Abnormal Gait Pattern Recognition of Stroke Patient in Initial Stage Using Smartphone and Hybrid Classification Methods

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Abstract

This paper proposes abnormal gait pattern recognition of Stroke patient in the initial stage using smartphone and hybrid classification methods. Our proposed research is divided into 2 parts: model building for abnormal gait pattern detection and system development. For a model of abnormal gait pattern detection, sensors (accelerometer and gyroscope sensor) on a smartphone are used to collect accelerometer and gyroscope data of gait pattern. Then, data of gait pattern are transformed and selected appropriated attributes to build a model using hybrid classification methods (Multilayer Perceptron, Decision Tree, and Support Vector Machine). From our experiments, the result shows that our proposed method achieved high accuracy of 99.40% for abnormal gait pattern recognition of Stroke patient in the initial stage and compared with previous research using accelerometer and gyroscope. Finally, our research developed a gait stroke detection system for abnormal gait pattern detection. When the system detects abnormal gait pattern, the system will send notification to caregiver and physician to reduce the risk of fall and accidence, especially, in the case of patient living alone at home. In addition, the system can help the physician to diagnose and train the gait pattern of post-stroke patients for rehabilitation.

Keywords: Abnormal Gait, Stroke, Smartphone, Hybrid Classification Methods, Notification.

1. Introduction

Stroke is "a major health problem for elderly people, especially male has the opportunity to occur more than female" [1]. In addition, it always leads to high costs for treatment because it is a chronic health problem. "Incidence of Stroke is increasing trend and in every 2 minutes, it detects new patient or approximately 16% of the global population and in every 4 minutes, the patient will die from Stroke" [2]. The main symptom of Stroke is "hemiparesis, hemi sensory loss, slurred speech, double vision, aphasia, hemianopia, and ataxia. If the patient has these symptoms, the patient should hurry go to meet physician within 4 hours or faster than which include obtaining prompt treatment to save the patient's life and to restore of the body to back to normal or close to normal" [3]. Therefore, symptom monitoring is one way to increase survival rate, especially, monitoring of numbness, sudden hemiparesis, and loss of balance, which is one of the important symptom to indicate Stroke in the initial stage. The aim of our research is abnormal gait pattern recognition of Stroke patient for early Stroke detection and developing a high-performance system to detect abnormal gait pattern of Stroke patient in the initial stage including immediate notification to caregiver and to support diagnosis of physician for further treatment.

There are several techniques for Stroke detection [4], [5],[6]. Each technique has different weaknesses and strengths. However, our research uses sensor on a smartphone based on Android platform to detect the gait pattern of the subject because it has high performance, ease of use, reliability, and affordability. To increase the accuracy and speed of abnormal gait pattern detection, there are several researches using classification method [7], [8]. However, the problem of

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an individual classifier is accuracy. Therefore, various researches are using hybrid classification methods to solve problem of accuracy [9], [10], [11]. From previous research, most of the research focuses on model building, but it still lacks a monitoring system and notification to relative person. While Tiamkao [12] developed a system called "FAST TRACK". The system is divided into 2 functions: ambulance calling and knowledge training about Stroke to people. When patient occurs symptom, patients can call an ambulance. However, this system is not still monitoring the behavior and symptom of the patient including immediate notification to the caregiver. In addition, there are several researches, which developed a system to detect abnormal gait pattern of Stroke patient using smart shoe sensor [13], [14], [15]. However, existing systems have to use devices, which may be expensive and complex to set up. To reduce cost and to increase the performance of detection, it should have system, which is accurate, affordable, reliable, and easy to use to reduce time to meet physician and to reduce rate of disability and death. This gap becomes the motivation of our research.

Therefore, this paper proposes abnormal gait pattern recognition of Stroke patient in the initial stage using smartphone and hybrid classification methods and develop a system to cope with abnormal gait pattern detection. The first step collects accelerometer data and gyroscope data of gait pattern using sensors on a smartphone. Then, these data are used to transform and select appropriated attributes for model building using hybrid classification methods such as Multilayer Perceptron (MLP), Decision Tree (DT), and Support Vector Machine (SVM) based on Majority voting to select the best answer. Finally, the result of model is applied to develop the system. If the system detected an abnormal gait pattern, the system will send an immediate notification to caregiver or physician to reduce the risk of fall and accidents that may occur, especially in the case of patient living alone. In addition, the system is a benefit for physician to support diagnosis and to train gait pattern of post-stroke for rehabilitation.

The existing structure of paper consists of related works, research methodology, experimental result and case study, and conclusion.

