Lower Limb Walking Gait Profiling Using Marker-less Motion Capture with GDL and R-GDL methods to Assist Physiotherapy Treatment

Nor Farahana Zainul Hisham, Azrul Amri Jamal, Wan Mohd Rizhan Wan Idris

Faculty of Informatics & Computing, Universiti Sultan Zainal Abidin, Besut Campus, 22200, Terengganu, Malaysia

ABSTRACT

Physiotherapy includes specialised therapist conducting mechanical force and movement onto human body in order to heal and avoid further physical injuries. Therapists rely on subjective estimation in order to measure the performance improvements after physiotherapy treatments. An automated method to analyse and measure improvement is needed to calculate improvements based on patients' walking gait. This method would require a gait profile database in order to be able to calculate patients' improvement after physiotherapy treatments. The new technologies with low cost sensing devices could provide new opportunities and potential to assist the effectiveness of physiotherapy treatment. This research proposed a framework for walking gait profiling using marker-less motion capture to assist physiotherapy treatment. The framework consists of two major modules which are: Motion Template Module and Motion Evaluation Module. The Motion Template Module includes the motion capturing process where the human body is precisely tracked in order to generate skeleton information, focused target and record the movements before developing a script of motion called GDL scripts (GDLs) as a template. The template will be used for categorisation purposes using Reverse-Gesture Description Language (R-GDL). Evaluations of other respondents' walking gait have been done in Motion Evaluation Module using GDL and the created GDLs. The GDL output is then calculated to generate the walking gait profile. The system can differentiate the similarities between normal and abnormal walking gait. This study shows that the framework can compare the walking gait among normal and abnormal walking, based on the generated template. Using the proposed framework, the effectiveness for walking gait profiling has been proven and can be used to assist the physiotherapy treatment.

Keywords: *Marker-less Motion Capture, Gesture Description Language, Reverse-Gesture Description Language, Walking Gait.*

I. INTRODUCTION

Playing sports, running, falling, or having an accident can brings to the common injuries like sprains, strains, joint dislocations, and fractures to any part of the body. Injuries to the lower limbs (e.g. foot, ankle, knee, or hip) will influence and make different to the walking gait of a person. Usually, rehabilitation and physiotherapy assessment rely on therapist's observation and judgement [1] and it can be very subjective to evaluate the improvement of the therapies [2]. The lack of strict scientific measurements makes the therapists have difficulties to calculate the quality of improvement of the therapies and only can figure the function roughly [3]. Due to lack of accuracy, efficiency and reliability, these data cannot be used as significant references [3].

Since 1980s, human motion tracking become an active research for rehabilitation [4]. These days, motion capture is widely used in many fields. Motion capture is the recording live movement event's process to acquire a single 3D representation of the performance into mathematical terms via tracking a number of key points in space over time [5]. Marker-less motion capture is mathematical term's process that study and expressing human motion capture without using markers or specialist suit attached to the body [6]. Rehabilitation helps patients in recovering their physical independence and functional ability to normal throughout daily routines [7]. Physiotherapy is one discipline of rehabilitation that can help one rehabilitate mechanical force and movements that applied by expert therapists to avoid and heal injuries [8]. Generally, the treatment's objective is to recover the walking's function and improving patient's balance and movement.

Existing motion capture in rehabilitation and physiotherapy come with so many methods. Classification of human motion tracking using sensor technologies can be divided into three which is non-visual, visual marker based, marker-less visual, and robot-aided systems [4]. Marker-less visual systems have advantages in low cost, robust performance and reduced constraint [4].

Gait analysis is a study of human movement by measuring body motion, posture and muscle while walking which is often cooperative in the medical management of those diseases which affect the locomotor system [9]. Human gait plays an important role as a pointer of the level of human health through diagnosis, monitoring or recovery [10]. Gait phase can be recognised; the kinematic and kinetic parameters of human gait events can be determined, and musculoskeletal function can be quantitatively assessed through gait analysis. Thus, gait analysis has been used in sports, rehabilitation and health diagnostics. Gait analysis is used to observe the recovery process of patient in orthopaedic and rehabilitation.

Gait analysis using Kinect was firstly proposed for passive fall risk assessment in home environments [11]. The proposed technique utilised the depth images from Kinect. It obtained a result of maximum percentage difference of 9.4% when compared to Vicon marker-based capture system. Gabel et al. were analysed human gait using skeleton provided by Kinect [10]. A huge set of features have been taken out and then are inserted into a regression model to calculate duration of stride and angular velocities of arm. The technique got the mean difference less than 1% result when compared with wearable sensors. Sun et al. proposed a technique to detect gait information and gait analysis by using a Kinect [12].

