Weight Sensors Based Human Walking Step Recognition System: Implementation and Statistical Evaluation

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Abstract

It is well known that with the growing of the humanity and all the development in technologies, there is an increasing in need for recognition systems. These systems can recognize people from distinct characteristics in which these are unique for each one individually. The researchers went to the finger print and eye recognition methods to be adopted as the dominated approaches, yet, these methods suffers from numerous health risks due to diseases transferring. Therefore, the walking step recognition method has been adopted recently. This is because each person has different walking style from others.

This paper proposed a human walking step recognition system that adopts group of weight sensors distributed amongst carpet. The reading data from sensors has been transmitted to the information center for processing. The data is transmitted through out a wired sensor network that includes sensor nodes and sink node. The latest node is used to collect the reading data from the sensor nodes. At the information center, the received data is processed using the proposed recognition algorithm. This algorithm gives two decisions; either matching with full information about the intruder or no matching. On the other hand, the proposed system has been designed and implemented using MATLAB simulator. Throughout this simulator, a database matrix is generated randomly to cover all the probability of walking step patterns available for humans. This matrix consists of three dimensions; one for users, second for sensor readings (walking patterns), and third for tries. Each user records numerous walking patterns by passing over the designed carpet several times at different modes just to cover the slightly changes in walking style in terms of modes. It is important to note, that the carpet include the sensors in between of two layers.

The simulation results show the successful performance of the proposed system with high efficiency and recognition accuracy. In addition, statistical analysis has been obtained using sampling theorem by adopting sample of 100 employees at University of Technology. This is done by distributing a questioner form over the employees to evaluate the acceptation of the proposed system by people in terms of health issues and ease of use. The outcome results show high ratio of accepted people in comparison with rejected.

Keywords*:* Pattern recognition, walking step recognition, sensors, statistical sampling

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نظام التعرف باستخدام خطوات مشي البشر ومتحسسات الوزن: تطبيق وتحليل احصائي

الخلاصة

من المعلوم أنه مع النمو للبشرية وكل التطور في مجال التقنيات، هناك زيادة في الحاجة إلى أنظمة التعرف. يمكن لهذه الأنظمة التعرف على الناس من الخصائص المميزة والتي هي فريدة من نوعها لكل واحد على حدة. ذهب الباحثون إلى اساليب بصمات الاصابع ومسح العين ، ولكن، وهذه الأساليب تعاني من العديد من المخاطر الصحية الناجمة عن نقل الأمراض عن طريق التلامس. ولذلك، فقد تم اعتماد أسلوب التعرف بواسطة خطوات المشي في الآونة الأخيرة. وذلك لأن كل شخص لديه نمط مشي مختلف عن الآخرين. تم في خذا البحث تم اقتراح نظام التعرف على خطوة المشي البشري الذي يتبنى مجموعة من أجهزة الاستشعار بالوزن توزيعها على السجاد. قراءة البيانات من المتحسسات تنقل الى مركز المعلومات للمعالجة. تنتقل البيانات من خلال شبكة سلكية من المتحسسات يتضمن عقد التحسس والعقدة الرئيسية. في مركز المعلومات، يتم معالجة البيانات الواردة باستخدام خوارزمية التعرف المقترحة. هذه الخوارزمية تعطي قرارين؛ إما مطابقة مع معلومات كاملة عن الدخيل أو لا توجد مطابقة. من ناحية أخرى، وقد تم تصميم النظام المقترح وتنفيذه باستخدام برنامج المحاكاة MATLAB. طوال هذه المحاكاة، يتم إنشاء مصفوفة لقاعدة البيانات عشوائيا لتغطية كل احتمالات انماط المشي المتاحة للبشر. يسجل كل مستخدم العديد من أنماط المشي التي تمر فوق السجادة المصممة بعدة محاولات في أوضاع مختلفة فقط لتغطية التغييرات الطفيفة في نمط المشي. أظهرت نتائج المحاكاة الأداء الناجح للنظام المقترح مع كفاءة عالية ودقة بالتعرف. وبالإضافة إلى ذلك، تم الحصول على التحليل الإحصائي باستخدام اسلوب أخذ العينات لعينة تتكون من 100 موظف في الجامعة التكنولوجية. أظهرت النتائج ان نسبة عالية من الناس فضلت استخدام النظام المقترح.

كلمات مفاتيح البحث: التعرف على الأنماط، التعرف بخطوات المشي، أجهزة المتحسسات، وأخذ العينات الإحصائية

INTRODUCTION

It is well known that the human recognition is considered as the most important step in security levels [1]-[2]. The human walking step recognition has solved the problem of recognition at save process in terms of health in comparison to finger print and eye approaches. In addition, this method works in easy procedure in which the person can pass over the designed carpet normally. In recent time, the methods of recognition for human walking behaviors has been described utilizing different categories of sensors and a simple algorithm to produce an efficient recognition systems. The investigated methods can evaluate the walking style or can be called pattern as well as the other characteristics, such as the number of steps and speed [3]-[5].