2. Related Works

"Stroke is the condition of damaged brain cells because of several causes such as cerebrovascular stenosis, clogged, or brain attack. These causes affect paralysis, disability, and death. In addition, the most of survivor' Stroke patient will have been chancing for recurrent and more severe until cause disability and death" [16]. Elderly people are risk of Stroke more than another group, especially, male is chance of Stroke than female [1]. "The symptom indicates Stroke such as droopy mouth, hemiparesis, hemi sensory loss, slurred speech, double vision, aphasia, hemianopia, and ataxia" [1]. Loss of balance is an early symptom of Stroke, which consider an abnormal gait pattern. Moreover, abnormal gait pattern detection also helps to train gait pattern of post-stroke for rehabilitation. There are numerous researches, which proposed method for Stroke detection, especially abnormal gait pattern detection using classification method to increase reliability, accuracy, and speed of processing [17], [18], [19]. Various classification techniques are used to detect abnormal gait pattern such as Multilayer perceptron (MLP), Support Vector Machine (SVM), Decision tree (DT), and hybrid classification methods. MLP [20], [21] is the process of computer, which imitates human brain. MLP is a popular technique for model building because it is robust to the error of the dataset and has high accuracy. This technique can apply to several problems such as sound recognition, handwriting recognition, and face detection. SVM [20], [22] is a new approach, which uses data classification with linear and nonlinear. SVM is classification using hyperplane to classify class. DT [20], [21] is attribute selection, which is most related to class to be root node called "Gini index". The correlation of attributes is called "Information gain". Then, continuous process until all nodes are the same class or the same value. We stopped the process. Hybrid classification methods are several classification techniques to find the best model.

To enhance accuracy and performance of an individual classifier, there are 3 techniques of hybrid classification methods [20]: 1) Vote Ensemble is training data with the same data, but model is built with several techniques. 2) Bootstrap Aggregating (Bagging) is a randomness of training data to divide into several datasets, but model is built with the same technique. 3) Random Forest is technically the same as Bagging. However, this technique is random to select the attribute and feature to divide into several datasets and the model is built with many Decision Tree [20]. Also, there are several researches using classification techniques to solve problems such as agriculture, education, and medical [23], [24], [25]. Several researches proposed method for Stroke detection. Ankitha, et al. [26] proposed a method to detect the type of stroke (i.e. Ischemic stroke, Hemorrhagic stroke, and Transient ischemic stroke). Nearest Neighbor is used to build model. Lastly, the model is used to develop system for physician to predict type of stroke.

Emon, et al. [27] presented Stroke detection using hybrid classification methods based on weighted voting. There are 10 classification methods such as "Logistic Regression, Stochastic Gradient Descent, Decision Tree Classifier, AdaBoost Classifier, Gaussian Classifier, Quadratic Discriminant Analysis, Multilayer Perceptron Classifier, Kneighbors Classifier, Gradient Boosting Classifier, and XGboost Classifier" [27]. The result shows that this model can detect Stroke with an accuracy of 97%.

Yu, et al. [28] proposed Stroke detection using EMG-bio-signals. Random Forest and Long Short-Term Memory are used to build model for Stroke detection. The result shows that Long Short-Term Memory is high accurate than Random Forest with an accuracy of 98.958% in Stroke detection.

Lee, et al. [29] proposed a method for Stroke onset detection using Machine Learning. There are 3 classification methods: "Logistic Regression, Support Vector Machine, and Random Forest" [29] to build model for Stroke onset detection with 4.5 hours. The result shows that Machine Learning approach can detect Stroke with accuracy, which is better than human reader.

Priyanka and Meera [30] proposed a method for Stroke detection using classification method. Dataset is prepared and select features using wrapper and filter model. Then, "Logistic Regression, Support Vector Machine, Naïve Bayes, and Random Forest" [30] are used to build model. The result shows that Support Vector Machine is higher accuracy than other methods with an accuracy of 83%.

In addition, abnormal gait pattern recognition is used to solve problem of Stroke in 2 types: Stroke detection and rehabilitation for post-stroke.

2.1 Stroke detection

For Stroke detection method using classification method, there are 2 techniques: individual classification method and hybrid classification methods.

2.1.1 Stroke detection method using an individual classification method.

There are various researches in abnormal gait pattern detection of Stroke using classification method based on sensor. For example, sensor on a smartphone is attached to the human body [31]. Wang, et al. [7] proposed abnormal gait pattern detection of Stroke patient using classification technique. Deep Neural Network is used to detect gait pattern. The result shows that this model can detect an abnormal gait pattern with an accuracy of 99.35%. Therefore, this model is a benefit for physician to diagnose and rehabilitate the patient.

