Identifying Abnormal Gait in Older People during Multiple-Tasks Assessment with Audio-Visual Cues

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***Abstract*— This research presents a feasibility to adopt a decision support system framework as a rehabilitation and assessment tool for supporting the physiotherapist in identifying the abnormal gaits of older people. The walking movement was captured by the Microsoft Kinect cameras in order to collect the human motion during 4-meters clinical walk test. 28 older adults participated in this research and perform their gait in front of the affordable cameras. To distinguish an abnormal gait with balance impairment from those of healthy older adults, two machine learning algorithms; ANN and SVM, were selected to classify the data. Experimental results show that SVM achieves the best performance of classification with 82.14% of accuracy, in single-task and double-task conditions, when compared with the standard clinical results. However, SVM cannot achieve an acceptable performance when classifying triple-task condition, achieving only 71.42% of accuracy. As a comparison, ANN delivers only 75.00% of accuracy, which is inferior to SVM. This study show that SVM can be considered as a rehabilitation measuring tool for assisting the physiotherapist in assessing the gait of older people.**

Keywords— gait analysis, abnormal gait, Kinect, support vector machine, artificial neural network, balance impairment

I. INTRODUCTION

In our lifetime, an ability to perform the activities daily living (ADLs) will be always reduced, especially, gait and balance [4] [5]. In addition, the older adult will gain more experiences on a fear of falling, tiredness, and weakness of cognitive function which are other side-effect factors to their gait performance [6] [7] [8]. To maintain this balance ability, the older people need many physical body mechanisms e.g. motor system, sensory system, and cognitive function, to work promptly together for performing their standing or walking activities. Therefore, it is a challenge to assess the physical body mechanisms of older people by assigning multiple tasks during performing their gait such that the physiotherapist can easily identify an abnormal gait.

To perform two parallel tasks at the same time, these activities have often affected to the mobility of the older people who has a balance impairment. This dual task activity will reduce a velocity of their gait in which the older people need a right rehabilitation programme to recover their abilities. Hence, there are many researches present a benefit of applying external cue to enhance ADLs in the older people [9] [10] [11] [12]. This additional environment can force the older people to perform a better gait by walking quicker and stronger through the frequently-heard signal. Thus, it is possible that the immediate effect of an audio-visual cueing can be adopted as a strategy to assess the multiple tasks walking in older people who have balance impairment problems.

Therefore, this research tries to identify the effects of the audio-visual cueing with multiple tasks by classifying the abnormal in gait using machine learning algorithms. Two well-known classification algorithms are selected to learn the data patterns, which are collected from the participants' walking performance through various tasks assignment.

II. THEORETICAL BACKGROUND

A. Audio-Visual Cueing

In physical rehabilitation, the cueing play an important role in changing motor behaviour in the outpatients [9]. It is used to increase an exercise intensity of the patients. However, doing self-rehabilitation at home is less resulted in improving gait performance [10]. Therefore, many researches proposed an external device to force the patients to pay more intention in practicing and rehabilitation training [10] [11] [12].

In this paper, an adaptation of immediate effect of the audio-visual cueing is used with multiple-tasks assignment as a

tool for identifying an abnormal gait in older people with balance impairment.

B. Decision Support System

Decision support system (DSS) has been used in many fields for managing the operation or business. Most of the DSSs are the data exploration system based on their complexity in the relational database with a huge amount of data. In the medical field, DSSs are used for supporting diagnosis in many disease problems e.g. operation of brain surgery [13], nursing operation in Singapore [14], and designing a treatment programme for the patients [15].

The machine learning with powerful classification algorithm is a famous approach for identifying two groups of different data in DSS development. This kind of algorithm can learn the patterns of data from a training set, which contains attributes and the respective outcome. There are various types of algorithms used to develop the DSS. The artificial neural networks was compared to the Decision tree, Naïve Bayesian classifier, and K-nearest neighbour algorithms in [16], for better predicting the static balance patterns of older people.