In 2013, Lei, Peng, et al, proposed a gait recognition algorithm for prosthetic knee of power-type control [6]. This algorithm analyzed the signal acquisition of the control system. The walking pattern features have been extracted and used for the designing of neural network. Makhdoomi, Gunawan, et al resented a simple baseline method for gait recognition based on walking pattern, in 2014 [7]. The recognition algorithm considered the body shape and walking pattern from different angles of view. In 2013, Valle and Starostenko presented a human action recognition algorithm [8]. The proposed algorithm considered the full body action analysis using convolutional neural network and specifically the configuration. The neural network extracted the pattern features optimally using variant of multilayer perceptron and then learnt the involved layers.

In 2001, Lee and Mase have proposed a method to recognize the walking style as well as counting the number of intruder's steps using accelerometers [9]. The dead-reckoning as a basic function was employed to find the location recognition inside building or as known as indoor. The obtained results showed a superior performance for the proposed algorithm in terms of recognition and classifications depending on the step count. In 2002, Davis and Taylor proposed a recognition method based on fronto parallel angle of the XY position [10]. The underlying angle is evaluated from the maximal forward extension of the one leg in front of the whole body with the other leg left behind the same body. In addition, the authors calculated the curvature of the body when the mentioned angle became zero. Trung, Makihara, et al presented a robust step recognition and detection method was proposed to segment the obtained signal into action pattern, in 2012 [11]. The proposed method was based on detecting the similarity of walking steps between people. Regardless the speed of walking, the introduced method is still working, i,e for various walking speed. Different walking environment has been considered in the experiments including walking on flat ground, down the stairs, up the stairs, down the slope and even up the slope.

In 1998, Cheng and Moura proposed a recognition algorithm based on human movements in live videos [12]. From the considered movement recorded in videos, the proposed algorithm extracted the motion shape and texture for a specific intruder. This algorithm solved the problem of tracking and action recognition in terms of human modeling and texture recovery. The motion evaluation was based on the action of body joints and rigid that is affected by the periodic walking style. The proposed systems have been tested using a live videos and the obtained results showed a positive response in terms of recognition accuracy. In 2008, Libby introduced an embedded hardware systems based step recognition method [12]. In the proposed algorithm, the step features have been extracted, such as the shape of the normalized step accelerometer signal, which is used to classify the walking style over different activities for the same person. Therefore, this algorithm is efficient for sport actions recognition, such as running and bicycling. In 2012, Brajdic and Harle used the accelerometer and gyroscope signal of pedestrians to build an efficient recognition method [14]. The proposed algorithm included two parts. The first part focused on the global locomotion, mode of motion and hand motion in recognition. While the second part dealt with the step detection and recognition.

In this paper, a human walking step recognition system has been proposed. The proposed system includes three levels, which are the covered area (designed carpet), data transmission (wired sensor network), and information center. The information center applies the proposed recognition algorithm depending on the received readings from the weight sensors distributed among the carpet. The main difference between this work and the previous ones [6]-[14] is the use of weight sensor at the designed carpet and the proposed algorithm. The proposed system has been simulated using MATLAB environment. The database matrix that contains the recorded walking patterns of the authorized persons has been generated randomly for simulation use. This matrix includes the data of sensors' readings that are saved in three dimensions; one for users, the other for sensors' readings, and the tries. The tries means that the authorized person records numerous walking patterns by passing over the carpet in different times and distinct modes, such as illness. A graphical user interface (GUI) is used to design interface interaction to do three functions. Firstly, generate the database matrix. Secondly, the testing of validating for the proposed algorithm by capturing samples from the generated database matrix and matching them with main matrix. On the other hand, a sample of 100 employees at the University of Technology has been considered to evaluate the acceptance of the proposed system by people. A questioner forms distribute over the sample and a statistical analysis is obtained using the sampling theorem. The simulated results show the superior performance of the proposed system in terms of accuracy and efficiency.

This paper is organized as: Section 2 explains the designed algorithm and setting of the proposed walking step recognition. Section 3 includes the statistical analysis of the considered sample. Section 4 illustrates the simulation results and discussion. Finally, Section 5 draws the conclusions.

The proposed Step Recognition System

In this work, the patterns of human steps have been considered to recognize the people passed over the designed carpet [1]. This Section explains the implementation of the proposed system as shown in Fig. 3.1. It is highlighted that the introduced system include the carpet and information center. In order to ease the reading of this work, the following sub-Sections have been included.