Li, et al. [8] proposed abnormal gait pattern detection of stroke patient using EFS method. Dataset is extracted feature to build model using 4 classification techniques such as "Support Vector Machine, Decision Tree, Multilayer Perceptron, and K-Nearest Neighbor" [8]. The result shows that K-Nearest Neighbor is high accuracy when compared with other classifiers.

Furthermore, several researches developed a system for abnormal gait pattern detection of Stroke patient. Snehasri and Raghava Swamy [13] developed system for gait pattern analysis of Stroke patient using IoT, which use Smartphone and shoe sensor. If the system detects an abnormal gait pattern, the system will send notification to user. The system is a benefit to help rehabilitation of gait pattern

and prevent injury of patient. Also, Atnoor, et al. [14] developed a system to detect abnormal gait pattern of Stroke patient using smart shoe sensor. The system sends notification to caregiver and physician when the system detects abnormal gait pattern. Therefore, this system is a benefit to protect fall of patient.

Qiu, et al. [15] developed a system for abnormal gait pattern detection using shoe integrated IMU. This system estimates gait pattern to help physician for diagnosis and train patient for rehabilitation.

2.1.2 Stroke detection method using hybrid classification methods

To increase accuracy and reliability of result, there are various researches in abnormal gait pattern detection of Stroke using hybrid classification methods based on sensor. Huan, et al. [9] presented gait pattern detection using acceleration sensor on a smartphone. Existing features and new features are used to build model using multiple scale voting. The result shows that this method can detect gait pattern with an accuracy of 98.42%.

Mannini, et al. [10] proposed a method for abnormal gait pattern detection using accelerometer and gyroscope sensor. Dataset is used to build model using Hidden Markov Model and Support Vector Machine based on a majority vote. The result shows that this model can detect an abnormal gait pattern with 90.5% of accuracy.

Hsu, et al. [11] proposed an abnormal gait pattern detection using accelerometer sensor. Dataset is prepared and built model using 4 kernels of Support Vector Machine (SVM). The result shows that Quadratic kernel of SVM is higher accuracy than other kernels with 93.46% of accuracy when compared to other kernels.

2.2 Rehabilitation for post-stroke

Moreover, there are numerous researches in abnormal gait pattern analysis of post-stroke for rehabilitation. Khoo, et al. [32] developed device to detect gait pattern. This device can calculate "gait time, swing time, and stance time" [32] to detect gait pattern and report to user. This paper is a benefit for rehabilitation of Stroke patient.

Zhang, et al. [33] proposed a method for gait pattern detection using 3D accelerometer based on feet sensor. In the experiment, there are compared with 2 experiments: walking with a cane and walking without a cane. This method can help post-stroke patient for rehabilitation.

Hussian and Park [34] proposed a method to detect an abnormal gait pattern for rehabilitation of Stroke patient after post-stroke using Electromyography. The walking dataset is used to build model using "Neural Network, C5.0, C&R Tree, Logistic Regression, Support Vector Machine, and Discriminant Analysis" [34]. The result shows that Neural Network is higher accuracy than other techniques (80 % of accuracy). Furthermore, Wang, et al. [35] presented a method to detect abnormal gait pattern of post-stroke patient. This paper uses data of spatiotemporal gait to compare "height, speed, and age of patient" [35] to detect an abnormal gait pattern of Stroke patient.

Schicketmueller, et al. [36] proposed technique to rehabilitate gait pattern of Stroke patient using robot. There are 2 robots (Lyra and Lokomat) to train gait pattern of Stroke patient. This paper is a benefit for the therapy of Stroke patient.

3. Research Methodology

The methodology is divided into 2 parts: model building and system development as shown in Figure 1.

From Figure 1, our proposed method is divided into 3 phases: 1) Model building for abnormal gait pattern recognition of Stroke patient in the initial stage using smartphone and hybrid classification methods. 2) System for abnormal gait pattern detection. 3) Notification as explained in the next section.