Microsoft Kinect can also be applied to analyse abnormality of gait. Arai and Asmara present a method by using a Kinect to categorise disable gait quality [2]. Subject walking from the left view is recorded and the motion is converted to BVH file format. Support Vector Machine (SVM) is used to categorise gaits into five different categories based on the extracted left knee angle features. The gaits are classified into categories ranging from normal to neuropathy gait. The classification achieved an accuracy of 86.63%. Dao et al. present a Kinect-based home healthcare system to discover abnormal gait and visualizing motion of gait [13]. The system used depth images and skeleton captured by the Kinect to produce a BVH file recording the motion information, extracts features of gait for identifying abnormal gait, and converts the 3D body model for personalized motion visualization. The method is reported to have a gait classification accuracy of 88%.

The adaptation of Gesture Description Language (GDL) approach for sport and rehabilitation data analysis and classification have been introduced by Hachaj & Ogiela [14]. GDL is real-time human gesture recognition that capable as a classifier while Reverse-GDL (R-GDL) is a generator of automatics scripts for gesture description using unsupervised learning approach [14;15;16]. Both techniques are managed to classify movements of human body in real-time and required only tiny training dataset [17].
This paper presents in detailed how to create a motion template of lower limb walking gait profiling based on [18] and R-GDL technique. GDL approach has been utilized in validation tests module. The main contribution of this paper is to create a profile of lower limb walking gait using the proposed methodology that could help to assist physiotherapy treatments.

II. METHODS AND MATERIALS

In order to evaluate physiotherapy treatment for lower limb, motion templates of normal walking gait should be developed firstly which are commonly derived from a healthy respondent's movements. Due to develop the new motion templates a framework of lower limb walking gait profiling is proposed as illustrated in Figure 1. This framework has been inspired from a framework of extrinsic feedback-based automated evaluation system of martial art [19]. The motion templates apply motion capturing process in Motion Template Module. In developing the templates for the healthy respondent's walking gait motions, R-GDL technique has been used. Motion Validation Module is implemented to obtain established motion templates. As a result, GDLs for the walking gait profiling and classification method based on rules in GDLs for validation purpose.

III. EXPERIMENT

In this research, a healthy respondent required to walk a few steps within three meters and needs to be repeated 10 times. The repetition is to acquire the right motions and ensure the captured motions generated by R-GDL approach are accurate. It is important to plan and schedule the experiments to produce good data collection for analysis. A standard Microsoft Kinect for Windows Version 2 and Kinect SDK 2.0 have been chosen to capture, track and records the motions of walking gait due to practicality and portability reasons. The proposed sensing device used is based on marker-less motion capture method which is the respondents do not need any marker to wear that will limit their movements and performance [19]. The experiments are conducted indoor and the respondent is positioned at the distance 3.8 meters from the device. The respondent walks a few steps forward within 3 meters toward the device start with right foot as illustrated in Figure 2.

IV. PROPOSED FRAMEWORK

As illustrated in Figure 1, the framework can be divided into 2 important modules involving of Motion Template module and Motion Evaluation module.

A. Motion Template Module

Motion Template module acts as the first module in the proposed framework. This module involves four main processes which are Motion Capturing, Reverse-Gesture Description Language (R-GDL), GDL script (GDLs) or Motion Template and walking gait profiling calculation. Motion Template module is used to develop a script of motions as template using R-GDL which called GDLs. In this study, Motion Template module uses GDL and R-GDL created by Dr. Tomasz Hachaj (as illustrated in Figure 3).