In this study, two classifiers; artificial neural networks and support vector machine, are used to identify a normal and abnormal gait in older people with balance impairment.

C. Artificial Neural Networks (ANNs)

By simulating biological neural networks, ANNs are used to exchange a data between an interconnection of neural nodes. In the neural network, these connections can be tuned based on an experience which is represented as a numeric weight that can adapt to the inputs and competent of learning.

The multilayer perceptron technique, presented in [17], become a popular algorithm which is widely documented as a new architecture for ANNs. It is famously used for the classification purposes that can approximate any regularity between the input and output. Furthermore, ANN can be trained by a supervised training procedure for adjusting and predicting with backpropagation. This technique will find an acceptable local minimum of the weighting score in the neural network for achieving a minimal error. All input layers will compute their weighted output formula that includes the optional bias and an activation function in their output.

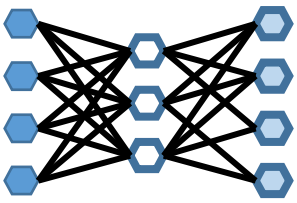

Fig. 1. Artificial neural networks

D. Support Vector Machine (SVM)

SVM is a supervised machine learning algorithm that uses the strategy to find the optimal hyperplane that can maximise the margin of a training data. This hyperplane must contain the shortest distance to the training dataset. There are many kernel functions used to find the optimal hyperplane e.g. linear, polynomial, radial basis function, sigmoid, etc. The linear kernel will be used in this research for separating the data into two classes of normal and abnormal gait patterns.

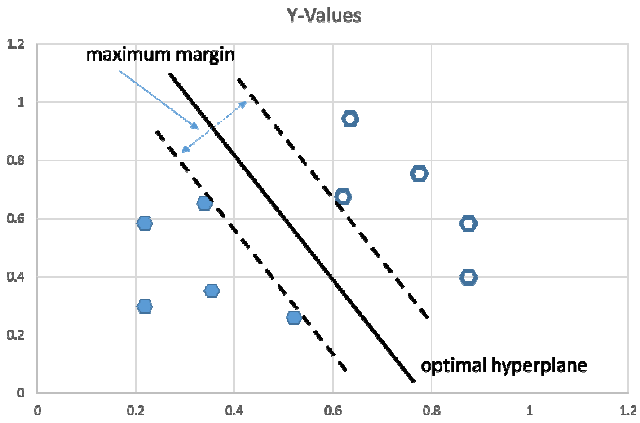

Fig. 2. Linear Support Vector Machine

III. Proposed Methodology

To identify the abnormal gait in older people with balance impairment, a new low-cost equipment is emphasized. This framework is purposed as a new measuring tool for multiple-tasks assignment in gait analysis.

A. Human Motion Analysis with Cueing Technology

To design a motion analysis system with an adaptation of a low-cost game controller, we use two Microsoft Kinect cameras to capture a motion of the participants by setting them at the side of the experimental walkway (Fig. 3). This motion data will be automatically converted to be a biomechanical value of their walking movement using MFU Affordable Clinical Walk Test (MFU-ACWT) [18]. Four biomechanical parameters, extracted from the raw data, are step length, stride length, cadence, and speed.

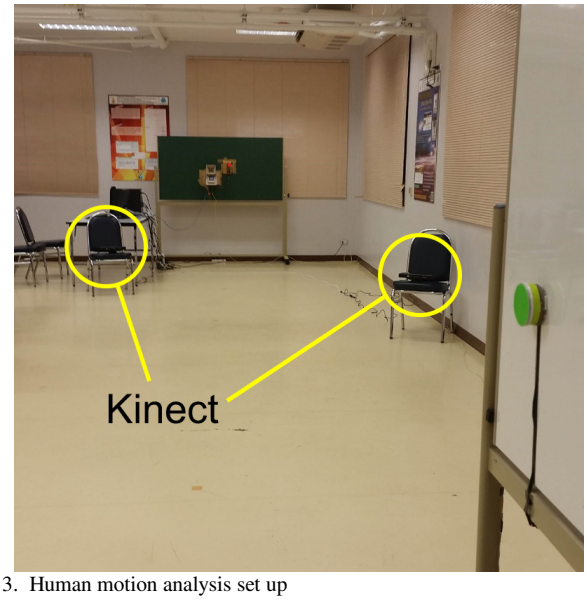

Fig. 3. Human motion analysis set up

In this research, the cueing technology was used to enhance an analysing of gait in multiple scenarios. This audio-visual