3.1 Model Building for Abnormal Gait Pattern Recognition of Stroke Patient in Initial Stage using Smartphone and Hybrid Classification Methods

For model building to detect abnormal gait pattern of Stroke patient in the initial stage using smartphone and hybrid classification methods, there are 3 steps: data collection,

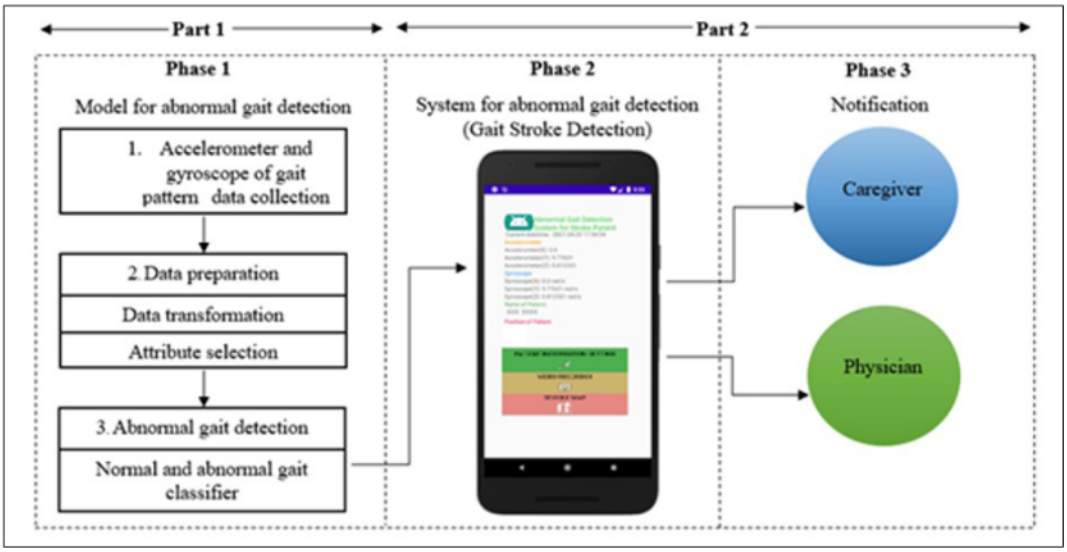


Figure 1. *Methodology of abnormal gait pattern recognition of Stroke patient in initial stage using smartphone and hybrid classification methods.*

data preparation, and model building as explained in the next section.

3.1.1 Data Collection

This section explains the dataset and experiment setting to collect gait data. We invited healthy sample subjects and Stroke patients to make a walking test. The dataset is used to build model and applied to develop a system that can detect abnormal gait pattern and notify to caregiver and physician. There are 10 sample subjects (patient in Transient ischemic attack as abnormal gait pattern and sample subject as normal gait pattern with an equal number of sample subject, age 55 ± 10 years, weight 75 ± 35 kg., and height 165 ± 15 cm.), All sample subjects signed informed consent forms approved by the Institutional Review Board (IRB). In our experiment, we collected normal gait pattern data from healthy sample subjects with 5 seconds per time at a distance of 3 meters. There is a total of 20 times. While Stroke patients in Transient ischemic attack as abnormal gait pattern were collected only 5 times with duration and distance the same as healthy sample subjects. In addition, our experiment is set up in the safety room such as no slippery floor and unobstructed, which attach smartphone on the thigh of the sample subject as shown in Figure 2.

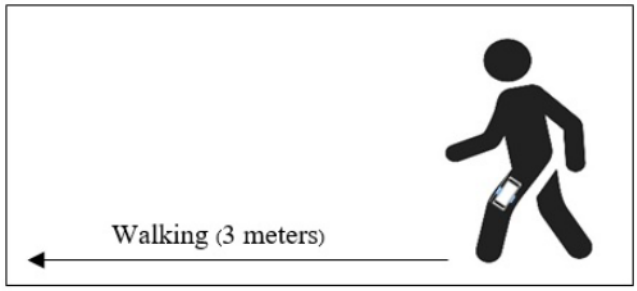


Figure 2. *Data collection of our experiment.*

From Figure 2, Sensors on smartphone collected accelerometer data (X, Y, Z) and gyroscope data (X, Y, Z) of the gait of the sample subject to build a model for an abnormal gait pattern recognition of Stroke patient in an initial stage. For a comfortable real use situation, a smartphone is in the trousers pocket. From experiments, we found that sensor data, obtained from attaching a smartphone to the trousers pocket may inaccurate than to attaching a smartphone to the thigh. There is a total of 23,316 rows (16,890 rows of normal gait pattern data and 6,426 rows of abnormal gait pattern data) as seen in Table 1.

3.1.2 Data Preparation

To obtain appropriate data for model building, we prepared data as follows.