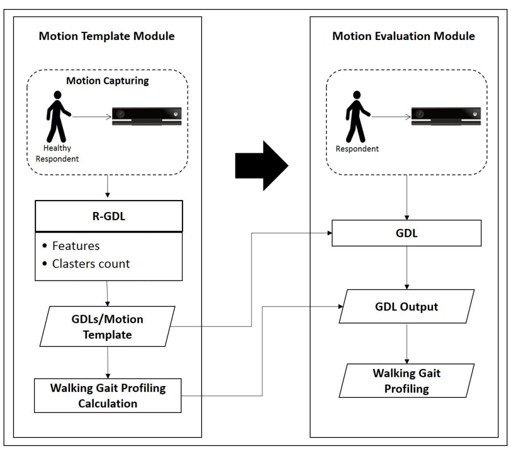


Fig.1 Framework of lower limb walking gait profiling system

- ***Motion Capturing***

Motion capturing process is one of the important processes in the Motion Template module that function to capture and track human bodies to generate skeleton, find the focused target, and record the motions. For this experiment, a Microsoft Kinect for Windows Version 2 and Kinect SDK 2.0 have been used to capture, track and record all the motion capturing process due to realism and portability aspects. This process required a healthy respondent to walk a few steps from point 1 to point 2 within 3 meters towards the Kinect for 10 times (Figure 2) while the Kinect recording all the motions data.

Fig.2 Motion capturing process

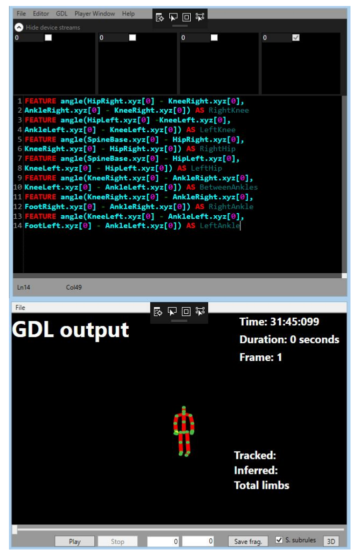


Fig.3 Interfaces of GDL and R-GDL

- ***Reverse-Gesture Description Language (R-GDL)***

After all the motions data are captured, R-GDL technique has been selected due to its ability to categorize data from unsegmented recording of healthy respondent's motions that contain multiple movements in order to generate the scripts [19]. R-GDL can generate syntactic descriptions which are easily understood by a computer programmer or an expert in the field.

In R-GDL, appropriate features for important limbs must be created. Since walking gait involves simultaneous movements, the movements of both right and left legs should be required and considered as important limbs. The legs movement may consist of hip, knee and ankle joints. For accurate measurement of parts movements, joint angles function is used to measure right and left hips, right and left knees, right and left ankles and between ankles. Therefore, the features for these parts movements are suggested as Figure 4 [12].

```
FEATURE angle(HipRight.xyz[0] - KneeRight.xyz[0],AnkleRight.xyz[0] - KneeRight.xyz[0]) AS RightKnee
FEATURE angle(HipLeft.xyz[0] -KneeLeft.xyz[0],AnkleLeft.xyz[0] - KneeLeft.xyz[0]) AS LeftKnee
FEATURE angle(SpineBase.xyz[0] - HipRight.xyz[0],KneeRight.xyz[0] - HipRight.xyz[0]) AS RightHip
FEATURE angle(SpineBase.xyz[0] - HipLeft.xyz[0],KneeLeft.xyz[0] - HipLeft.xyz[0]) AS LeftHip
FEATURE angle(KneeRight.xyz[0] - AnkleRight.xyz[0],KneeLeft.xyz[0] - AnkleLeft.xyz[0]) AS BetweenAnkles
FEATURE angle(KneeRight.xyz[0] - AnkleRight.xyz[0],FootRight.xyz[0] - AnkleRight.xyz[0]) AS RightAnkle
FEATURE angle(KneeLeft.xyz[0] - AnkleLeft.xyz[0],FootLeft.xyz[0] - AnkleLeft.xyz[0]) AS LeftAnkle
```

Fig.4 Features of lower limb walking gait profiling

The number of Cluster Count part will be filled based on the number of important steps in the walking movement. According to Hachaj & Ogiela [13], epsilon parameter is set to 10 in considered cases because all features use angles factor (angles in GDL are calculated in degrees from range [0, 180]) and the value is about 10% of overall possible range of angle values. Due to the data capturing hardware used for data acquisition is a multimedia device that might be very inaccurate, the quantisation time is set to t_q = 0.5 sec [13].

Since GDL 1.1 version is the latest and enhanced version, hence this version has been chosen. The new GDL script containing Rules are generated below the written Features in the writing script part in the Main interface. The new GDL script will be saved automatically in the Debug folder as new *.gdl.gdl.

- ***R-GDL for Normal Walking Gait***

A healthy respondent has been walked (as illustrated in Figure 2) and these movements involve in five steps.

