Real-time Gait Monitoring System for Consumer Stroke Prediction Service

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Abstract—Gait monitoring is considered as a significant marker of disability, injury, and gait symmetry. The goal of this study is to develop a real-time consumer health monitoring system based on IoT sensors and Machine learning technique in order to detect health abnormalities such as, stroke onset. The proposed consumer stroke prediction system consists of IoT based gait monitoring sensors, real-time vital sign monitoring and machine learning based disease prediction model to predict the disordered gait and the healthy gait. This study will be useful for post-stroke gait coordination for rehabilitation and consumer health monitoring service.

Keywords—Stroke, Gait, Health Monitoring, Machine learning Algorithms.

I. INTRODUCTION

With the increased understanding of health and life; as well as advancement of medical technology, Health has become a major point of interest nowadays. For well-being, it is necessary to spend a significant amount of time of daily life on walking, moving here and there [1]. Some health abnormality happens during walking like heart problem, stroke and so on; ability of movement reduces due to health complexity such as stroke [2].

Stroke is one of deadly disease; especially for above the age of 60 years, and its proportion is rising [3, 4]. Many health abnormality happens after stroke. Stroke is the sudden collapse of brain cells due to lack of oxygen, caused by blockage of blood flow to the brain or breakdown of blood vessels [5]. The stroke symptoms are a weakness in the arm or leg or both on the same side, loss of balance, sudden headache, dizziness, coordination problems, vision problems, difficulty in speaking, and weakness in the face muscle [6]. Gait disorders is observed as one of the most common disabilities after stroke [7-9]. Stroke effected persons lose conscience and ability to contact emergency services or hospital. Without immediate detection and treatment of stroke, it is very difficult to prevent and recover complications [10].

For accessing gait pattern of an individual; acceleration, foot pressure are generally measured. In most of case, accelerometer, gyro sensor, insole pressure sensor, pedometer, GPS (Global Positioning System), footswitches are used to capture gait parameter [11]. Several Significant parameters are extracted such as number of steps or walking bout, step time and stride time, step length and stride length, credence, GRP (Ground Reaction Force), speed and so on.

The Internet of Things (IoT) plays an important role in the development of connected people, which offers cloud connectivity, smartphone integration, safety, security, and healthcare services [12, 13]. Several researchers are working to develop IoT based health monitoring system for various purposes [14, 15]. Gait monitoring is one of most interesting application of wearable devices for clinical and daily regular activity monitoring. Gait monitoring is also widely used in healthcare, sports.

Fig. 1. Device Layout of Gait Monitoring System.

This paper focused on briefly explaining classification of Gait patterns of Stroke Patients and Elderly Adults using machine learning (ML) algorithms such as Support vector machines and neural network. Here we also proposed real-time gait monitoring system especially for elderly persons in order to successfully detect stroke onset.
II. CONCEPT AND METHODOLOGY

A. Gait Monitoring System

Proposed Gait monitoring system consists of insole foot Pressure sensor and accelerometer which will be attached to foot as shoe insole for gathering gait speed, foot pressure and other gait signals. Additionally, ECG patch is needed for high risk stroke patients. As shown in Fig. 1, an insole foot pressure and accelerometer are designed and prototyped and tested. Gait pattern such as the gait speed, foot pressure etc. of normal person and stroke patient are significantly different from each other. Stroke patient has unbalanced gait pattern compared to normal person [7]. IoT devices and Machine learning technique are able to detect stroke onset of elderly adults. Entire system will feed subject’s physiological data to cloud engine to compare real-time data and already stored reference data in order to detect stroke. The layout of smartphone Health monitoring application is presented in Fig. 2.

B. System Architecture of Stroke Monitoring System

Physiological parameters are marker for physiological and health status of individual. Fig. 3 shows the overall framework and dataflow of the stroke monitoring system during walking using IoT gait sensor and Machine learning model. Gait sensor data feed to Elasticsearch DB through phone data collection application using BLE and Wi-Fi network. Data context prediction and Gait features extraction are done. Then ML models will be involved in data training and prediction of the disordered gait by analyzing the changes in gait signals. Medical ontology framework will find the possible diseases based on gait disorder. Health advisor will suggest the necessary steps needed to be taken. If there are, any abnormalities in the significantly gait parameter during walking, the stroke monitoring system detects and generates an alarm or messages as a notification to get the timely medical assist. The self-learning engine system consist of Big data, real-time monitoring, network security. The knowledge base system will generate a stroke alert so that the patients can get the timely medical assistance. The various bio-signals can be measured, analyzed and classified using this framework. This study particularly focuses on the Gait signals.

