An Approach to Data Utilization of The Lokomat Rehabilitation Robot

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Abstract—**The use of exoskeleton robot worn on human body has been widely researched and some have been commercialized. Lower limb exoskeleton robot worn in parallel on human lower body has found many applications especially in the rehabilitation of human walking gait. It is used as a robotic therapy in assisting patient with walking difficulties to recover back his walking ability. Using Lokomat rehabilitation robot for therapy is not meant to guide the patient to walk only; but this robotic therapy system has the ability to record information signals during each therapy session. It is found out that less research and attention has been given on the methods that can utilize the recorded data which could be very useful and very informative for physiotherapy study. Thus, the objective of this paper is to highlight the method to utilize the recorded data from Lokomat physiotherapy session.**

Keywords—Lokomat, Robotic therapy, Gait Rehabilitation, Clinical Gait Analysis

I. INTRODUCTION

Exoskeleton robot is a powered wearable robotic suit which is worn on the whole or any parts of the human body to augment and to assist for rehabilitation therapy. Some of the widely known exoskeletons are BLEEX [1] for augmentation, HAL [2] for assistance and Lokomat [3] for rehabilitation therapy. The lower limb exoskeleton robot is designed to be worn in parallel to the lower part of the human body for the following purposes; to load and carrying while walking, walking trajectory, walking endurance, walking assistance and rehabilitation therapy [4-6]. The purpose of the rehabilitation therapy using lower limb exoskeleton is to restore the function of human lower limb.

There are many commercially available rehabilitation robots so far and Hocoma from Switzerland is one of the manufacturers that produce the widely used Lokomat gait rehabilitation robotic therapy system. Currently, the upgraded version of Lokomat is the Lokomat Pro.

Lokomat is a type of lower limb exoskeleton robot used for walking gait rehabilitation therapy. A treadmill based rehabilitation orthosis with hip and knee joints on both legs, it guides patient to walk on predefined gait trajectories to regain back prior walking abilities. This device has been recognized worldwide and commercially available in many countries.

In Malaysian context, there are four centers that have the Lokomat installation for rehabilitation therapy, namely:

1. Perkeso Rehabilitation Centre Melaka
2. Sau Seng Lum Stroke Rehabilitation Centre, Petaling Jaya
3. Cheras Rehabilitation Hospital
4. iRehab Physiotherapy Centre, Subang Jaya

Fig. 1. below shows the Lokomat Pro robotic therapy at Perkeso Rehabilitation

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Centre, is an upgraded version of Lokomat. Patients undergoing the Lokomat therapy at the centre consist of those suffering from spinal cord injury (SCI), traumatic brain injury, stroke, musculoskeletal patient and any neurological conditions causing walking difficulties or impairments. Throughout this paper, the Lokomat refers to the rehabilitation robot used in walking gait rehabilitation therapy.

Fig.1. Lokomat Pro in Perkeso Rehabiliation Centre Melaka

Walking gait impairment mostly happens as a result of damage to the human central nervous system (CNS) [6-8] which consists of brain and spinal cord. Any injuries happens to either the brain or the spinal cord parts which control the nervous system to the lower limb can cause difficulty in walking or gait disorder. In severe injuries, the lower limb may become paralyzed and the sufferer cannot walk anymore.

In order the regain back the walking ability apart from the person with total paralysis problem, walking therapy as a rehabilitation process is required. Due to the advancement of robotic technology nowadays, exoskeleton robot has been used alongside and lesser number of therapists are required to perform the walking rehabilitation. Over the years, researches around the world have been studying on the use of exoskeleton for rehabilitation of walking gait [8-10].

There have been many therapies and researches on stroke, SCI and other neurologic injuries around the world utilizing the Lokomat for walking gait rehabilitation therapy and study. Some researchers studied on the effect of using Lokomat for stroke patients [10]–[15], SCI patients [3], [16], person with brain trauma [17] and patients with neurologic problem [18], [19]. They may have interest in obtaining and applying the numerical data from the therapy sessions in order to assess and to study patients' recovery. However, most researches did not mention or did not give guidance on how the data taken from Lokomat are obtained, or processed and how it can be used for Clinical Gait Analysis (CGA) beside some steps and definitions given by the Lokomat manufacturer [10-11].

Due to that reason, the purpose of this paper is to highlight the approaches taken in order to use the recorded data obtained from Lokomat after a therapy session for CGA, physiotherapist or researcher use from the authors perspective.