Step#1	: Stands
Step#2	: Right leg in front of left leg
Step#3	: Left leg in front of right leg
Step#4	: Right leg in front of left leg
Step#5	: Left leg in front of right leg

Using R-GDL technique in generating GDLs for normal walking gait, its SKL file is loaded and parameter values are set as follows:

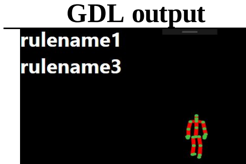
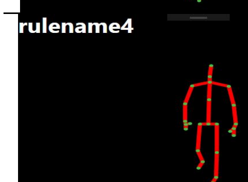
Clusters count	:	5
Min. time [sec]	:	0.5
Rule Name	:	rule
Epsilon	:	20
Max. iterations	:	10000
GDL version	:	GDL 1.1
Random initialization	:	Yes

The produced GDLs using R-GDL technique consists of five rules namely ruleName0-ruleName4

```
RULE abs(rightknee -rightknee_MEAN_0) <= rightknee_DEV_0 + rightknee_EPS & abs(leftknee -leftknee_MEAN_0) <= leftknee_DEV_0 + leftknee_EPS & abs(righthip -righthip_MEAN_0) <= righthip_DEV_0 + righthip_EPS & abs(lefthip -lefthip_MEAN_0) <= lefthip_DEV_0 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_0) <= betweenankles_DEV_0 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_0) <= rightankle_DEV_0 + rightankle_EPS & abs(leftankle -leftankle_MEAN_0) <= leftankle_DEV_0 + leftankle_EPS THEN ruleName0
RULE abs(rightknee -rightknee_MEAN_1) <= rightknee_DEV_1 + rightknee_EPS & abs(leftknee -leftknee_MEAN_1) <= leftknee_DEV_1 + leftknee_EPS & abs(righthip -righthip_MEAN_1) <= righthip_DEV_1 + righthip_EPS & abs(lefthip -lefthip_MEAN_1) <= lefthip_DEV_1 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_1) <= betweenankles_DEV_1 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_1) <= rightankle_DEV_1 + rightankle_EPS & abs(leftankle -leftankle_MEAN_1) <= leftankle_DEV_1 + leftankle_EPS THEN ruleName1
RULE abs(rightknee -rightknee_MEAN_2) <= rightknee_DEV_2 + rightknee_EPS & abs(leftknee -leftknee_MEAN_2) <= leftknee_DEV_2 + leftknee_EPS & abs(righthip -righthip_MEAN_2) <= righthip_DEV_2 + righthip_EPS & abs(lefthip -lefthip_MEAN_2) <= lefthip_DEV_2 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_2) <= betweenankles_DEV_2 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_2) <= rightankle_DEV_2 + rightankle_EPS & abs(leftankle -leftankle_MEAN_2) <= leftankle_DEV_2 + leftankle_EPS THEN ruleName2
RULE abs(rightknee -rightknee_MEAN_3) <= rightknee_DEV_3 + rightknee_EPS & abs(leftknee -leftknee_MEAN_3) <= leftknee_DEV_3 + leftknee_EPS & abs(righthip -righthip_MEAN_3) <= righthip_DEV_3 + righthip_EPS & abs(lefthip -lefthip_MEAN_3) <= lefthip_DEV_3 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_3) <= betweenankles_DEV_3 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_3) <= rightankle_DEV_3 + rightankle_EPS & abs(leftankle -leftankle_MEAN_3) <= leftankle_DEV_3 + leftankle_EPS THEN ruleName3
RULE abs(rightknee -rightknee_MEAN_4) <= rightknee_DEV_4 + rightknee_EPS & abs(leftknee -leftknee_MEAN_4) <= leftknee_DEV_4 + leftknee_EPS & abs(righthip -righthip_MEAN_4) <= righthip_DEV_4 + righthip_EPS & abs(lefthip -lefthip_MEAN_4) <= lefthip_DEV_4 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_4) <= betweenankles_DEV_4 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_4) <= rightankle_DEV_4 + rightankle_EPS & abs(leftankle -leftankle_MEAN_4) <= leftankle_DEV_4 + leftankle_EPS THEN ruleName4
```

Using Player Window, the capture of main posture based on the generated GDLs can be identified. The outputs produced are in form of rules describe the steps executed by the healthy respondent as shown in Table 1.

