Labview-based Gait Analysis System for Rehabilitation Monitoring

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Abstract

In this paper, a newly approach of human gait analysis for rehabilitation monitoring is presented. We developed a prototype for the gait analysis system and display the gait pattern by using LabVIEW software tool. The analysis is carried out by using the gait analysis hardware (GAH) that complete with sensory board, ultrasonic and wireless communication system. There are two types of system which are Gait Analysis Software Ultrasonic (GAS-US) and Inertial Measurement Unit (GAS-IMU) have been simulated to get minimum foot clearance (MFC) and orientation measurement. For the complete solution with the feature of error correction, both of GAS-US and GAS-IMU have been combined to perform a gait analysis system. The gait patterns that produce by the systems is displayed and achieved the rapid analysis of human gait by using LabVIEW.

1. Introduction

Stroke is the leading cause of disability in older people [1]. Around 75% of patients who have experienced a stroke have difficulty on carrying out basic activities of daily living and above 50% have struggle walking [2, 3]. Once the patient started to struggle walking, the rehabilitation will be hard to perform. Therefore, patients need to be monitored continuously and accurately by rehabilitation center. With the assist of the rehabilitation monitoring system using LabVIEW, the patient can be recovered in a shorter period. The LabVIEW has been chosen because of its proven performance, industry standard and also widely accepted. In LabVIEW, the graphical user interface (GUI) can be categorized into two types, namely front view and block diagram. Front View is basically the page that can be viewed with button etc. The block diagram is the individual algorithm associated with the button on the page. In LabVIEW, user needs to set the instructions for program execution using the dataflow...
execution order block diagram while all the user interface are build up using the graphical representation of function at the front panel section. The block diagram consists of a set of graphical representation of functions that are used to control the front panel objects. All front panel objects are appearing as terminals on the block diagram. The terminal on the block diagram is a data type either the data control or the data indicator. The wire is used to transfer the data by connecting the terminal to the graphical representation of function. While running, the front panel appears at the front and the block diagram is hidden at the back. The front panel consists of a set of control and indicator objects which is a user interaction of input and output object. The control object control the input data and the input of instrumentation device, while the indicator object is represents the display of data generated or acquired and the output of instrumentation device.

### Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>θ</td>
<td>Foot Angle</td>
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<tr>
<td>ϕ</td>
<td>Phase</td>
</tr>
</tbody>
</table>

#### 1.1. System Configuration

Three types of GAS were used. The custom designed software are GAS-Ultrasonic (GAS-US), GAS Inertial Measurement Unit (GAS-IMU) and GAS-Combination of Ultrasonic and IMU (GAS-COM). The GAS-US is focused on the ultrasonic system to measure the foot clearance. In order to get the better result of the foot clearance, the algorithm of ultrasonic measurement error need to be included. For the GAS-IMU, a MEMS IMU sensor comprises of accelerometer and gyroscope is used for foot orientation measurement. This paper proposed a new idea where the GAS-US and GAS-IMU are integrated together in order to produce the gait analysis for rehabilitation monitoring. The GAS-COM is custom designed software for the shoe attachment unit as shown in Fig 1.

#### 1.2. GAS-Ultrasonic (GAS-US)

GAS-US is specifically designed to display the ultrasonic measurement result in LabVIEW using the shoe attachment unit and it customized for the Gait Analysis Hardware development. The work started with small sensory board and it is compatible for any shoes using Velcro strap. The board is attached on the shoes and operates wirelessly with a 9V power supply. Thus, the system can be operated immediately.

The objectives are to capture the gait pattern and foot movement of the patient during rehabilitation period. The pattern can help the doctor to identify weakness and thus improve the patient condition. The considered parameters are foot clearance, minimum foot clearance and toe off point. Once the device is powered, the sensory board will transmit wirelessly the data continuously and the recorded data in the database can be viewed as a real time gait pattern graph. The graph is displayed using the custom designed Gait Analysis Software.
In GAS-US as shown in Fig. 2, the graph plots the foot clearance versus time. From the graph, the minimum foot clearance and toe off can be determined based on [4]. It is suggested that several patterns were captured to get the average value for toe off and minimum foot clearance, MFC in order to get the accurate data for both parameters [4]. The parameters to be displayed can be changed even during the running of the software according to user requirement. There are three patterns which are strip chart (similar to a paper tape strip chart recorder), scope chart (similar to an oscilloscope display) and sweep chart (similar to an electrocardiography display). The clearance reading also can be viewed as numeric data in millimeter unit.

