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A Reliable Gait Analysis Using Fuzzy Logic

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Abstract. In this paper, an artificial intelligence technique which is fuzzy logic is used as an online prediction of a patient (especially Alzheimer patient) motion status. It depends on the input variables: GPS, GPRS, accelerometer, gyroscope, temperature, heartbeat rate, and the motion status (standing, walking, and running) as an output variable. Fuzzy logic can detect the motion status based on 385 rules for all inputs and output variables. A low-cost smart shoe with embedded positioning tracking is implemented based on sensors and microcontrollers to help Alzheimer patients. The first phase of the experimental work is based on GPS, GPRS, GSM, accelerometer, heartbeat rate sensor, temperature sensor, and a microcontroller, mounted on the shoe side to navigate according to the pedestrian or patient movement. All sensors data are collected by the microcontroller and are transmitted to the GSM receiver in SMS message. The GSM module is connected to the PC via a USB serial port. Transmitting data is periodically sent upon a specific time. The detected data is stored in the database as a function of time. The data includes the position of the patient (latitude and longitude) located on the Google map software, health status (heartbeat rate), gyroscope and accelerometer (x, y, z) of movement as a function of time.

Keywords: Gait Analysis, GPS navigation, Accelerometer, Gyroscope, Visual Basic, Fuzzy Logic.

1. Introduction
Detection of abnormalities in gait phases has been a great issue. Gait analysis systems have been developed during the past years to detect and solve the causalities human gait motion [1]. Human gait has many phases that can be detected by developed algorithms. The initial contact is the instant when the foot contacts the ground, the heel touches the ground. The second phase is the loading response which is the initial double stance period. It begins with the initial contact and continues until the other foot is lifted for a swing. The midstance phase begins with the end of loading response as the other foot is lifted from the ground and continues until the body weight is aligned over the forefoot. The terminal stance phase begins with the heel rise and continues until the other foot strikes the ground. The pre-swing phase begins with the final contact of stance and the initial contact of the other foot’s limb. The swing phase is the last phase of the human gait and the foot does not touch the ground.

The main objective of this paper is developing a robust gait analysis algorithm based on Fuzzy logic intelligence technique. This paper, additionally, proposes a wearable low-cost smart shoe that can be used for numerous guidance and health monitoring applications. This can be used for Alzheimer patients to allow their family members for tracking them 24 hrs, different designs are introduced. The paper provides a complete design that can be used for guidance, navigation, gait analysis and health monitoring applications.

A wearable GPS shoe based on Arduino microcontroller for pedestrian navigation is designed. The GPS traces latitude and longitude of the shoe. Its present location is mapped on LabVIEW software. The GPS module is connected to the Arduino microcontroller. The latitude and longitude are
fetched by GPS and are transmitted via a Zigbee wireless network connected to a personal computer. The pedestrian navigation is described based on NavCube, which has been designed to carry a wide variety of navigation sensors [2]. The data from these sensors are sent to a base station. On the other hand, the receiver collects the latitude and longitude and send them to the LabVIEW, which depicts the exact location of the object [3]. A dynamic pattern is extracted. The personal mobile sends latitude, longitude, and time on a geographical information system (GIS) [4]. The experimental results show a clear discrimination of patterns between static and dynamic patterns.

The remainder of this paper is organized as follows. Section 2 describes the system design, including the system modules and the software tools. The obtained results are displayed and discussed in Sec. 3. This is followed by the main conclusions in Sec. 4.

2. System Design
The smart shoe is designed for Alzheimer patient, old adults, kids, and retarded persons for better health and security. The block diagram in Figure 1 shows the outline of smart shoe design.

![Figure 1. Block diagram of smart shoe design.](image)

The components of the design are as follows.
1. Heart pulse Sensor 5EN-11574 [5].
2. Gyroscope, Accelerometer, and Temperature Sensor (MPU-6000/MPU-6050) [6].
3. GPS SKM 53 Module [7].
4. GSM (SIM 900 GSM/GPRS Module) [8].
5. GPRS SIM808 [9].

The software used includes:
1. Embedded "C" for microcontroller programming.
2. Visual Basic for display on the PC screen.
3. Eagle Simulation.
4. MATLAB fuzzy logic toolbox.

The first phase of experimental work is performing the smart shoe module as follows. The transmitter GSM module sends the data to the receiver GSM module through an SMS message. Then, the GSM module in the receiver transmits the data to the microcontroller of the receiver circuit. This
microcontroller receives the data store it. Then, it transmits this data to a hyper terminal program on a PC connected to the internet through a USB to serial cable. The hyper terminal program then organizes the data and displays it on a designed visual basic program.