Table 1 Outputs produced by GDLs for normal walking gait

GDL output	Rules	Steps
	ruleName1	Step#2 Step#4
	ruleName4	Step#2 Step#4
	ruleName0	Step#3 Step#5
	ruleName3	Step#1
	ruleName2	Step#1

Since there are certain redundant rules in the GDLs, adjustment to the rules is required for better classification including rules removal. The issues arise and actions taken as following:

- The right order of the rules should start with ruleName2/3, ruleName1/4, ruleName0, ruleName1/4 and ruleName0.
- ruleName2 and ruleName3. Both rules represent the same posture which is the stand posture. For this case, ruleName3 is remained because from the data analyzing, the ruleName3 is appeared more than ruleName2. Stand posture seem to be appeared with the rules that for the next movements after stand.
- Same goes to ruleName1 and ruleName4 refer to the same posture which is the right leg in front of the left leg. Since the rules overlap with each other, one of these rules can be removed. For this case, ruleName4 is remained because from the data analyzing the rule is more appeared than ruleName1.
- The GDLs orders the approach steps by rules make the steps in GDLs are scattered. The remaining rules will be sorted by the steps of normal walking gait should be.
- The rules in GDLs will be combined with the type of steps as their rule names since it is difficult to retrieve the type of steps executed by numbering.

- ***GDL script (GDLs) or Motion Template***

GDLs is a dedicated computer language that defined gesture [12]. GDLs files will include with definition of initial feature, epsilon values that defines all features, cluster computed centres as average value of all elements allocated to them (all features have the same weight), spatial dimensionality of clusters computed as standard deviation value of all elements assigned to them (all features have the same weight) and definition of key frames (each key frame corresponds to the single cluster) [19]. For the purpose of classification, new GDLs are going to be used as reference. If necessary, the generated rules in the GDLs will possibly be sorted manually.

- ***Walking gait profiling calculation***

All GDLs generated using R-GDL technique have been changed in term of rules' names, orders and removal due to redundant steps. The alterations are important to create GDLs that similar to normal walking gait. The GDLs that have been improved is new profiling for lower limb walking gait which can be used for future evaluation, inheritance and conservation.

➢ *Improved R-GDL for Normal Walking Gait*

The improved GDLs for normal walking gait is as follows:

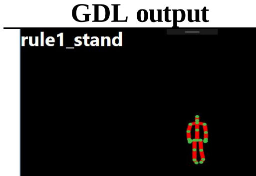
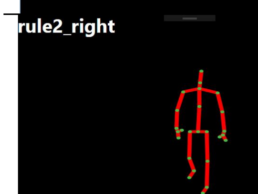
RULE abs(rightknee -rightknee_MEAN_3) <= rightknee_DEV_3 + rightknee_EPS & abs(leftknee -leftknee_MEAN_3) <= leftknee_DEV_3 + leftknee_EPS & abs(righthip -righthip_MEAN_3) <= righthip_DEV_3 + righthip_EPS & abs(lefthip -lefthip_MEAN_3) <= lefthip_DEV_3 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_3) <= betweenankles_DEV_3 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_3) <= rightankle_DEV_3 + rightankle_EPS & abs(leftankle -leftankle_MEAN_3) <= leftankle_DEV_3 + leftankle_EPS THEN rule1_Stand

RULE abs(rightknee -rightknee_MEAN_4) <= rightknee_DEV_4 + rightknee_EPS & abs(leftknee -leftknee_MEAN_4) <= leftknee_DEV_4 + leftknee_EPS & abs(righthip -righthip_MEAN_4) <= righthip_DEV_4 + righthip_EPS & abs(lefthip -lefthip_MEAN_4) <= lefthip_DEV_4 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_4) <= betweenankles_DEV_4 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_4) <= rightankle_DEV_4 + rightankle_EPS & abs(leftankle -leftankle_MEAN_4) <= leftankle_DEV_4 + leftankle_EPS THEN rule2_Right

RULE abs(rightknee -rightknee_MEAN_0) <= rightknee_DEV_0 + rightknee_EPS & abs(leftknee -leftknee_MEAN_0) <= leftknee_DEV_0 + leftknee_EPS & abs(righthip -righthip_MEAN_0) <= righthip_DEV_0 + righthip_EPS & abs(lefthip -lefthip_MEAN_0) <= lefthip_DEV_0 + lefthip_EPS & abs(betweenankles -betweenankles_MEAN_0) <= betweenankles_DEV_0 + betweenankles_EPS & abs(rightankle -rightankle_MEAN_0) <= rightankle_DEV_0 + rightankle_EPS & abs(leftankle -leftankle_MEAN_0) <= leftankle_DEV_0 + leftankle_EPS THEN rule3_Left