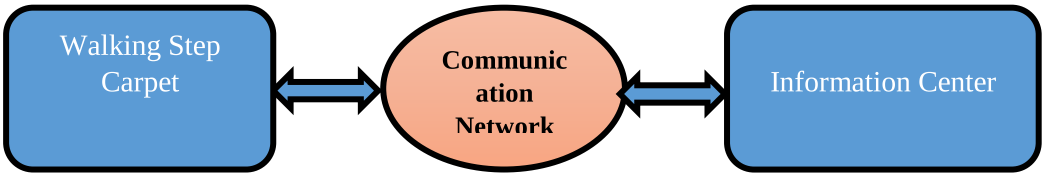


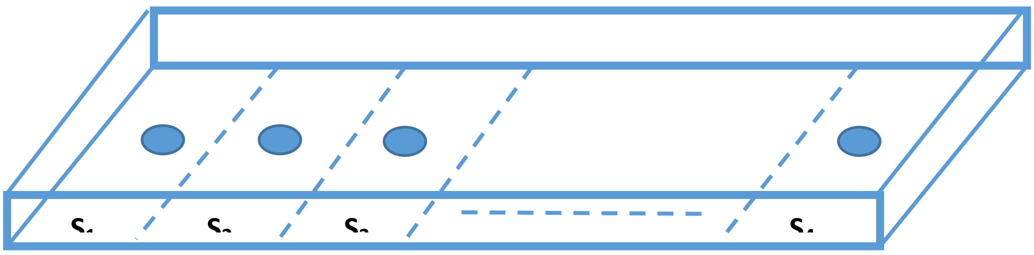
Figure (1). The proposed step recognition system

The Designed Carpet

The employed carpet is a specially made for this system. It includes two layers and in between sensors. The ground layer is stuff and the above one is more flexible. The distributed sensors of type of weight measuring are connected to sink node that collects and manages the readings from them.

Fig. 2 shows the designed carpet. It is noted that the sensors have been distributed in rows and columns as a uniform two dimension matrix. The readings of these sensors are sent to the information center for the next step of recognition process.

From above explanations, it is concluded that the sensor network is a uniform type and as mentioned earlier the sink node is the core of data transmission.



Figure(2). Designed carpet

Information Center

In the most recognition and monitoring systems, there is an information center. This center is responsible on collecting the data required for processing the underlying algorithm and then responding the sources with the right decision [5].

In this work, the information center collects the reading data of the considered weight sensor distributed amongst the carpet. Then, the proposed recognition algorithm is implemented to produce the results for the entering objects. Fig. 3 illustrates the structure design of the information center that includes three levels.

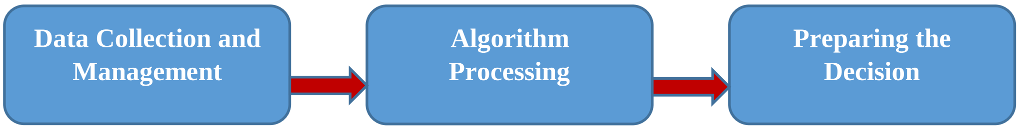


Figure (3). Information Center Structure

First level, is Data collection and management, groups the received reading data from the sensors and arranges these data in two dimension matrix. Each row of this matrix represents the person and each column refers to a sensor. Therefore, in the proposed algorithm there are two identifiers to recognize the person, which are location of foot step and weight. This is to increase the efficiency of recognition and reducing the error ratio. The entered data is compared with available data base for the authorized people. This data base is a three dimensions matrix, dimension for sensors, another for each person pattern shape and the last dimension for whole authorized persons. To be more precise, each authorized person records the walking step pattern by passing over the carpet for numerous times at different time and modes. This is to increase the probability of walking pattern shape in which covering different modes of each person, such as upset, happiness and illness as it is well known that the mode can affect the pattern directly.

Second level, called Algorithm processing, performs the proposed algorithm that recognize the entered object. The output of this algorithm can be either "match" or "no match". This is done by comparing the collected data of the intruder with the database matrix and then come up with the right decision. The next sub-section explains this algorithm in details.