Fig. 2. The Walking Graph of Gait Pattern Using Ultrasonic Sensor

Fig. 3 shows the block diagram for GAS-US. The block diagram is divided into three parts namely baud rate, match pattern and graph. Baud rate is the amount of data transferred for wireless communication protocol. The data transferred will be filtered by the match pattern. Data transferred that contains header letter U only be accepted. The letter U symbolize for ultrasonic sensor data. Finally, the accepted data will be sent to the graph section and will be displayed as graph in the front view.

Fig. 3. GAS-US Block Diagram
1.3. GAS-Inertial Measurement Unit (GAS-IMU)

The research has recognized few errors arisen during gait measurement reading especially during toe off and landing phase. The placement of ultrasonic to the ground and the vibration of ultrasonic sensor are factor for the errors to happen. So, in order to unravel the problem, the research proposes a new invention which is uses IMU Sensor to compensate the error reading of ultrasonic measurement. The method of acquiring IMU data is same with the Ultrasonic data acquisition. This GAS-IMU is custom designed to use with Gait Analysis Hardware. Fig. 4 shows the GUI for GAS-IMU and also the graphical output when the patient is walking.

![Fig. 4. The Running Graphs of Gait Pattern Using IMU Sensor without Ultrasonic Sensor (Graph Degree versus Time)](image)

The outputs from the IMU sensor consist of roll, pitch, and yaw. The combination of roll, pitch and yaw data versus time are also plotted in one graph. The capability to produce separate graphs is also considered to make it easy for the user to analyze the gait pattern by individual orientation. Meanwhile, the combination graphs permit the user to analyze all three orientation of gait pattern simultaneously. Fig.5 shows the GAS-IMU block diagram that consists of baud rate part, match pattern part, graph part and additional algorithm part. This additional algorithm part is where the raw data from the IMU is converted to the value in degree using C Language.

![Fig. 5: GAS-IMU Block Diagram without Ultrasonic Sensor](image)
1.4. GAS-Combination of Ultrasonic and IMU (GAS-COM)

The GAS-COM is a complete solution for clearance measurement with features of error correction. From the GAS-COM, the orientation and distance of the human foot to the ground can be determined. Basically, the GAS-COM is the combination of GAS-US and GAS-IMU. The GAS-COM are user friendly, easy accessible and well organize. The error correction is an algorithm used to correct the error of foot clearance value using trigonometry concept. This error is occurring when the position of ultrasonic is not perpendicular to the ground during toe-off, landing, stance, and swing phase. Fig. 6 shows the feet angle (φ toe-off) during toe-off phase where the distance measured is not the actual foot clearance. Because of this situation, the IMU sensor was used to measure the pitch angle (φ toe-off). The calculation for this situation is state in Eq. 1.

\[
c_{\text{toe-off}} = a_{\text{toe-off}} \cos \varphi_{\text{toe-off}}
\]

Fig. 6. Feet Angle (φ toe-off) During Toe-Off Phase (a) and equation.1 (b)

Fig. 7 shows the foot angle (φ landing) during landing phase where the distance measured is not the actual foot clearance. Same like toe-off phase, this situation also used the IMU sensor to measure the pitch angle (φ landing). The calculation for this condition is stated in Eq. 2.

\[
c_{\text{landing}} = -a_{\text{landing}} \cos \varphi_{\text{landing}}
\]

Fig. 7. Feet Angle (φ landing) During Landing Phase

Fig. 8 shows the error correction algorithms that are build up in block diagram page. The Eq.1 and 2 are programmed into the formula box.
Table 1. Technical Parameters for GAS-US and GAS-IMU