The improved GDLs covers only three rules to describe 3 steps in normal walking gait. Table 2 will define the rules' postures as follows:

Table 2 Outputs produced by Improved GDLs for normal walking gait

GDL output	Rules	Steps
	rule1_stand	Step#1
	rule2_right	Step#2 Step#4
	rule3_left	Step#3 Step#5

The generated GDLs is successfully recognize all main postures or steps in walking gait. Even there are three rules generated in GDLs, rule2_right and rule3_left containing step#4 and step#5 simultaneously.

B. Motion Evaluation Module

In order to produce motion template for lower limb walking gait, validation tests have been realized. The validation test done by reuse the same motion templates by cutting and segmented into 10 different motion clips based on one cycle walking within 3 meters [14]. In this case, the healthy respondent can walk about five to six steps within 3 meters. So that, the clip will include only cut for 5 steps as average.

These tests are to certify accuracy and effectiveness of the created motion templates before measuring the patients' abnormal walking gait. The same approach will be utilized to validate the others respondent to recognize whether they are walking like normal or otherwise.

Using Player Window interface in GDL Studio 2 platform (Figure 5), the segmentations of the recordings can be done manually by dragging the provided slider to choose the relevant frames (starting and end frames). Each range of frames are saved as different motion clip names for easier access and reference [14]. Therefore, there are 10 motion clips for the normal walking gait.

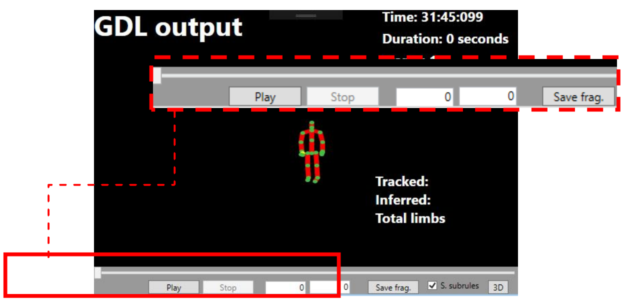


Fig. 5 Interface of Player window in GDL Studio 2 platform

i. Segmentation of normal walking gait

One whole clip of 10 rounds of walking within 3 metres range have been segmented into 10 motion clips to test their validations of the respective GDLs improved. Every motion clip will only include 5 steps of walking which is right, left, right, left and right. It is because average walking steps for every cycle of walking is 5 and start with stand posture. The results of segmented motion clips are as follows:

Table 3 Segmentation of normal walking gait

Motion Clip	Time	Frames	Total Frame
MC_1	4 Sec	1:123	123
MC_2	4 Sec	265:381	117
MC_3	4 Sec	490:600	111
MC_4	3 Sec	740:855	116
MC_5	5 sec	916:1073	158
MC_6	3 Sec	1175:1277	103
MC_7	3 Sec	1428:1535	108
MC_8	4 Sec	1637:1752	116
MC_9	4 Sec	1881:2000	120
MC_{10}	4 Sec	2130:2250	121

As illustrated in Table 3, average of frame taken to complete a cycle of walking gait within 3 meters is 119.3.

GDL technique has been used for validation tests after all the recordings segmented. GDL technique is utilized to test and examine how the 10 segmented motion clips can be recognized or classified by the relative GDLs created separately. These tests are supposed to generate a motion template that possible to be references, evaluation, preservation and inheritance in the future.

The implementation of validation tests has been done by using GDL Studio 2 platform. The previously created of improved GDLs are loaded in the Main Interface of GDL Studio 2. Each motion clip is then loaded ang replayed for profiling purpose using Player Window interface. The results of the profiling for all segmented motion clips using GDL technique are form into GDL output list as defined in Table 4. Analysis of the results has been elaborated in the results and discussion section.