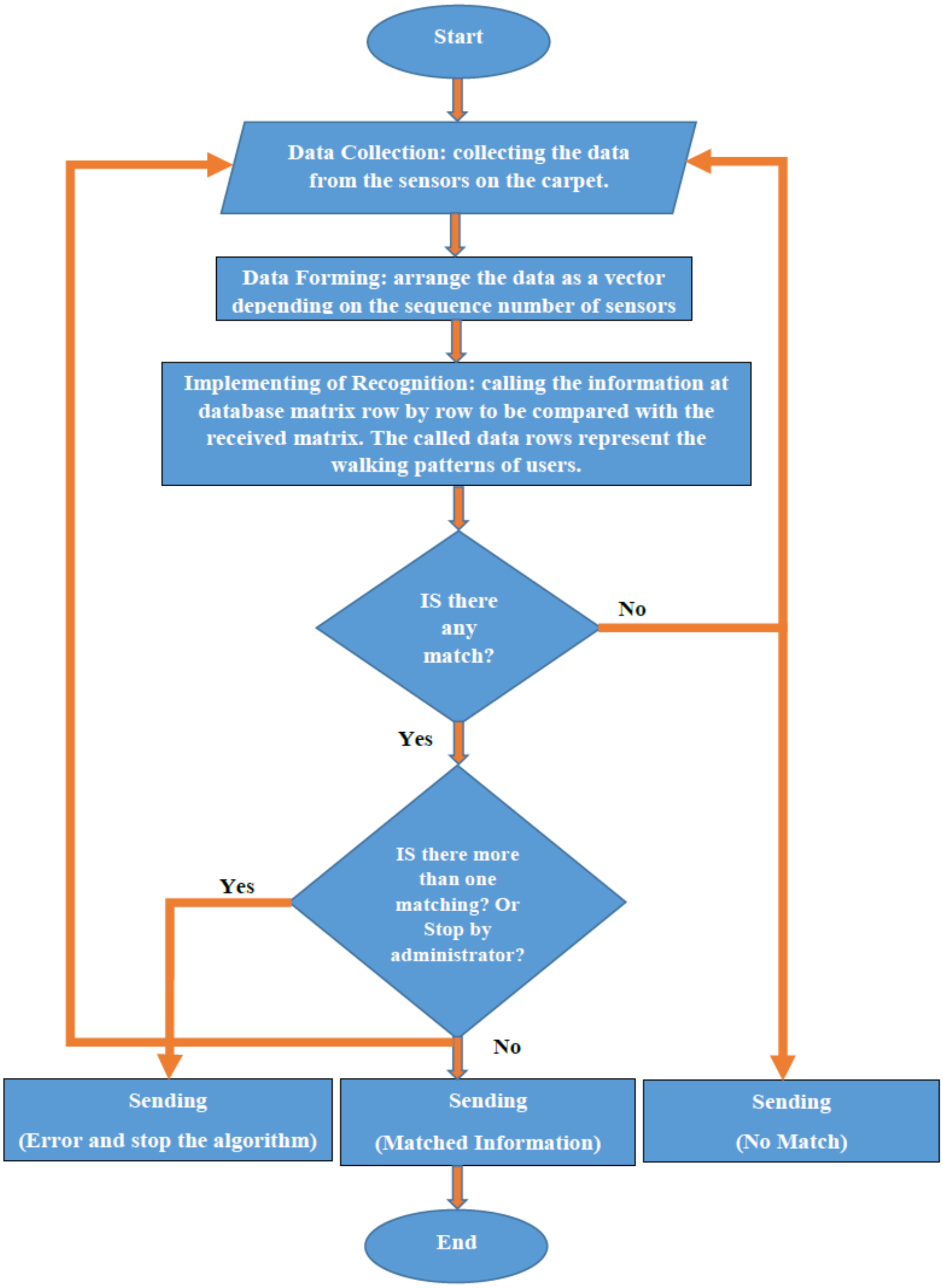
Third level is called "Preparing the decision" that sends the response of the proposed algorithm to the entrance for deciding the preventing or allowing the object from entering.

The Proposed Recognition Algorithm

It can be concluded that the core of the proposed system is the recognition algorithm [4]. This algorithm has been explained in the flow chart of Fig. 4. We can notice that the flow chart contains seven steps excluding the start and end.

The first step of the algorithm is collecting the sent data from the involved weight sensors. The receiving of data can be done using one of communication systems available in the environment, such as mobile network, ZigBee technology and wired network. The adopted method in this work is the wired data communication network.

The second step, called Data forming, reforms the received data in a vector forming represent the walking pattern of each user individually. The forming process includes the filling of the reading data to the correct location at vector for comparison with database information. The third step represents the core of the algorithm which is the recognition process. This can be done by matching the entered data of an intruder with the database and producing the decision. The positive decision is matching and the related information of the recognized person. On the other hand, the negative decision returns the no matching message. After that the algorithm can repeat the process according to the number of intruders. The comparison is done by checking the identically of received data with stored information row by row, where each row represents the walking pattern of a user. It is important to note that in case of appearing more than one matching records; the algorithm stops the operation and gives alarm signal to the administrator. I addition, the administrator can stop the algorithm operation, which leads to stop the system manually.

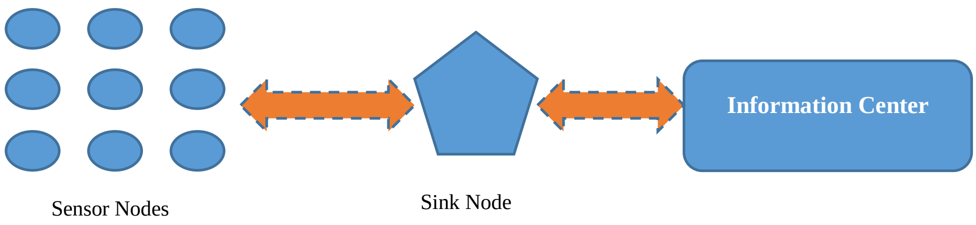


Figure(4). Flow chart of the proposed recognition Algorithm

Sensor Network Structure

As highlighted above, the adopted networking method is wired sensor network. Fig. 5 shows the designed network that includes three main stations. These stations are sensor nodes, sink node and information center [6]. The data is transmitted in both directions from the sensors to the information center and the opposite way.