cueing device uses 1Hz rhythmical auditory beats to demonstrate as zebra crossing situation. It was set up at the end point of the walkway for displaying the light and sending the audio sound.

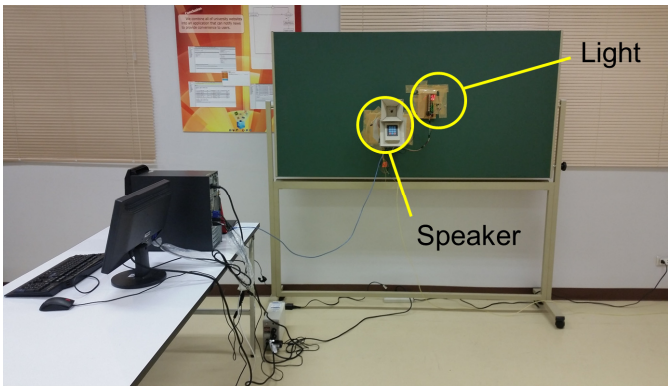

Fig. 4. Audio-visual cueing

B. Sample Selection

In this research, 14 healthy older adults and equally 14 older adults with balance impairment were invited to the experiment. These twenty-eight older people, 11 males and 17 females, are living in Nang Lae village of Chiang Rai province. These recruited participants must be able to perform their walking without any assistance from the physiotherapist or using gait aids for a minimum of eight meters. After the recruitment to the research, these participants are the older people have an age between 60-74 years old. They had been checked for making sure that there is no cognitive impairment by testing with Thai-MMSE, and no fear of falling by testing with Thai FES-I. Additionally, they must have no medical history which affected to their walking. In case that they get a pain during the experiment, we will exclude them from the research. The protocol to conduct this experiment has been approved by the Ethics Committee of Mae Fah Luang University as a part of the project titled "the immediate effect of an audio-visual cueing by simulated traffic lights on dual task walking in older adults with balance impairment" [19].

C. Data Collection

The participants were asked to perform their natural gait speed on 4-meters walk test. By adapting the protocol from [3], there are four trials of walking that include a practice trial at the first round. It was a two minutes rest period during each walking trial. The participants had to repeat the protocol for three times based on three different conditions; which are single-task (baseline walking condition), double-tasks (walk while performing a naming cognitive task), and triple-tasks (walk while performing a naming cognitive task with the addition of traffic light). Therefore, in total, these participants had to walk for 48 meters.

After finishing the clinical walk test, the research assistants who are physical therapy students had interviewed the participants for acquiring their profiles and activity daily living (ADLs) information. The summary of this interviewed information is shown in table 1.

TABLE 1. Inclusion Criteria

Criteria	Statistic		
	Max	Min	Average
BMI*	32.70	14.16	23.51
Education	9.00	0.00	3.18
MMSE*	30.00	15.00	23.14
FES*	26.00	16.00	17.75

* BMI = Body Mass Index
MMSE = Mini-Mental State Examination
FES = Thai Fall Efficacy Scale-International

D. Data Classification

In this study, two data classification algorithms; back propagation neuron network, and linear support vector machine, were selected to identify an abnormal gait performance of the participants. These classification algorithms are a novel predicting technique that identifies a data set into the right category of similar data output according to its defined attributes. They are the effective machine learning method and easy tool for classification, decision making and forecasting from training datasets [1]. The number of repeat validation, so-called cross-validation technique was used to test the performance of the algorithms with five-fold cross-validation.