C. Experimental Methodology:

1) Gathering of Gait Data

Gait parameters of 63 Stroke patients and 208 Elderly healthy persons have been measured in Chungnam National University Hospital Rehabilitation Center, Daejeon, South Korea. Gait parameters are foot pressure, gait acceleration and Ground reaction force (GRP). 3ILab sensor used for data acquisition. Subjects walked and perform activities like walking, sitting, standing, doing some regular activities during gait data acquisition. Room temperature was maintained at 24°C and relative humidity 40%.

2) Gait Feature Extraction

Gait features such as, foot pressure, acceleration etc. are most important for disease prediction. Foot pressure and GRP (Ground Reaction force) are extracted from insole pressure signal and foot acceleration data has been extracted from accelerometer signal.
3) Gait Pattern Classification

Machine learning models have been used to classify gait data of stroke patient and normal person. Logistic Regression, Support vector machine (SVM, LSVM) and CART, C4.5, Decision tree algorithms have been used to classify foot pressure, acceleration and GRP data of stroke patients and normal person. 50% Data has been used for training, 30% data for testing and 20% gait data for validation of classification models. Classification process is shown in Fig. 4.

D. Algorithms Overview:

Logistic regression is a machine learning technique for binary classification problems (problems with two class values). Support Vector Machines (SVM and LSVM) is a supervised learning classification algorithm. SVM is capable to build a maximum margin hyperplane that separates two opposite groups [16]. SVM is one of most efficient classifiers widely applied in physiological data analysis. C4.5 and CART are algorithms based on decision tree [17, 18].

III. RESULTS & DISCUSSION

In order to evaluate classification accuracy, ROC (Receiver operating characteristic) curve and Gini coefficient are most effective tools [19]. Classification accuracy of different Machine Learning algorithms are listed as AUC (Area under curve) and Gini coefficient in Table 1. In the training phase of models, it is found that C5.0 model shows highest accuracy (AUC: 0.995, Gini: 0.993)) and CART model results lowest accuracy (AUC: 0.87, Gini: 0.74) among all ML models to classify gait pattern of stroke patients and healthy normal subjects. SVM, Random Tree, Logistic Regression, LSVM shows accuracy more than 90%; AUC: 0.978, Gini: 0.956; AUC: 0.94, Gini: 0.88; AUC: 0.91, Gini: 0.821 and AUC: 0.908, Gini: 0.816 respectively.

<table>
<thead>
<tr>
<th>ML Model</th>
<th>Training AUC</th>
<th>Training Gini</th>
<th>Test AUC</th>
<th>Test Gini</th>
<th>Validation AUC</th>
<th>Validation Gini</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Tree</td>
<td>0.94</td>
<td>0.88</td>
<td>0.935</td>
<td>0.87</td>
<td>0.935</td>
<td>0.87</td>
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<tr>
<td>CART</td>
<td>0.87</td>
<td>0.74</td>
<td>0.866</td>
<td>0.732</td>
<td>0.869</td>
<td>0.738</td>
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<tr>
<td>C5.0</td>
<td>0.995</td>
<td>0.993</td>
<td>0.983</td>
<td>0.967</td>
<td>0.984</td>
<td>0.968</td>
</tr>
<tr>
<td>SVM</td>
<td>0.978</td>
<td>0.956</td>
<td>0.977</td>
<td>0.954</td>
<td>0.976</td>
<td>0.952</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>0.91</td>
<td>0.821</td>
<td>0.908</td>
<td>0.817</td>
<td>0.909</td>
<td>0.818</td>
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<tr>
<td>LSVM</td>
<td>0.908</td>
<td>0.816</td>
<td>0.906</td>
<td>0.812</td>
<td>0.906</td>
<td>0.813</td>
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In data testing and validation phase, classification algorithms show similar trends as training phase. In pattern testing phase, C5.0 model shows highest accuracy (AUC: 0.983, Gini: 0.967) and CART model results lowest accuracy (AUC: 0.866, Gini: 0.732) to classify gait pattern. In final validation step, C5.0 model again shows highest accuracy (AUC: 0.984, Gini: 0.968) and CART model results lowest accuracy (AUC: 0.869, Gini: 0.738) to classify gait pattern of stroke patients and healthy normal.

Poststroke Hemiplegic gait caused by sensory motor impairment makes different gait pattern compared to healthy gait of normal people [20]. Our result predicts this case and classified impaired poststroke gait pattern and normal healthy gait. Real-time IoT gait monitoring and cloud-based machine learning classification of impaired gait and normal gait that will come to help stroke vulnerable people.

IV. CONCLUSION

This study proposes a stroke prediction system using gait monitoring system. Details of sensors, dataflow, system architecture, ML model stroke prediction results are presented. For prediction of stroke in daily activities; such as driving, sleeping and working, other kinds of bio signals such as EEG, Breathing, ECG, EMG are required to be involved in the stroke monitoring system.
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