Table 1. *Dataset of sample subject.*

Normal gait pattern	Abnormal gait pattern
16,890 rows (5 subject/20 times)	6,426 rows (5 subject /5 times)

1) Data Transformation

From dataset, as explained in section 3.1.1, there is a total of 23,316 rows (16,890 rows of normal gait pattern and 6,426 rows of abnormal gait pattern) of accelerometer data (X, Y, Z) and gyroscope data (X, Y, Z) of the gait pattern of the sample subject. Each sample subject is various scales to transform the same scale of data for easy to process. Therefore, we transform data using min-max normalization [20], [21] on the scale of [0,1] as shown in Equation 1.

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \qquad (1)$$

X is considered data

min (x) is minimum of data

max(x) is maximum of data

2) Attribute Selection

Once, we transformed accelerometer data (X, Y, Z) and gyroscope data (X, Y, Z) of the gait pattern of the sample subject using min-max normalization. We conducted experiments to select an appropriate attribute for model building using an attribute selection approach of InfoGainAttributeEval [37] based on Ranker [38]. There are 6 attributes: accelerometer data (X, Y, Z) and gyroscope data (X, Y, Z) as seen in Table 2.

Table 2. *Data attribute.*

Attributes	Meaning
Accelerometer_x	Accelerometer data of axis x
Accelerometer_y	Accelerometer data of axis y
Accelerometer_z	Accelerometer data of axis z
Gyroscope_x	Gyroscope data of axis x
Gyroscope_y	Gyroscope data of axis y
Gyroscope_z	Gyroscope data of axis z

From appropriated attribute selection, the result is shown in Table 3.

Table 3. *Appropriated attribute selection for model building.*

No. of Attribute	Result
6 attributes (Accelerometer (X,Y,Z) and Gyroscope (X,Y,Z))	99.17%
4 attributes (Accelerometer (X and Y) and Gyroscope (X and Y))	99.40 %*
2 attributes (Accelerometer (X) and Gyroscope (X))	79.17%

**highest accuracy*

From Table 3, there are 4 attributes (accelerometer data (X, Y) and gyroscope data (X, Y)), which affect the high performance of the model. In processing, we are sliding window every 5 seconds (shift to 3 seconds and retrospect in 2 seconds) to compute change value of axis X and axis Y of accelerometer and gyroscope of normal gait pattern and abnormal gait pattern [39], [40] for model building in next section.

3.1.3 Model Building

When we prepared data as explained in Section 3.1.2, dataset (23,316 rows) are used to build a model using hybrid classification methods such as Multilayer Perceptron (MLP), Decision Tree (DT), and Support Vector Machine (SVM).

For model building, we evaluated model using 10-fold cross-validation [12], which the whole dataset was split into a training dataset for 5,141 rows of abnormal gait pattern and 13,512 rows of normal gait pattern from eight sample subjects while the remaining dataset was used to test our model and defined parameter as follow.

For MLP, we conducted experiments to set parameters in various patterns. From our experiments, we found that the parameter setting, which is a high accuracy of MLP, is input (4 attributes: accelerometer data (X, Y) and gyroscope data (X, Y)), output (normal gait pattern and abnormal gait pattern), 3 layer nodes, 0.3 learning rate, and 0.2 momentums as shown in Figure 3.

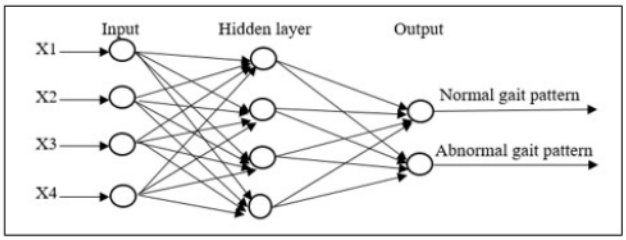


Figure 3. *Model for abnormal gait pattern recognition of stroke patient in initial stage using MLP.*

For SVM, we conducted experiments to set various kernel functions. The result shows that poly kernel is suitable for this model. Therefore, we set the parameters as follows input and output are the same as MLP model. We use SMO algorithm and kernel function (poly kernel).

For DT, we set input and output, which is similar to MLP and SVM model. We use J48 algorithm and set batch size (100), seed (5), and confidence factor (0.5).

From our experiments, this paper detects abnormal gait pattern of Stroke patient in the initial stage using hybrid classification methods with Vote Ensemble. We set the parameters of hybrid classification methods with Vote Ensemble: MLP, SVM, and DT based on combination rule with Majority voting.