IV. EXPERIMENTAL RESULTS

The abnormal gait identification system was developed to find a proper classification algorithm for predicting gait pattern during three different scenario walk tests. There are 10 attributes, shown in table 2, within 28 observation that fed to the algorithms. These classifiers were performed in MATLAB® version 2016b [2]. The results of classification can be shown in table 3.

TABLE 2. Example of 10 Attributes

Type of Data	Input Data Attributes	Example data
Personal Profile	- sex	F
	- age	62
	- BMI	14.16
	- education	4
	- MMSE	29
	- FES	20
Biomechanical features collected from Microsoft Kinect	- step length	0.39
	- stride length	0.77
	- cadence	142.54
	- speed	0.93

TABLE 3. Classification Accuracy

Algorithms	*Accuracy (%)*		
	Single Task	***Dual Task***	***Triple Task***
ANNs	67.85	75.00	57.14
SVM	82.14	82.14	71.42

This experiment, in table 3, shows the correctness of predictive labels comparing to the one that diagnosed by the physiotherapist during the sample selection process. The ground truth contains two categories of normal and abnormal

gait based on the clinical tests. As a result, SVM can perform better in all tasks scenario. It achieves the best performance in single-task and dual-task conditions with 82.14% of accuracy. However, with the triple-task condition, the SVM cannot achieve the acceptable accuracy which is only 71.42% when comparing to other scenarios.

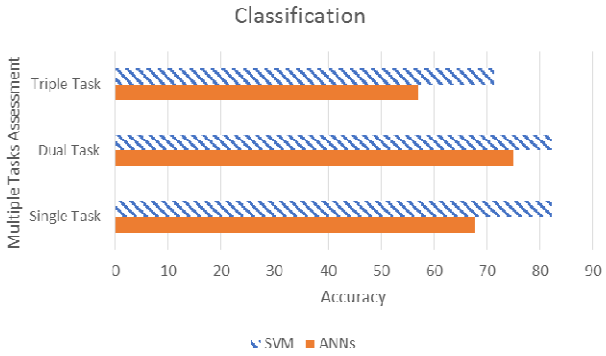

Fig. 5. Accuracy comparison

V. CONCLUSION

In order to identify the abnormal gait in older people, two classification algorithms were used to test with the data that collected during 4-meters walk test. There are three scenarios of clinical walk tests which were performed by the participants. The classification results show that SVM perform better in all scenarios with the highest accuracy of 82.14% on single-task and dual-task conditions. However, SVM cannot achieve acceptable accuracy on triple-tasks clinical walk test. Therefore, SVM algorithm is a remarkable classifier for implementing the abnormal gait identification system to support the physiotherapist. The experimental result can confirm that this classifier is adaptable to all clinical scenarios of the abnormal gait analysis in older people.

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REFERENCES

[1] C. Bauckhage, A. Drachen, R. Sifa. Clustering Game Behavior Data. IEEE Transactions on Computational Intelligence and AI in Games, vol 7(3), pp.266–278. 2015.

[2] T. M. Inc. (2016, Aug.) R2016b at a glance. [Online]. Available: https://uk.mathworks.com/products/newproducts/release2016b.html

[3] M.K.Y. Mak, J. Yu, C.W.Y. Hui-Chan. The immediate effect of a novel audio-visual cueing strategy (simulated traffic lights) on dual-task walking in people with parkinson's disease. European Journal of Physical and Rehabilitation Medicine, vol 49, pp.153-159. 2013.

[4] C.A. Laughton, M. Slavin, K. Katdare, L. Nolan, J.F. Bean, D.C. Kerrigan. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. Gait Posture, vol 18(2), pp.101-108. 2003.

[5] S.U. Ko, J.M. Hausdorff, L. Ferrucci. Age-associated differences in the gait pattern changes of older adults during fast-speed and fatigue conditions: results from the Baltimore longitudinal study of ageing. Age Ageing, vol 39(6), pp.688-694. 2010.