II. METHODOLOGY

The definition of the terms used by Lokomat [20] are given by Hocoma. Normally, the data obtained from therapy sessions can be used for clinical or research purpose. The recorded data can be selected in term of signals and can be obtained by following the guides [21] provided by Hocoma. The recorded data depends on the types of data or signals selected in the interface.

The authors are interested in obtaining the gait characteristics in one gait cycle for each joint. By definition, one gait cycle or 100% gait is taken from heel strike to the next heel strike of a leg. The time taken to complete the cycle is called a stride time. In Lokomat, as it uses Gait Index (GI), the numerical value to complete a gait cycle is 1000 GI. The recorded data is to be obtained in the format of "Recording_ YYMMDD_ HHMMSS.txt", where YY is the last two digits of the year, MM month, DD day, hh hours, mm minutes and ss seconds [20].

A. *Recording Data*

An example of the recorded data which is extracted from a patient who is undergoing a therapy session is a good elaboration for this paper. The patient profiles are age 67 years, height 156 cm, weight 69 kg and suffering from SCI. The recorded data is for the 9th therapy session. The therapist selects the required data signals for recording during that therapy session. After the session ended, the recorded data was obtained in the text format as Recording_180117_093456.txt.

B. Extraction of Recorded Data

Fig. 2. shows the data when opened using Notepad. It can be seen that the raw data is not readable and unidentifiable as the data is only separated by semicolon (;).


```
Date=17.01.2018 09:34
Signals=time;Hip joint angle left [Radians];Knee joint angle left [Radians];Hip joint angle right [Radians];Knee joint angle right
0.000000;0.172444;-0.095214;0.074635;0.157339;-9.210675;-1.410193;-2.944980;1.401628;0.000000;0.000000;0.000000;0.000000;0.000000;0
0;-9.532883;-1.259824;-3.017605;1.445798;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.032000;0.172547;-0.095790;0.074375
00000;0.000000;0.000000;0.000000;0.000000;0.000000;0.060000;0.172803;-0.095217;0.074427;0.157769;-9.367774;-1.284712;-3.072555;1.45
000000;0.088000;0.173061;-0.095108;0.074328;0.157233;-9.564184;-1.183990;-3.083998;1.473891;0.000000;0.000000;0.000000;0.000000;0.0
1;0.157881;-10.184318;-0.952621;-3.011207;1.453578;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.120000;0.172651;-0.09531
8697;1.419111;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.148000;0.172804;-0.095668;0.074330;0.157632;-10.605431;-0.723
000;0.000000;0.000000;0.000000;0.176000;0.173112;-0.095550;0.074222;0.157769;-10.651721;-0.686611;-2.846074;1.432852;0.000000;0.000
000;0.172701;-0.094935;0.074584;0.157379;-10.398674;-0.800658;-3.046834;1.464923;0.000000;0.000000;0.000000;0.000000;0.000000;0.000
300;-10.547682;-0.803875;-3.103796;1.459165;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.236000;0.173061;-0.094801;0.074
396314;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.264000;0.172549;-0.094633;0.074845;0.157404;-10.618979;-0.797194;-2.
00000;0.000000;0.000000;0.292000;0.172908;-0.095270;0.074999;0.157069;-10.220300;-0.892675;-2.960164;1.435005;0.000000;0.000000;0.0
0;-0.095204;0.074231;0.157527;-9.533363;-1.146549;-2.981320;1.461898;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.324000
82004;-2.944666;1.460642;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.352000;0.173163;-0.095265;0.074530;0.157332;-9.550
0.000000;0.000000;0.000000;0.000000;0.380000;0.172702;-0.094864;0.074689;0.157355;-10.053171;-1.064666;-2.834114;1.382905;0.000000;
0.408000;0.172753;-0.095118;0.074646;0.157981;-10.029976;-1.148535;-3.077910;1.441293;0.000000;0.000000;0.000000;0.000000;0.000000;
88;-9.076945;-1.546560;-3.321476;1.510781;0.000000;0.000000;0.000000;0.000000;0.000000;0.000000;0.440000;0.172702;-0.094684;0.0752
```


Fig. 2. Raw data of Recording_180117_ 093456.txt file

The recorded raw data in the text file format can be further processed by opening the text file in MS Excel as practiced by many therapists. Once opened in MS Excel, a text import wizard will open and asking several steps to be taken so that the data can be properly arranged by columns as depicted in Fig. 3. The appearance in columns follow the sequence of signal shown in table of [21] and only the selected signals during data recording will appear.