3.2 System for Abnormal Gait Pattern Detection

Once, we got a model for abnormal gait pattern detection of Stroke patient in an initial stage. We applied this model to develop a system called "Gait Stroke Detection" (GSD), for abnormal gait pattern detection of Stroke patient in the initial stage to support physician for diagnosis and to train gait pattern of post-stroke patient for rehabilitation.

3.3 Notification

In addition, our proposed system is a benefit for caregiver and physician to acknowledge abnormal gait pattern of Stroke patient, especially, in case of caregiver is not staying with the patient. If the system detects an abnormal gait pattern of Stroke patient in the initial stage, the system will send notification to caregiver or family. However, in case of patient was not aided by a caregiver, the system will send notification to physician. Finally, the results of notification were recorded for further use as shown in Figure 4.

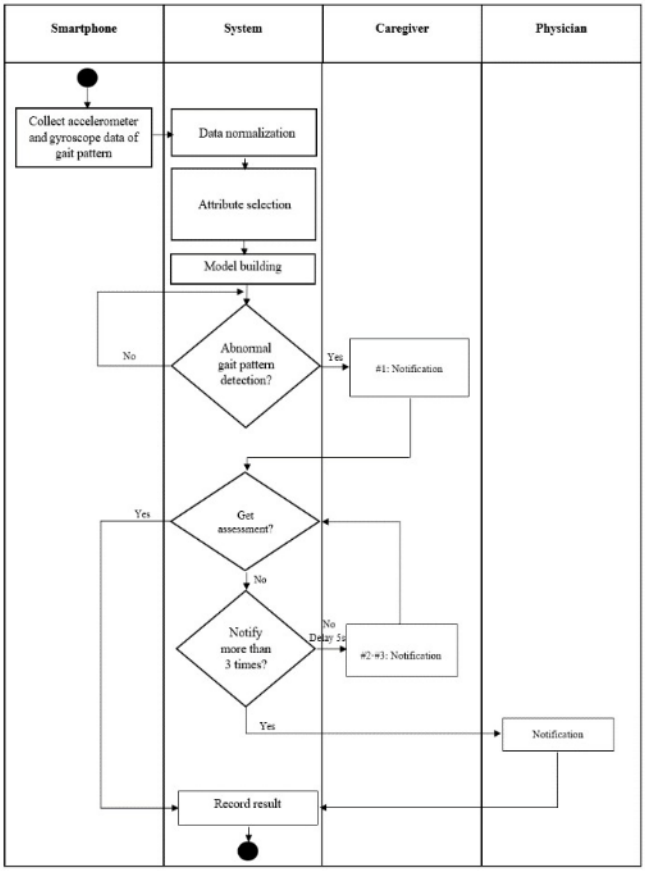


Figure 4. *Process of notification.*

From Figure 4, once an abnormal gait pattern is detected, the system that sends a message notification to caregiver will be automatically triggered. Then, the system examines that the patient obtained assistance or not. If the patient is still not assisted, the system will send notification messages to caregiver (#2 message and #3 message). In addition, if notification message is sent more than 3 times and the caregiver is not ready to aid, the system will send notification to physician to promptly aid.

3.4 Performance Measurement of Model

Performance measurement of model computed from confusion matrix as seen in Table 4 [20]. There are 4 measurements such as accuracy, precision, recall, and F-measure as shown in Equation 2-5 [20].

Table 4. *Confusion matrix [20].*

Actual result / Prediction result	True	False
True	TP	FP
False	FN	TN

4. Experimental Result and Case Study

In this section, we discuss the experimental results and case study to demonstrate the performance of our proposed model.

4.1 Experimental Result and Discussions

In this section, we explain the experimental results of abnormal gait pattern detection. Dataset consists of 23,316 rows as explained in section 3.1.1, to build the model and evaluate the effectiveness of the model with 10-fold cross-validation [20]. The result of an abnormal gait pattern recognition of Stroke patient in an initial stage using 3 classification methods with 4 measurement methods, accuracy, precision, recall, and F-measure is shown in Table 5.

From Table 5, the result of performance measurement of model using individual classifier shows that MLP is higher accuracy than other classifiers with 99.31% of accuracy. The inferior performance is detection using DT with an accuracy of 99.17%. Lastly, SVM can detect an abnormal gait pattern of Stroke patient in an initial stage with an accuracy of 99.00%. However, individual classifier also has error detection in some cases. For example, case of patient bending forward or lateral, which is detected an abnormal gait pattern. To solve the problem of accuracy and to improve the performance of detection, we propose a method for an abnormal gait pattern detection of Stroke patient in an initial stage using hybrid classification methods. The result is shown in Table 6.