The designed network is assumed to be in short distances and then there is no need for repeaters. In addition, the number of nodes in the network is quite small and therefore, the need for routers is rear.



Figure(5) Wired Sensor Network

Statistical Analysis

As mentioned earlier, a statistical analysis of a sample of people has been considered to evaluate the acceptability of the proposed system by them. This is important step before implementing this system in real life. The sample is taken by different age and cultural levels from the employees at University of Technology. The questioner form focuses on the health issues and ease of use. The mean of health issues is the problems of diseases transfer happened by finger print and eye recognition methods. In addition, the ease of use in terms of passing over a carpet and taking the finger print and eye scan processing [15]. Fig. 6 shows the questioner form.

Questioner Form for University of Technology Sample Walking Step Recognition		
No		
Name	Age	Position
Degree	Marital Status	No. of Children
Which of the following recognition methods you prefer in terms of health issues and ease of use? *(please tick the right answer)*		
Walking Recognition		
Eye Recognition		
Finger Print Recognition		

Figure(6) Questioner form for sample

Table 1 shows the age classes and the total number of people for each as well as the responses. It is shown that the total number of employees in the selected sample is 100 and each class has individual number and responses. It is important to note that WR is walking recognition, ER is eye recognition and FPR is finger print recognition.

Table (1) Statistical Evaluations

No	Age Class (year)	Total Number	No. of WR selection	No. of ER selection	No. of FPR selection
1	25-34	50	42	5	3
	35-44	30	25	3	2
	45-54	10	8	1	1
	55-64	10	5	2	3
Sum		100	80	11	9

To evaluate the mean values of the classes, which is reflected on the outcome results that show the acceptance of the proposed system, Table 2 has been found to compute mid-point and frequencies of each class [15].

Table (2) Statistical class evaluation

No	Age Class (year)	Mid-Point (X_i)	Frequencies (F_r)	Frequency Ratio (F_x)	Cumulative Ratio
1	25-34	30	42	0.525	0.525
2	35-44	40	25	0.312	0.837
3	45-54	50	8	0.1	0.937
3	55-64	60	5	0.0625	1

where,

$$F_x = \frac{F_r}{A}, \qquad \ldots(1)$$

and ***A***=80 is the total number of people accept the proposed system [15]. In addition

$$Cumulative\ Ratio = \sum F_x(\text{i}) \qquad \ldots(2)$$

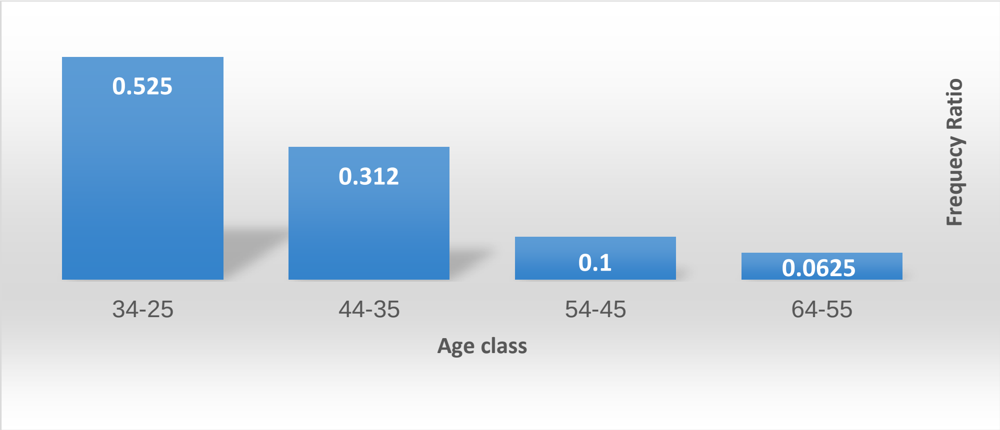
In order to compute the mean of the classes in terms of acceptance ratios of members of sample, the following formula is adopted [15]

$$Mean = \bar{X} = \sum_{i=1}^{N} \frac{X_i F_{r_i}}{\sum F_{r_i}} \qquad \ldots(3)$$

$$\bar{X} = \frac{(30 \times 42) + (40 \times 25) + (50 \times 80) + (60 \times 5)}{80} = 33.875$$

It is important to note that the class of age (25-34) get the most repetitions in the acceptance level of the proposed system.

Fig. 7 explains the statistical frequency ratio, F_x, of acceptance for the walking recognition system. This ratio has been adopted from Table 2 [15].