V.RESULT

The analysis result based on the GDL outputs generated for profiling purposes for all segmented motion clips are as follows:

Table 4 Result of GDL rules for Normal Walking Gait

	rule1_stand	rule2_right	rule3_left	Total
MC_1	63	34	26	123
MC_2	52	40	13	105
MC_3	49	49	18	116
MC_4	57	48	15	120
MC_5	94	66	14	174
MC_6	46	40	13	99
MC_7	68	47	15	130
MC_8	56	26	15	97
MC_9	66	46	15	127
MC_{10}	56	45	20	121
Total	607	441	164	1212

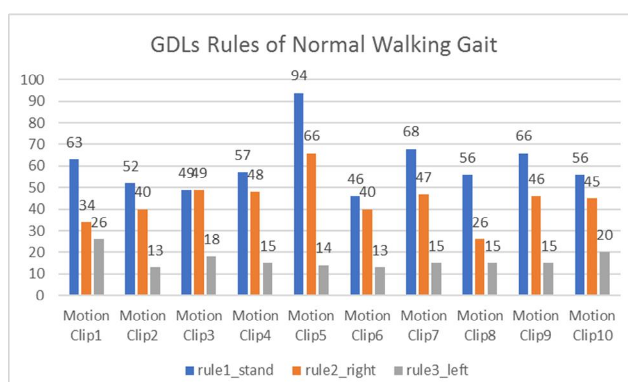


Fig. 6 Bar chart of GDL rules for normal walking gait

Table 4 shows the results of all three rules in the improved GDLs that have been recognized by all segmented motion clips of normal walking gait. 1212 rules sequence has been generated for the frames containing the postures related to the rules. The maximum number of rules generated is 174 which found in Motion $Clip_5$. As illustrated in Figure 6, rule3_left shows that the frequency of the rules is always the lowest for every motion clip since the postures that described the rule are less than the rule1_stand and rule2_right.

Table 5 Range of result GDL rules for normal walking gait

Range of total frame	103 – 158
Range of total rules	97 – 174
Range of total rule1_stand	46 – 94
Range of total rule2_right	26 – 66
Range of total rule3_left	13 – 26

Based on Table 3, Table 4 and Figure 5, the range of all the result can be illustrated as shown in Table 5. If the frequency of the rules for the walking gait is included between the range of the total rules, the walking gait can be categorized as normal walking gait.

Table 6 Result of GDL rules for walking gait by other respondents (R_x)

		rule1_stand	rule2_right	rule3_left	Total
R_1	0:100 (101)	40	28	20	88
R_2	0:96 (97)	32	31	15	78
R_3	10:133 (124)	11	5	8	24
R_4	0:113 (114)	67	20	18	105
R_5	10:133 (124)	56	33	30	119

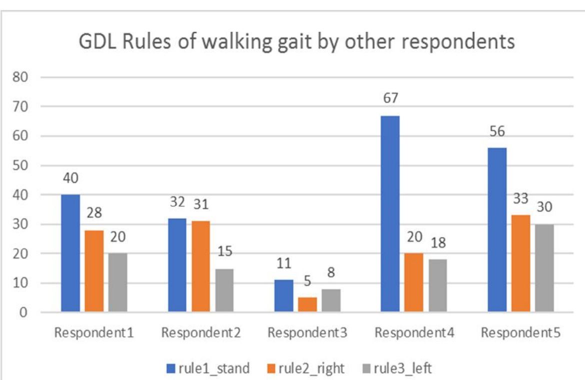


Fig.7 Bar chart GDL rules for walking gait by other respondents

Table 6 shows the result of GDL rules for walking gait by other respondents that are picked randomly for validation tests. As illustrated in Table 6 and Figure 7, all the rules have been recognized for each respondent walking gait. The frequency of the rules detected for each motion clips of other respondents can be defined respectively.

As shown in Figure 7, $Respondent_1$, $Respondent_2$, $Respondent_4$ and $Respondent_5$ have similarities where there is only one of the rules are not match the range of the total rules for normal walking gait. But, the frequency of the rules only has some little number of difference and it's not a significant difference.

However, $Respondent_3$ has the lowest rules sequence that have been recognized and got very huge difference to be compared with the range in Table 5. During the experiment, $Respondent_3$ cannot straight the left leg and walking properly. Thus, the walking gait for $Respondent_3$ can be classified as abnormal walking gait..

VI. CONCLUSION

The efficiency and effectiveness for lower limb walking gait profiling have been proven using GDL and R-GDL techniques. Using R-GDL technique, a template of lower limb walking gait profiling has successfully recognized the postures and rules for the main steps in walking gait. Besides, GDL technique also can categorize the executed movements based on the template generated effectively. Along with that, the system also can differentiate the similarities between the normal and abnormal walking gait through the tempo frames' and rules. Nevertheless, there are improvements can be done in the future to get better result in this study.

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