286	1.13389
Y-axis	-1.61106	-1.61048	-1.61192	-1.61091	-1.60205
Z-axis	0.27739	0.27950	0.27878	0.28745	0.29677

E. The Replay Rehabilitation Exercise Function

This function allows users to replay the recorded "in-hospital" video that encapsulates the exercise previously performed by them under a professional's supervision. The users would then follow the recorded video and perform the same exercise with a Kinect at home. The user performed exercise at home will also be recorded and saved as "at-home" video. The sequence of skeleton data from at-home video will then be evaluated against the skeleton data from in-hospital video as described in the following section. Advices can then be provided according the evaluation outcome.

F. The Evaluate Rehabilitation Exercise Function

This is the core function in KHRD system. This function applies the DTW algorithm that can adapt to sequences that vary in speed and time for measuring the similarity of streaming joint data between "at-home" and "in-hospital" videos. When a patient executes a prescribed exercise by following an "in-hospital" video within a Kinect setting, the patient's joint data will be captured as described in section 3.2.2. The sequence of captured joint data (at-home data) will then be used to compare against the sequence stored (in-hospital data) in the data repository. An evaluation result will then be derived based on the degree of similarity between the two sequences. The outcome can be used as a reference for the user and physician or for issuing advice for preventing adverse events. The process of "Evaluate rehabilitation exercise" is illustrated in Fig. 7.

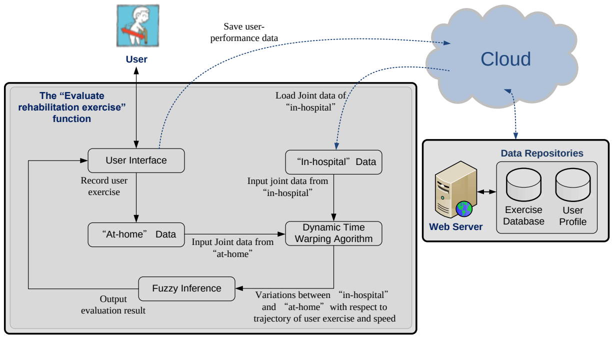

Fig. 7. The process of evaluating rehabilitation exercises.

The DTW algorithm has earned its popularity by being efficient as a time-series similarity measure which minimizes the effects of shifting and distortion in time. By allowing elastic transformation of time series, the DTW has been proven effective in detecting similar shapes. In the remaining of this section, we describe the way that DTW functions in KHRD. A warping path P is a contiguous set of matrix elements that defines a mapping between A and B. where and max. The warping path must satisfy the following criteria:

- **Boundary condition:** $p_1 = (a_1,\ b_1)$ and $p_s = (a_m,\ b_n)$. This requires the warping path to start and finish in diagonally opposite corner cells of the matrix.
- **Continuity:** Given $p_k = (i,\ j)$ then $p_{\mathrm{k}-1} = (i',\ j')$ where $i - i' \leq 1$ and $j - j' \leq 1$. This restricts the allowable steps in the warping path to adjacent cells.
- **Monotonic condition:** Given $p_k = (i, j)$ then $p_{k-1} = (i', j')$ where $i - i' \geq 0$ and $j - j' \geq 0$. This forces the points in P to be monotonically spaced in time.

For example, two time series A and B generated from the position data of in-hospital's and at-home "Hand_Left" joints respectively as illustrated in Table II and Table III.

TABLE II: THE POSITION DATA OF IN-HOSPITAL'S "HAND_LEFT" JOINT

Hand Left	a1	a2	a3	a4	a5	a6
X-axis	-1.0327	-1.0139	-1.0028	-1.0770	-1.0772	-1.0775
Y-axis	-1.6134	-1.6298	-1.6503	-1.6327	-1.6255	-1.6246
Z-axis	-0.4816	-0.4648	-0.4562	-0.5138	-0.5159	-0.5187

TABLE III: THE POSITION DATA OF AT-HOME'S "HAND_LEFT" JOINT

Hand Left	b1	b2	b3	b4	b5
X-axis	-1.0147	-1.0418	-1.0768	-1.1063	-1.2570
Y-axis	-1.5879	-1.5756	-1.5638	-1.5339	-1.4822
Z-axis	-0.3981	-0.4068	-0.4217	-0.4210	-0.4633

The Euclidean distance and DTW distance between A and B are shown in Table IV and Table V. The DTW distance is computed according to the following algorithm:

- $\mathrm{DTW}\ (a_1, b_1) = \mathrm{Euclidean}(a_1, b_1)$
- First row: $\mathrm{DTW}(a_1, b_j) = \mathrm{DTW}(a_1, b_{j-1}) +$
- $\mathrm{Euclidean}(a_1, b_j),\ j \in [2, n]$