From Table 6, the result shows that abnormal gait pattern detection of Stroke patient in an initial stage using hybrid

Table 5. *Result of performance measurement of model using MLP, SVM, and DT.*

	Our proposed model			Our proposed model (SMOTE)			Our proposed model (our dataset and dataset of Anguita, et al. [31])		
	MLP	SVM	DT	MLP	SVM	DT	MLP	SVM	MLP
Accuracy	99.31 %*	99.00%	99.17%	99.22%*	98.91%	99.15%	98.69%*	98.21%	98.54%
Precision	0.993	0.990	0.992	0.992	0.989	0.991	0.987	0.982	0.985
Recall	0.993	0.990	0.992	0.992	0.989	0.991	0.987	0.982	0.985
F-measure	0.993	0.990	0.992	0.992	0.989	0.991	0.987	0.981	0.985

*highest accuracy

$$Accuracy = \frac{TP + TN}{TP + FN + TN + FP} \quad (2)$$

$$Precision = \frac{TP}{TP + FP} \quad (3)$$

$$Recall = \frac{TP}{TP + FN} \quad (4)$$

$$F - measure = \frac{2xPrecisionxRecall}{Precision + Recall} \quad (5)$$

Table 6. *Result of performance measurement of model using hybrid classification methods.*

	Our proposed model (Vote Ensemble of MLP, SVM, and DT)	Our proposed model (Vote Ensemble of MLP, SVM, and DT)-SMOTE	Our dataset and dataset of Anguita, et al. [31] using our proposed model
Accuracy	99.40 %	99.31%	98.74%
Precision	0.994	0.993	0.9874
Recall	0.994	0.993	0.9874
F-measure	0.994	0.993	0.9874

classification methods with Vote Ensemble achieved high accuracy with 99.40%.

Furthermore, to reduce the problem of bias of data and our proposed model, we estimate the performance of our proposed model with the dataset of Anguita, et al. [31]. There is a total of 2,947 rows (6 activities: walk, walk upstairs, walk downstairs, sit down, stand, and lie down). In this experiment, a smartphone is used to collect accelerometer data and gyroscope data. There are 30 sample subjects. However, we use the dataset of Anguita, et al. [31] only for walk activity (normal gait pattern), which consists of 496 rows and we use our dataset (abnormal gait pattern) with our proposed method using MLP, SVM, and DT to build model. The result is shown in Table 5. The result shows that our proposed model can detect an accuracy of 98.69% using MLP. In addition, abnormal gait pattern detection of Stroke patient in an initial stage can detect using DT and SVM with an accuracy of 98.54% and 98.21%, respectively. MLP is high accuracy when compared to other classifiers. Moreover, we measure the performance of the model using hybrid classification methods (MLP, DT, and SVM) based on Vote Ensemble as shown in Table 6. The result shows that our proposed model is an accuracy of 98.74%. Therefore, our proposed method can apply to use with other datasets.

To increase the reliability and performance of our dataset and our proposed model, we prepared the dataset using min-max normalization and oversampling (SMOTE) [20] to handle unbalancing data of the minority class. There is a total of 33,780 rows (an equal number of abnormal and normal gait classes). We divided the training data set into 23,646 rows (an equal number of abnormal and normal gait classes). The remaining data are used to test. The result is shown in Table 5-6. From the experiment, the result shows that abnormal gait detection using MLP is more accurate than other classifiers with an accuracy of 99.22%. DT is accuracy of 99.15%, and SVM is an accuracy of 98.91%. In addition, abnormal gait detection using hybrid classification methods is an accuracy of 99.31%.

In addition, we evaluated our proposed method, which compares with previous research as explained in the literature review [10]. The result of re-executed method of this approach on our dataset is shown in Table 7.

Table 7. *Comparison of method for abnormal gait pattern detection.*

	Our proposed model	**Previous research [10]**
Accuracy	99.40%	90.45%
Precision	0.994	0.9045
Recall	0.994	0.9045
F-measure	0.994	0.9045

From Table 7, the result shows that our proposed method outperforms previous research. A case of error is performing activities such as bending down. Therefore, our proposed model is used to develop a prototype system for abnormal gait pattern detection of Stroke patient in the initial stage. Our proposed system is very practical for applying in real-life events because it is accurate, reliable, affordable, and easy to use.

4.2 Case Study

To illustrate process of our proposed system, we demonstrate how the proposed system will process in a simulated situation. The subject simulates sudden loss of balance, which is symptom of Stroke. The system monitors symptom of patient as shown in Figure 5.