Figure(7) Chart of acceptance frequency ratio versus age class

Simulation System Setting and Results

It is important to verify the efficiency of the proposed systems. This can be done by testing the designed systems using simulation software before the step of hardware implementation to reduce the cost and time. In this work, MATLAB simulator has been adopted. For more sense in the meaning of explanation, this Section is divided into sub-Sections as follows.

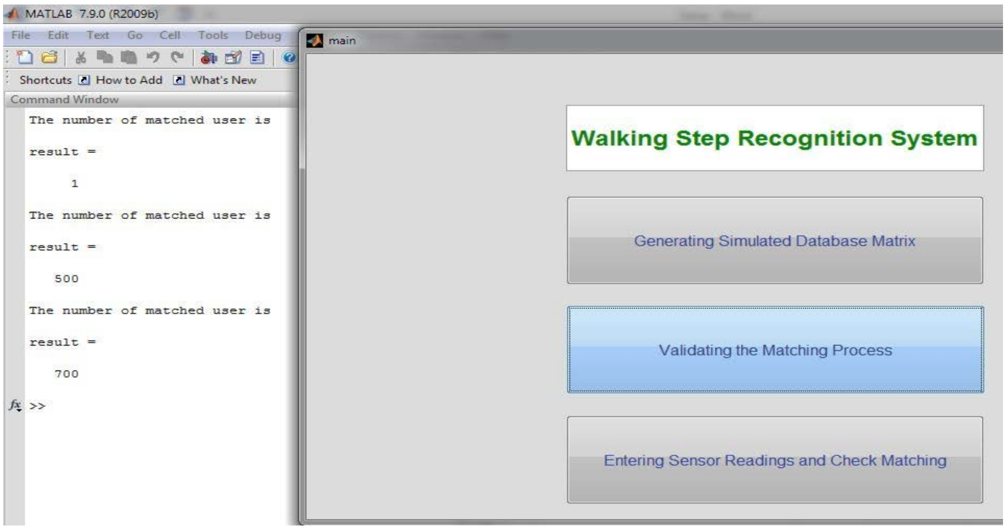
Simulated System Setting

As mentioned earlier, the proposed system consists mainly of the carpet that represents the covered area, wired sensor network, and the information center. Fig. 8 explains the Graphical User Interface (GUI) of the proposed system and the main three buttons for the functions in the proposed systems, which do the following:

Figure(8) GUI of the proposed system

Generating Simulation Database Matrix: The function of this button is generating the simulated database matrix for, $K=1000$ users and each user has two dimensions matrix. The columns represent the, $S=10$ weight sensors distributed along the carpet as a vector. Additionally, the rows refer the number of walking tries. As highlighted above, we record different walking pattern for each user to cover the effects of distinct modes. In this work the adopted number of tries is, *T=10*. The random generation can cover the wide range of people walking in terms of weight and distances between walking steps for different people.

Validating the Matching Process; this button is used to verify the operation of the proposed algorithm. This can be done by capturing some selected reading data of sensors for users and then match them with the database matrix. If the response is positive this can be considered the right indicator to the efficiency of the proposed algorithm. Otherwise, there are some errors and the responsible should find out the wrong. Moreover, the matched results include the information of the intruder. Fig. 9 shows the run of this push button. One try for three users has been considered, which are k=1,500, 750. The matched results verify the expected response.



Figure(9) Validating the Matching Process

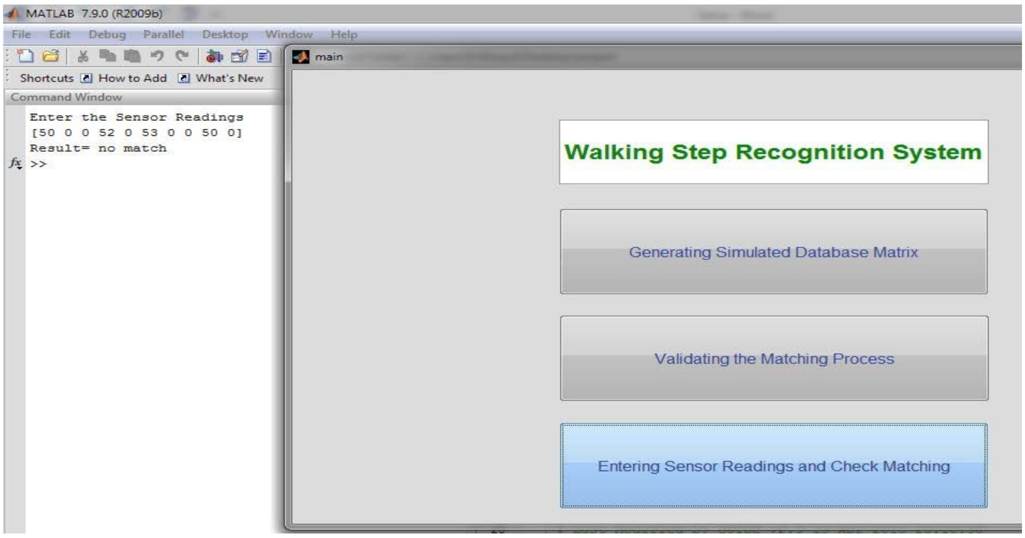
Entering Sensor Readings and Check Matching: The function of this push button is to read the current readings of the pressed sensors for matching. In the simulation, we do it manually as vector values and then the operation of matching is begin. Therefore, we should enter ten values as the number of sensors is assumed to be *S=10*. The response also can be either match or no match depending on the entered and saved database. Fig. 10 explains the process of entering the readings of sensors as a vector.