- First column: $\mathrm{DTW}(a_i, b_1) = \mathrm{DTW}(a_{i-1}, b_j) + \mathrm{Euclidean}(a_i, b_1), \quad i \in [2, m]$
- All other elements:

$$\mathrm{DTW}\,(a_i, b_j) = \mathrm{Min}\left[\mathrm{DTW}\,(a_{i-1}, b_j), \mathrm{DTW}\,(a_i, b_{j-1}), \mathrm{DTW}\,(a_{i-1}, b_{j-1})\right] + \mathrm{Euclidean}(a_i, b_j), i \in [2, m], j \in [2, n]$$

TABLE IV: THE EUCLIDEAN DISTANCE BETWEEN A AND B

	b_1	b_2	b_3	b_4	b_5
a_1	0.07627	0.07513	0.06953	0.06725	0.06578
a_2	0.07814	0.07695	0.07159	0.06930	0.06781
a_3	0.07988	0.07865	0.07346	0.07116	0.06964
a_4	0.08106	0.07982	0.07469	0.07239	0.07087
a_5	0.08210	0.08083	0.07561	0.07328	0.07174
a_6	0.08190	0.08063	0.07536	0.07303	0.07148

TABLE V: THE DTW DISTANCE BETWEEN A AND B

	b_1	b_2	b_3	b_4	b_5
a_1	0.07627	0.15139	0.22093	0.28818	0.35396
a_2	0.15440	0.15322	0.22298	0.29023	0.35599
a_3	0.23429	0.23186	0.22668	0.29414	0.35987
a_4	0.31535	0.31168	0.30137	0.29907	0.36501
a_5	0.39745	0.39251	0.37698	0.37235	0.37081
a_6	0.47935	0.47315	0.45234	0.44538	0.44229

TABLE VI: THE DTW DISTANCE OF (a_6, b_4), (a_5, b_4), AND (a_5, b_5).

Possible warping paths of (a_6, b_5)	(a_6, b_4)	(a_5, b_4)	(a_5, b_5)
DTW distance	0.45381	0.372353	0.370809

TABLE VII: THE DTW DISTANCE OF (a_5, b_4), (a_4, b_4), AND (a_4, b_5).

Possible warping paths of (a_5, b_5)	(a_5, b_4)	(a_4, b_4)	(a_4, b_5)
DTW distance	0.372353	0.29907	0.365014

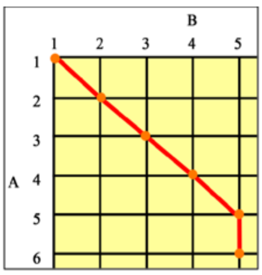

Fig. 8. The optimal warping path of A and B.

We then start to find the optimal warping path. According to the boundary condition: $p_1 = (a_1, b_1)$ and $p_s = (a_6, b_5)$; The criteria of continuity and monotony imply that $p_{s-1} = (a_6, b_4), (a_5, b_4)$, or (a_5, b_5) ; The DTW distance are computed for these three points as shown in Table VI. Set $p_{s-1} = (a_5, b_5)$ for (a_5, b_5) has the minimal DTW distance. Similarly, $p_{s-2} = (a_5, b_4)$, (a_4, b_4) or (a_4, b_5). Set $p_{s-2} = (a_4, b_4)$ for it has the minimal DTW distance as shown in Table VII.

The algorithm continues until the $p_1 = (a_1, b_1)$ reached. In this example, the optimal warping path would be $\{(a_6, b_5), (a_5, b_5), (a_4, b_4), (a_3, b_3), (a_2, b_2), (a_1, b_1)\}$ as depicted in Fig. 8. Finally, the Euclidean distance Ed of the optimal path is calculated for serving as a metric of disparity between A and B: Ed = 0.071483 + 0.07174 + 0.072393 + 0.073461 + 0.076948 + 0.076268 = 0.442293

G. Design of Fuzzy Inference

The performance evaluation regarding rehabilitation exercises usually conducted in a subjective and experience-based fashion by physicians. They use such words as “your arm positions are too high”, “you move too fast”, etc. These words contain imprecise information in noncrisp expressions. We use the Fuzzy inference to deal with uncertain and imprecise information. Using this approach, subjective judgments of professionals can be captured in a mathematical model for providing real-time evaluation for patients to exercise at home.