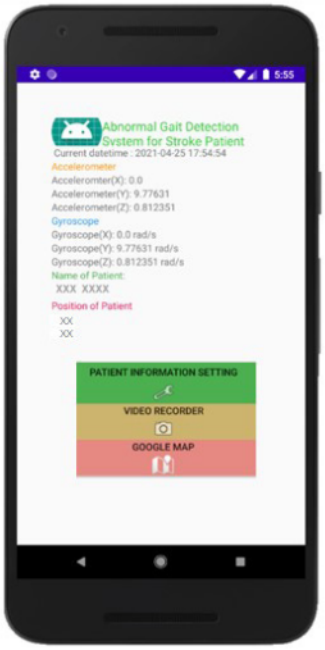
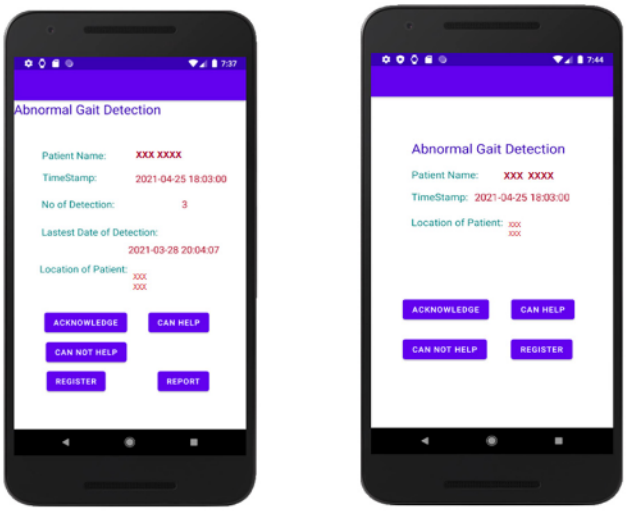


Figure 5. *System for abnormal gait pattern detection of stroke patient in an initial stage.*

From Figure 5, the abnormal gait pattern event was recorded data such as timestamp, accelerometer data, gyroscope data, patient name, and position of patient. In addition, the patient can register member and can record video to track daily life of patient, record environment, and check the current position via a map.

How the system immediately responds to the event of abnormal gait pattern detection to support aiding the patient is shown in Figure 6 (a.) - 6 (b.).



(a.)Notification to caregiver (b.) Notification to physician

Figure 6. *Screen for notification.*

From Figure 6(a.), if the system detects abnormal gait pattern of Stroke patient in an initial stage, the system will send a message to caregivers and family, which consists of name of patient, timestamp, number of detections, the latest timestamp of detection, and location of the patient. Caregiver can perceive situations and can assist with patient in-time, although, the caregiver is not staying with the patient always the time. Caregiver can acknowledge and aid patient by pressing button. In addition, other people can perceive that the patient obtained assistance. Furthermore, caregiver can get a report of notification. These data are a benefit to physician for diagnosis and further treatment. However, if a patient still has not received assistance from caregiver or family, the system will send notification to physician as shown in Figure 6 (b.).

5. Conclusion

This paper proposed abnormal gait pattern recognition of Stroke patient in the initial stage using smartphone and hybrid classification methods. For model building, accelerometer data and gyroscope data are collected from sensor on a smartphone. Then, these data are transformed using min-max normalization and select suitable attributes to build a model using hybrid classification methods (MLP, Decision tree, and SVM) based on majority voting. Our proposed method can detect abnormal gait pattern of Stroke patient in the initial stage using hybrid classification methods with high accuracy of 99.40%. Moreover, to enhance performance of our proposed model, we measure the performance of our model with our dataset (abnormal gait data) and dataset of Anguita, et al. [31] (normal gait data). The result shows that our proposed model can detect an abnormal gait pattern of Stroke patient in the initial stage with an accuracy of 98.74%.

Moreover, we re-executed method of another research [10] with our dataset to enhance effectiveness and reduce non-bias. The result shows that our proposed method outperformed existing model in previous research using accelerometer and

gyroscope, especially in case of subject is bending down.

Lastly, the system called "Gait Stroke Detection" (GSD) for abnormal gait pattern detection is developed to aid patient and to support diagnosis of physician. The system will send notification to caregiver or physician to reduce fall and accident, especially, in the case of the patient living alone. Therefore, we concluded that our proposed system conforms to our objective.

For future work, we will develop the system by combining another factor that indicates Stroke in the initial stage such as a droopy mouth. In addition, we plan to develop a complete prototype system for further use in reality.

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