In the visual basic program, two options could be used. Latitude and longitude are displayed on Google Earth. Google Earth then starts searching for the provided latitude and longitude and shares the exact location, making it easy now to locate the person suffering from Alzheimer.

3. Results and Discussions
The system is designed for tracing and monitoring the patient during movement and to collect data manually or automatically at a certain time. On the display screen, there are three outputs from GPS (latitude and longitude), Gyroscope (GX, GY, GZ), and accelerometer (AX, AY, AZ) and also the patient health status (heartbeat rate). Anyone of these outputs can be chosen to monitor it on the screen as a function of time. The program starts when you click on start and the microcontroller begins collecting the data from all the sensors and stores it as shown in Figure 2.

![Figure 2](image)

Figure 2. Block diagram of the second phase of work.

The data being stored is transmitted through the serial cable and is displayed on a text file in the PC. The readings are collected at different states; in case of standing, walking, and running.

Fuzzy logic is used for detecting the state of motion based on a handheld device are applied. In each experiment, 77 readings are collected and stored. The input parameters of the fuzzy logic algorithm are the readings of the accelerometer in (x, y) directions, gyroscope in (y) direction, heartbeat rate. The output of the fuzzy algorithm determines the motion state. All detected data are stored in a text file. An artificial intelligence technique is used as the online prediction for the motion state based on fuzzy logic.

4. Prediction of Patient Health Status Based on Fuzzy Logic
A Fuzzy Logic (FL) technique is used as on hire prediction of the output status and classification. The FL has the ability to mimic the human mind by employing modes of reasoning that are approximate rather than exact. It is based on If-Then Rule and is one of the tools that can be used to model multi-input, multi-output systems. It depends on a set of membership functions for the input and output variables.
The fuzzy inference process can be described in five steps:
1. Fuzzy inputs and outputs variables via membership functions.
2. Apply fuzzy operators; the degree to which each part of the antecedent has been satisfied.
3. For-Each rule.
4. Apply the implication method.
5. Aggregate all outputs.

Defuzzify the output of the defuzzification process is a crisp value [11], [12-14].

Four input variables are used based on Mamdani fuzzy controller which are accelerometer (AX, AY), gyroscope (GY) and heartbeat rate. One output variable is used which is the motion state (standing, walking, running). Each parameter has 77 rules, Mamdani-Type fuzzy controller with aggregation method using “AND” gate with the input variables and “OR” gate for the output variable. Then, a defuzzification process is carried out by using the centroid method to get the decision [15, 16].

Figure 3 shows the membership function for all inputs (AX, AY, H, GY) and the output state of motion (standing, walking, running) based on a triangular membership function. Table 1 shows the minimum and maximum values for all readings out of 385 for each parameter which is called universe of discourse.

Table 1. Minimum and maximum values of variables.

<table>
<thead>
<tr>
<th></th>
<th>AX</th>
<th>AY</th>
<th>H</th>
<th>GY</th>
<th>Motion State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>-0.01</td>
<td>-0.14</td>
<td>65</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>0.83</td>
<td>0.95</td>
<td>238</td>
<td>150</td>
<td>1</td>
</tr>
</tbody>
</table>

Figures 4-a, 4-b, 4-c, 4-d represent all inputs simultaneously, (AX) acceleration in x-direction, (AY) acceleration in y-direction, (H) heartbeat rate, and (GY) gyroscope in y-direction. Figure 4-e displays the output variable which is the motion state (standing, walking, and running).
Using MATLAB fuzzy toolbox and by entering 385 rules from the recorded measurements, the Mamdani controller method is implemented for all rules in linguistic variables IF-Then Rules for all input and output variables. The centroid method is applied to get the crisp output shown in Figure 5.

The predicted fuzzy output surface which is called defuzzification is presented in Figures 6-11, simultaneously, discriminating the three cases of motion. Upon the conditions of the experimental work, the output surface of standing state at 0.25 threshold level, while the threshold surface of walking state is at 0.5, and the threshold of running state is at 0.85.
5. Conclusion
A simple and cost-effective smart shoe is designed and implemented. GPS, gyroscope, accelerometer, heartbeat rate, and PIC microcontroller are used. The software used includes embedded C, Visual Basic, Eagle, and MATLAB. An artificial intelligence technique based on fuzzy logic is used to give online prediction of the person moves. Fuzzy logic can detect the motion status based on 385 rules for all inputs and output variables. It depends on the input variables from the accelerometer, gyroscope, and heartbeat rate. Its output is the motion status (standing, walking, and running). This implemented design can be applied in various cases such as shoes assisted device for elders, Alzheimer patient, pedestrian, kids, pregnant woman, diabetic patients, disorder patient, and monitoring of people health in daily life.
References