[6] K. Jahn, A. Zwergal, R. Schniepp. Gait disturbances in old age: classification, diagnosis, and treatment from a neurological perspective. Dtsch Arztebl Int, vol 107(17), pp.306-315. 2010.

[7] S. Lord, L. Rochester. Walking in the real world: concepts related to functional gait. NZ Physiother, vol 35(3), pp.126-130. 2007.

[8] S. Shin, R.J. Valentine, E.M. Evans, J.J. Sosnoff. Lower extremity muscle quality and gait variability in older adults. Age Ageing, vol 41(5), pp.595-599. 2012.

[9] R. Gallagher, H. Damodaran, W.G. Werner, W. Powell, and J.E. Deutsch. Auditory and visual cueing modulate cycling speed of older adults and persons with Parkinson's disease in a Virtual Cycling (V-Cycle) system. Journal of NeuroEngineering and Rehabilitation, vol 13(77), pp.1-11. 2016. DOI 10.1186/s12984-016-0184-z

[10] R.D. Icco, C. Tassorelli, E. Berra, M. Bolla, C. Pacchetti, and G. Sandrini. "Acute and Chronic Effect of Acoustic and Visual Cues on Gait Training in Parkinson's Disease: A Randomized, Controlled Study," Parkinson's Disease, pp.1-9. 2015. doi:10.1155/2015/978590

[11] E. Nackaerts, A. Nieuwboer, and E. Farella, "Technology-Assisted Rehabilitation of Writing Skills in Parkinson's Disease: Visual Cueing versus Intelligent Feedback," Parkinson's Disease, pp.1-7, 2017. doi:10.1155/2017/9198037

[12] M.K.Y. Mak, J. Yu, C.W.Y. Hui-Chan. The immediate effect of a novel audio-visual cueing strategy (simulated traffic lights) on dual-task walking in people with parkinson's disease. European Journal of Physical and Rehabilitation Medicine, vol 49, pp.153-159. 2013.

[13] S. Yao, C. Chien-Hung, S. Mengkai, L. Tsong-Hai, C. Yeu, W. Ho-Fai, C. Shy, and G. Scott. "Computer-Aided Diagnosis of Hyperacute Stroke with Thrombolysis Decision Support Using a Contralateral Comparative Method of CT Image Analysis," Journal of Digital Imaging. vol 27(3), pp. 392-406, 2014.

[14] P. C. B. Khong, S. Y. Hoi, E. Holroyd, and W. Wang. "Research in brief - Mental representation of nurses in their adoption of an innovative Wound Clinical Decision Support System in Singapore," Singapore Nursing Journal. vol 42(2), pp. 26-30, 2015.

[15] H. A. Aziz, R. L. Bearden, and A. Elmi. "Patient-Physician Relationship and the Role of Clinical Decision Support Systems," Clinical Laboratory Science. vol 28(4), pp. 240-244, 2015.

[16] C. Mekurai, K. Kaewkaen, W. Rueangsirarak, and R. Chaisricharoen. "Static Balance Assessment in Elderly using Low-cost Game Device," International Conference on Digital Arts, Media and Technology. pp. 261 – 266, 2016.

[17] M. Z. Uddin, and M. A. Yousuf. "A New Method for Human Posture Recognition Using Principal Component Analysis and Artificial Neural Network," Journal of Scientific Research. vol 7(3), pp. 11-19, 2015.

[18] S. Uttama, K. Kaewkaen, and W. Rueangsirarak. Abnormal Gait Identification using Four Meters Clinical Walk Test with Kinect. *Mae Fah Luang University International Conference 2016 and Kaleidoscope of Traditional and Complementary Medicines International Conference 2016 (MFUIC 2016 & KTCM 2016)*, pp.34-40. 2016.

[19] P. Vongsamud, J. Ngaothanyaphat, P. Supawarapong, W. Rueangsirarak, S. Uttama, and K. Kaewkaen. The immediate effect of an audio-visual cueing on dual task walking in older adults with balance impairment: a pilot study. *PTAT Conference 2016*, pp.98. 2016.