1) Input and output value define

- **Input** Trajectory: similar; dissimilar.
- **Input** Speed: too fast; Just right; too slow.
- **Output** Evaluation: Excellent; Good; Bad.
- **Rules** of fuzzy
  a) If the trajectory is similar and speed is just right, then the evaluation is excellent.
  b) If the trajectory is similar and speed is too slow, then the evaluation is good.
  c) If the trajectory is dissimilar or speed is too fast, then the evaluation is bad.

The membership functions used are generated by gathering domain expert knowledge.

2) Membership function define

The expressing function of fuzzy set is the value from 0 to 1. It is called membership function. Membership function denotes as $u_A(x):\ 0 \le u_A(x) \le 1$. Fig. 10 and Fig. 11 showed four membership functions of joints we used in this paper. The vertical value means the degree of membership between 0 and 1. And the horizontal value means the total trajectory error value.

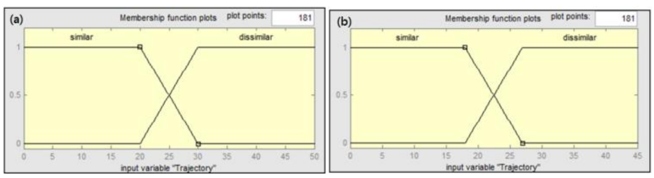

Fig. 10. The “trajectory” membership function of hand joint (a) and wrist joint (b).

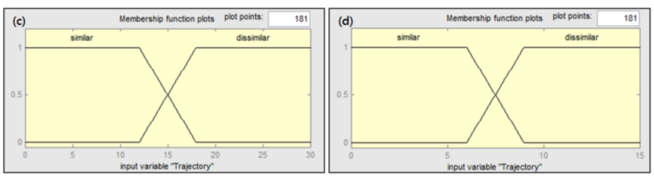

Fig. 11. The “trajectory” membership function of elbow joint (c) and shoulder joint (d).

In Fig. 12 e), the horizontal value means the time consumption in completing a designated exercise by user divided by the time consumption of reference exercise. The horizontal value of Fig. 12 f) means the evaluation score between 0 and 10. Each joint has different "Trajectory" membership function, but their "Speed" and "Evaluation" membership functions are the same.

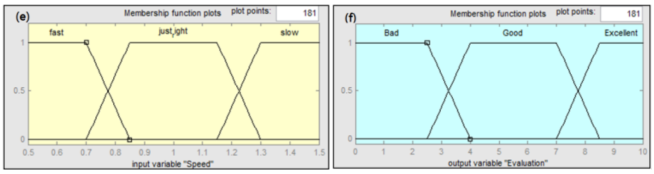

Fig. 12. The "speed" (e) and "evaluation" (f) membership function of all joints.

3) *Fuzzy inference and defuzzify*

Fig. 13 showed the sample of defuzzify using Matlab. The input "trajectory" value was 24.5 and "speed" value was 1.2, then the output "evaluation" value was 5.14, it meant "good".

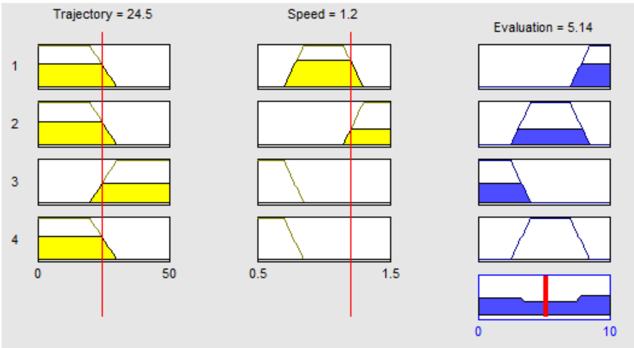

Fig. 13. Defuzzify using matlab.

H. Data Repository

The Data Repository module was designed for storing user profile and the data of rehabilitation exercises in the KHRD:

- **Activity Database:** stores all information of rehabilitation activities recorded by physicians. Physicians can modify rehabilitation activities which designed for their patients.
- **User Profile**: stores user's such basic information name, gender, weight, and height, etc. as well as "at-home" exercise records.

IV. Conclusion And Future Works

The development of our KHRD is crucial for the future of home-based rehabilitation. From the physician point of views, rehabilitation participated in a formal setting is sometimes insufficient for the patient's recovery. A consistent rehabilitation exercise at home is required to expedite the recovery. In addition, KHRD can ensure patient's accurate rehabilitation exercise, which can help course of treatment. From the patient point of views, the problem of the inconvenience in traveling to the clinic for regular therapy services can be solved. Ultimately, the adverse rehabilitation exercises can be greatly decreased when conducting home-based rehabilitation without the presence of a physician. We tested our KHRD on three different shoulder rehabilitation exercises performed by four different people. By comparing KHRD and the physician, the evaluation of KHRD coincided 80.01% with the physician. This result shows that KHRD is suitable for home-based rehabilitation exercise.