It is important to note that the designed simulated system is extendable for any number of users, tries and sensors. In addition, it is reliable and secure if an extra security level, such as algorithm or methods, is added. This is to verify the security of data that belongs to people.

Generated Database Matrix

As explain previously, the database matrix has been generated using MATLAB simulator. In this sub-Section samples of this matrix for different users are shown as follows:

Tables 3-5 introduce the two dimensions matrix of user *k=1*,500 and 750, where the rows are the walking pattern tries, *T=1,…,10*, and the columns are the readings of sensors, $S=1,\ldots,10$. It is shown that the values of the sensors' readings can be varied accordingly with the pattern tries of each user. This is due to the type of walking and person's mode as well as the pressing method on the weight sensors. In addition, it is noted that the patterns for each user can be changes with the tries significantly due to the start and end walking step allocation. Furthermore, there are numerous tries appear the same as it is the normal walking pattern for the each user.



Figure(10) Entering Sensor Readings and Check Matching

Table(3) User 1 Sensors' Readings

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
T_1	0	54	0	54	0	54	0	55	0	56
T_2	56	0	56	0	55	0	55	0	54	0
T_3	0	55	0	56	0	56	0	55	0	56
T_4	54	0	56	0	54	0	56	0	56	0
T_5	0	56	0	55	0	55	0	55	0	55
T_6	56	0	54	0	56	0	55	0	54	0
T_7	0	54	0	55	0	56	0	55	0	56
T_8	54	0	55	0	55	0	55	0	54	0
T_9	0	55	0	54	0	56	0	56	0	54
T_{10}	54	0	54	0	55	0	56	0	56	0

Table (4) User 500 Sensors' Readings

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
T_1	59	0	59	0	59	0	58	0	58	0
T_2	0	58	0	60	0	60	0	60	0	58
T_3	59	0	59	0	60	0	59	0	59	0
T_4	58	0	59	0	59	0	59	0	58	0
T_5	0	58	0	58	0	58	0	59	0	58
T_6	59	0	59	0	58	0	60	0	59	0
T_7	0	60	0	58	0	58	0	60	0	60
T_8	0	59	0	58	0	60	0	60	0	60
T_9	58	0	59	0	60	0	60	0	58	0
T_{10}	59	0	59	0	58	0	60	0	60	0

Table (5) User 750 Sensors' Readings

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
T_1	80	0	80	0	79	0	80	0	80	0
T_2	0	79	0	79	0	79	0	79	0	80
T_3	0	81	0	79	0	81	0	81	0	80
T_4	80	0	81	0	79	0	79	0	80	0
T_5	0	79	0	81	0	79	0	81	0	79
T_6	0	79	0	79	0	80	0	80	0	81
T_7	81	0	80	0	81	0	79	0	79	0
T_8	81	0	79	0	80	0	79	0	81	0
T_9	80	0	79	0	79	0	79	0	80	0
T_{10}	81	0	79	0	79	0	79	0	81	0