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>PARAMETERS</th>
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<tbody>
<tr>
<td>GAS-US</td>
<td>Ultrasonic Foot Clearance</td>
</tr>
<tr>
<td>GAS-IMU</td>
<td>Orientation of roll, yaw and pitch</td>
</tr>
</tbody>
</table>

2. Result

2.1 Analysis of GAS-US System

Fig. 9 shows the gait pattern for walking subject using GAS-US System. From the graph, the gait pattern based on foot clearance is determined in millimeter. From the foot clearance, the MFC data, toe off data and landing data is determined. The gait pattern captured is proved based on the previous study in [4]. The Gait Analysis Hardware is attached to the subject shoes and the subject walked during their daily activity. This experiment is conducted out of laboratory to ensure this system can be used in real life. In this GAS-US System, the error correction algorithm features is not implemented.

Fig. 9. Gait Pattern for Walking Subject using GAS-US System

The developed system is successful in displaying the gait pattern of subject during walking. The GUI shows the several cycle of gait pattern including the gait phase such as MFC, toe off and landing phase. However, the measurement still incorrect due to the offset start reading point and the angle of feet during walking. The GAS-US System gives the direct distance reading instead of the foot clearance reading. But the successful display of the gait pattern of subject during walking is shows the applicability of the system. The captured gait pattern and data collected from GAS-US System is a solid prove that the GAS-US can be used for gait analysis measurement. Fig. 10 shows the similarity of the gait pattern captured by GAS-US System and the gait pattern captured by [4].

Fig. 10. (a) Gait Pattern by Begg’s [4] and (b) Gait Pattern by GAS-US System
2.2 Analysis of GAS-IMU System

GAS-IMU System is the combination of GAH with GAS-IMU. Fig. 11 shows the gait pattern for walking subject using GAS-IMU System. This system is used to study the gait pattern from the IMU sensor measurement and compared the gait pattern captured during walking with the gait pattern from GAS-US System. Similar with the analysis of GAS-US System, this system also analyse the gait pattern based on foot clearance but the data displayed in degree. The GAH system is fixed on top of attachment unit and attached to the subject shoes. The subject is walked during their daily activity.

![Gait Pattern for Walking Subject using GAS-IMU System](image)

The gait pattern in Fig. 12(a) is careful analysed and observed. The GAS-IMU System is acceptable to be used in gait analysis measurement because of the collected gait pattern is almost similar with the previous study in [5] as shown in Fig. 12(b).

![Gait Acceleration Signal Gafurov’s [5] and (b) Gait Signal by GAS-IMU System](image)

However, the reading is slightly different to the gait pattern captured due to the positioning of the sensor. As study in [5], the sensor is attached at the lower leg. But the Gait analysis hardware is attached at the front of shoe and parallel to the ground. So, the clearance measurement is more accurate compared to the gait in [5]

2.3 Analysis of GAS-COM

Fig. 13 shows the gait pattern for walking subject using combination of ultrasonic sensor and IMU sensor. For this system, the data collected is more detail compared to the previous system. The system will analysed the gait pattern based on foot clearance that classified to gender, feet, age range, and toe off phase, MFC phase and landing phase. The data collected from a group of subjects are presented in Table 2. The system is fixed on the shoe attachment unit and attached to the subject shoes. To ensure this system can be used for rehabilitation of patient, this experiment is conducted out of laboratory. In this version, the error correction features is applied where
the error correction features is the new approach for foot clearance measurement which is being the innovation of this research.

Fig. 13. Gait Pattern for Walking Subject using Ultrasonic Sensor combined with IMU Sensor

Table 2. Data classified of sensor, feet, age range, and toe off phase, MFC phase and landing phase.

<table>
<thead>
<tr>
<th>Condition</th>
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<th></th>
<th></th>
<th></th>
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<tr>
<td></td>
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4. Conclusion

In this paper, we constructed a prototype for human gait analysis system for rehabilitation using LabVIEW software tool. From the analysis done on different system of GAS-US, GAS-IMU and GAS-COM, it is proven that the LabVIEW software tool is capable to display the rapid human gait. From the result, the data collected in GAS-COM is more detail than GAS-US and GAS-IMU.

References