References

[1] A. Pham. (2009). E3: Microsoft shows off gesture control technology for Xbox 360. [Online]. Available: http://latimesblogs.latimes.com/technology/2009/06/microsofte3.html

[2] Microsoft. (2009). E3 2009: Microsoft at E3 Several Metric Tons of Press Releaseapalooza. [Online]. Available: http://blog.seattlepi.com/digitaljoystick/2009/06/01/e3-2009-microsoft-at-e3-several-metric-tons-of-press-releaseapalooza/

[3] Microsoft Reaserch. (2011). Kinect Effect" Magic Pushes Beyond the Living Room. [Online]. Available: http://www.microsoft.com/Presspass/Features/2011/oct11/10-31KinectEffect.mspx

[4] C. Myers, L. Rabiner, and A. Rosenberg, "Performance tradeoffs in dynamic time warping algorithms for isolated word recognition," *IEEE Trans. on Acoustics, Speech, and Signal Processing*, vol. 28, no. 6, pp. 623-635, December 1980.

[5] H. Sakoe and S. Chiba, "Dynamic programming algorithm optimization for spoken word recognition," *IEEE Trans. on Acoustics, Speech, and Signal Processing*, vol. 26, no. 1, pp. 43-49. February 1978.

[6] S. Arteaga, J. Chevalier, A. Coile, A. W. Hill, S. Sali, S. Sudhakhrisnan, and S. H. Kurniawan, "Low-Cost Accelerometry-Based Posture Monitoring System for Stroke Survivors," in *Proc. the 10th international ACM SIGACCESS conference on Computers and accessibility*, 2008, pp. 243-244.

[7] C. H. Shih, M. L. Chang, and C. T. Shih, "A limb action detector enabling people with multiple disabilities to control environmental stimulation through limb action with a Nintendo Wii Remote Controller," *Research in Developmental Disabilities*, vol. 31, no. 5, pp. 1047-1053, September-October, 2010.

[8] Microsoft. (2012). Kinect games. [Online]. Available: http://marketplace.xbox.com/zh-tw/proexercise/kinectgames

[9] M. Raptis, D. Kirovski, and H. Hoppe, "Real-Time Classification of Dance Gestures from Skeleton Animation," *Eurographics/ ACM SIGGRAPH Symposium on Computer Animation*, pp. 147-156, 2011.

[10] D. S. Alexiadis, P. Kelly, P. Daras, N. E. O'Connor, T. Boubekeur, and M. B. Moussa, "Evaluating a dancer's performance using Kinect-based skeleton trajectorying," *ACM international conference on Multimedia*, pp. 659-662, 2011.

[11] Y. J. Chang, S. F. Chen, and A. F. Chuang, "A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities," *Research in Developmental Disabilities*, vol. 32, no. 6, pp. 2566-2570, November.-December. 2011.

[12] B. Lange, C. Y. Chang, E. Suma, B. Newman, A. S. Rizzo, and M. Bolas, "Development and Evaluation of Low Cost Game-Based Balance Rehabilitation Tool Using the Microsoft Kinect Sensor," in *Proc. 33rd Annual International Conf. of the IEEE EMBS Boston*, 2011, pp. 1831-1834.

[13] K. K. Wu, "Using Human Skeleton to Recognizing Human Exercise by Kinect's Camera," Master thesis, Dept. Computer Science and Information Engineering, National Taipei Univ. of Technology, Taiwan, ROC, 2011.

[14] OpenNI. (2011). OpenNI. [Online]. Available: http://75.98.78.94/default.aspx

[15] A. Corradini, "Dynamic Time Warping for Off-Line Recognition of a Small Gesture Vocabulary," *RATFG-RTS '01 Proc. of the IEEE ICCV Workshop on Recognition, Analysis, and Tracking of Faces and Gestures in Real-Time Systems*, USA, 2001, pp. 82.

[16] C. C. Tappert, C. Y. Suen, and T. Wakahara, "he state of the art in online handwriting recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 12, no. 8, pp. 787-808, August 1990.

[17] V. Niennattrakul and C. A. Ratanamahatana, "On Clustering Multimedia Time Series Data Using K-Means and Dynamic Time Warping," *2007. International Conf. on Multimedia and Ubiquitous Engineering*, pp. 733-738, April 2007.

[18] C. Bahlmann and H. Burkhardt, "The writer independent online handwriting recognition system frog on hand and cluster generative statistical dynamic time warping," *Pattern Analysis and Machine Intelligence, IEEE Trans. on Germany*, vol. 26, no. 3, pp. 299-310, March 2004.