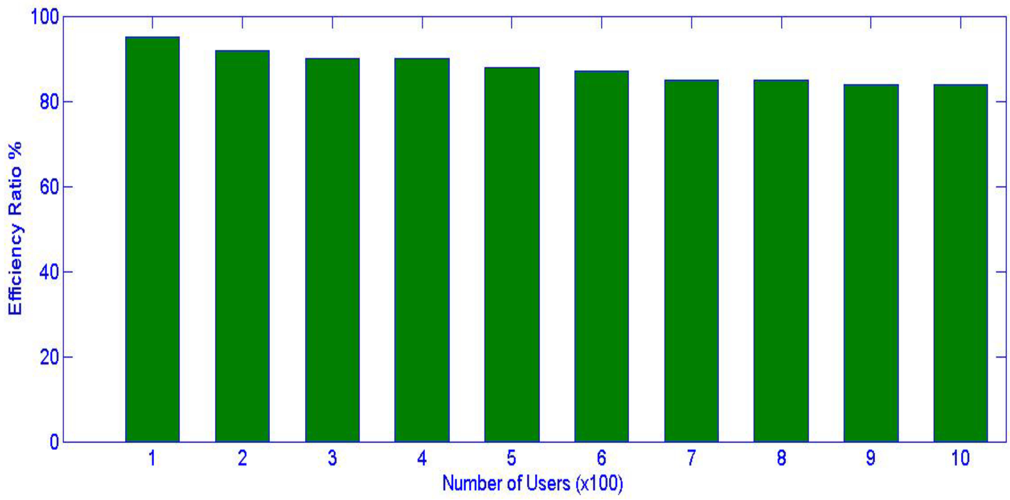
Recognition Efficiency

The completion of the simulations for the proposed system is verified by producing the efficiency of the underlying system. Different number of users has been considered in the simulation to evaluate the efficiency using the following formula:

$$Efficiency = \frac{No\ of\ correct\ matching}{Total\ number\ of\ matching} \times 100, \qquad \dots(4)$$

From Equation 1, we can find that the efficiency is a ratio without unit and has been computed for huge number of matching process for each group of users.

Fig. 11 shows the efficiency ratio for different number users. It is noted that the efficiency has been reduced with the increasing of the number of users. This is due to increase the number of similarity positively with the number of users, in which the reduction of the efficiency ratio is considered with the acceptable ranges in the recognition methods, such as eye and fingerprint, which is over 80% [1]-[2]. Accordingly, it is noted that the error ration is appeared to be fixed after 900 users, which is almost 85%.

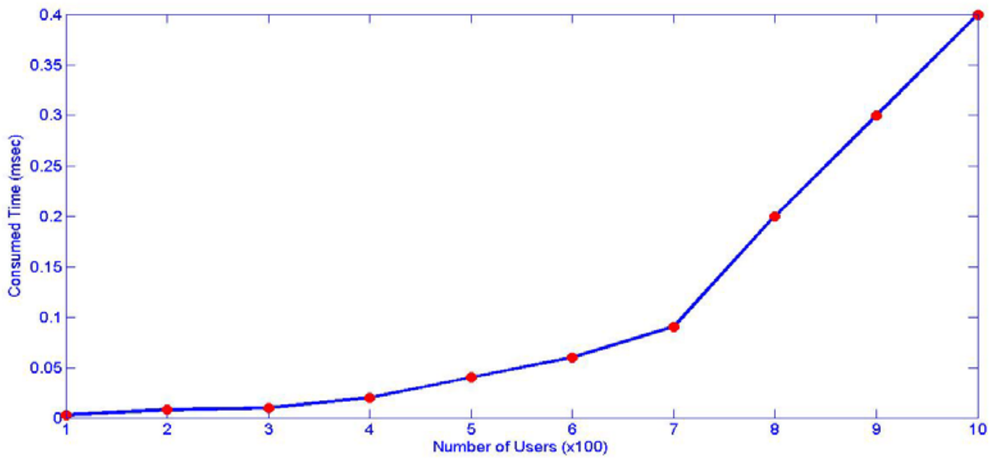


Figure(11) Efficiency ratio versus number of users

In addition, the reduction in the efficiency with the raising of user's number is normal and it is the result of repeating the random generation to the same walking pattern in the database matrix. Additionally, the similarity in the position and values of walking pattern for different users may lead to errors in matching procedure which results in wrong decision.

Matching Speed

The speed of finishing matching process is considered as the important indicator for efficient systems. Therefore, the use of (tic toc) function in MATLAB produces the required time for giving the results in terms of user's number. Fig. 12 illustrates the consumed time required for processing the matching process. It is noted from the figure that there is a sharp increasing in the time consumed for processing. This is due to the MATLAB software that suffers from problem in memory management for high level of matrix dimensions data, which lead to delay in processing and results in the sharp increasing of running time.



Figure(12) Consumed processing time versus the number of users

Conclusions

In this work, a walking human step recognition system has been proposed based on a reliable algorithm. The aim of the proposed system was to recognize people, who passed over a designed carpet. The aim was achieved as explained in the resulting figures in terms of matching efficiency, time consumed and error ratio. The designed carpet that has two layers and sensors, contained several weight sensors that connected in a wired network. The introduced system included three levels. These levels were covered area (carpet), transmission network (wired sensor network), and information center. The last level applied the proposed walking pattern recognition to decide whereas the intruder included in the database or not. There were two different decisions; positive with matching and related information, as well as the negative with no matching. The proposed system has been designed and implemented in the environment of MATLAB simulator. This is to simulate the whole system as a step before real-time implementation. The database data has been generated using MATLAB in three dimensions matrix as users, walking patterns (sensors' readings), and number of tries. These tries have been recorded to each user at different modes and times to simulate the possible walking patterns that can be affected by surrounding circumstances. On the other hand, a statistical analysis has been obtained based on sample of 100 persons to find out if the system is accepted by people. The outcome results showed the high ration of acceptance by people in terms of low health risks.

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