[19] T. Kahveci and A. Singh, "Variable length queries for time series data," in *Proc. 17th International Conf. on Data Engineering*, CA, 2001, pp. 273-282.

[20] A. F. Bobick and A. D. Wilson, "A State-Based Technique to the Representation and Recognition of Gesture," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 19, no. 12, pp. 1325-1337, December 1997.

[21] R. Muscillo, M. Schmid, S. Conforto, and T. D'Alessio, "Early recognition of upper limb motor tasks through accelerometers:real-time implementation of a DTW-based algorithm," *Computers in Biology and Medicine*, vol. 41, no. 3, pp. 164-172, March 2011.

[22] W. Y. Chen, "Automatic Human Pose Estimation and Behavior Matching System Using Video Sequences," Master thesis, Dept. Information and Computer Engineering, Chung Yuan Christian Univ., Taiwan, ROC, 2008.

[23] Rymix. (2011). Kinect SDK Dynamic Time Warping (DTW) Gesture Recognition. [Online]. Available: http://kinectdtw.codeplex.com/

[24] Rhemyst. (2011). Dynamic time Warping to recognize gestures. [Online]. Available: http://social.msdn.microsoft.com/Forums/nl/kinectsdknuiapi/thread/4a428391-82df-445a-a867-557f284bd4b1

[25] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338-353, June 1965.

[26] L. A. Zadeh, "Outline of a new approach to the analysis of complex systems and decision processes," *IEEE Trans. on Systems, Man and Cybernetics*, vol. SMC-3, no. 1, pp. 28-44, January 1973.

[27] L. A. Zadeh, "Is there a need for fuzzy logic?" *Information Sciences*, vol. 178, no. 13, pp. 2751-2779, July 2008.

[28] E. H. Mamdani and S. Asslilan, "A fuzzy logic controller for a dynamic plant," *International Journal of Man-Machine Studies*, vol. 7, pp. 1-13, 1975.

[29] G. Gokmen, T. C. Akinci, M. Tektaş, N. Onat, G. Kocyigit, and N. Tektaş, "Evaluation of student performance in laboratory applications using fuzzy logic," *Procedia-Social and Behavioral Sciences*, vol. 2, no. 2, pp. 902-909, 2010.

[30] I. A. Ioannidou, S. Paraskevopoulos, and P. Tzionas, "An interactive computer graphics interface for the introduction of fuzzy inference in environmental education," *Interacting with Computers*, vol. 18, no. 4, pp. 683-708, July 2006.

[31] K. T. Chen, "Rule Based Human Normal and Abnormal Activity Recognition," Master thesis, Dept. Electrical and Control Engineering College of Electrical Engineering and Computer Science, National Chiao Tung Univ., Taiwan, ROC, 2008.

[32] K. T. Li, "Fuzzy Rule-Based Human Actions Recognition for Home Care System," Master thesis, Dept. Graduate Institute of Communication Engineering College of Electrical Engineering and Computer Science, National Taiwan Univ., Taiwan, ROC, 2005.

[33] C. J. Su, J. Y. Huang, and S. F. Huang, "Ensuring Home-based Rehabilitation Exercise by Using Kinect and Fuzzified Dynamic Time Warping Algorith," in *Proc. the 13th Asia Pacific Industrial Engineering & Management Systems Conference,* 2012, pp. 884~895.

Chuan-Jun Su was born on August 20, 1956 in Taiwan. Prior to joining the University, he was an assistant professor in the Department of Industrial Engineering and Engineering Management at The Hong Kong University of Science and Technology University. He was also the founder of Horky.com Corporation. He received his PhD in industrial engineering from Texas A&M University in College Station, Texas. His research interests include Information Technology, Mobile Commerce, Enterprise Information Systems, and Virtual Reality.

He is currently an associate professor in the Department of Industrial Engineering & Management, Yuan Ze University, Taiwan. His recent related publications: 1) **Chuan Jun Su***, Hsin-Chi Chuang, Toward Mass Customized Product Deployment in E-Commerce: The Modularization Function and Postponement Strategy, Journal of Organizational Computing and Electronic Commerce, Volume 21(1), Jan. 2011, pp. 24-49. 2) **Chuan Jun Su***, Chia-Ying Wu, JADE implemented mobile multi-agent based, distributed information platform for pervasive health care monitoring, Applied Soft Computing, Volume 11(1), Jan. 2011, pp. 315-325. 3) **Chuan Jun Su***, Mobile multi-agent based, distributed information platform (MADIP) for wide-area e-health monitoring, Computers in Industry, Volume 59(1), Jan. 2008, pp. 55-68.