Date=17.01.2018 09:34													
Signals=time	Hip joint angle left [Radians]	Knee joint angle left [Radians]	Hip joint angle right [Radians]	Knee joint angle right [Radians]	Hip joint torque left [Nm]	Knee joint torque left [Nm]	Hip joint torque right [Nm]	Knee joint torque right [Nm]	Gait index left (0-1000)	Gait index right (0-1000)	Hip joint angle dev. left	Knee joint angle dev. left	Hip joint angle dev. right
78.568	0.206389	0.230325	0.227376	1.175922	-6.39341	2.468653	0.725376	-10.263428	501.376805	1.376805	-0.009669	-0.008954	-0.003127
78.572	0.203814	0.230467	0.23091	1.178973	-6.225456	2.438412	0.996801	-10.545214	502.843702	2.843702	-0.009536	-0.009639	-0.002287
78.576	0.201907	0.230398	0.235695	1.182573	-5.91781	2.367659	1.291517	-10.735217	504.310931	4.310931	-0.010089	-0.01014	-0.00272
78.58	0.199383	0.229928	0.240222	1.184097	-5.575549	2.33944	1.205397	-10.729072	505.775997	5.775997	-0.010041	-0.010268	-0.002916
78.584	0.197735	0.230643	0.244126	1.187261	-5.230787	2.27962	0.839889	-10.626	507.240783	7.240783	-0.010886	-0.011609	-0.002509
78.588	0.195366	0.229364	0.248708	1.190333	-4.897728	2.283067	0.976586	-10.7116	508.703435	8.703435	-0.011026	-0.010982	-0.002799
78.592	0.19197	0.229301	0.252667	1.192151	-4.678764	2.258308	1.8314	-10.939754	510.163965	10.163965	-0.010153	-0.011598	-0.002484
78.596	0.190375	0.228821	0.256686	1.194902	-4.512847	2.220344	2.830662	-11.277687	511.625513	11.625513	-0.011098	-0.011824	-0.002244
78.6	0.187444	0.227697	0.261172	1.196435	-4.419336	2.227623	3.215578	-11.358454	513.084951	13.084951	-0.010721	-0.01143	-0.002487
78.604	0.185285	0.227653	0.263783	1.198479	-4.215868	2.154828	2.438805	-11.133999	514.544168	14.544168	-0.01113	-0.012142	-0.00087
78.608	0.182458	0.225878	0.268431	1.201615	-3.923157	2.134194	1.161703	-10.951682	516.001932	16.001932	-0.010886	-0.011146	-0.001303
78.612	0.17917	0.226221	0.272347	1.20287	-3.650438	2.148225	0.131639	-10.926111	517.458864	17.458864	-0.010194	-0.012292	-0.001016
78.616	0.17804	0.225653	0.276481	1.205474	-3.338564	2.120562	-0.381976	-10.961546	518.915603	18.915603	-0.011673	-0.01255	-0.000959
78.62	0.174601	0.224013	0.280971	1.206311	-3.115188	2.078434	-0.678847	-10.864051	520.370287	20.370287	-0.010856	-0.011759	-0.001271
78.624	0.172804	0.22452	0.283956	1.207378	-2.933631	2.053991	-1.051824	-10.715916	521.824791	21.824791	-0.011693	-0.013135	-0.000087
78.628	0.170443	0.22269	0.288145	1.210492	-2.79525	2.119832	-1.347962	-10.720796	523.277267	23.277267	-0.011977	-0.012196	-0.000118
78.632	0.167364	0.22203	0.291287	1.210733	-2.706755	2.218214	-1.515389	-10.763053	524.7271	24.7271	-0.011555	-0.012445	0.000885
78.636	0.16526	0.221144	0.295689	1.212791	-2.569639	2.22733	-1.578847	-10.784734	526.177431	26.177431	-0.012117	-0.012489	0.00062
78.64	0.162648	0.219459	0.299561	1.213506	-2.427007	2.199357	-1.547828	-10.773163	527.627015	27.627015	-0.012182	-0.011751	0.000873

Fig. 3. A well arranged data in MS Excel

C. Changing The Unit For Angle

The data for joint angle is taken in a unit radian (rad). In order to plot the joint angle vs. % gait, the unit radian needs to be converted into degree (deg.) unit.

D. Determining A Gait Cycle

The gait cycle can be determined when a cycle complete and repeats for the next subsequent cycles. This can be seen when a gait index (GI) starts from numerical value 0 linearly increases and finishes at numerical value 1000 of either the right or left leg. Immediately after 1000, the value starts again at 0 and this process repeats as long as the data is recorded. There are many repeated cycles in a recorded data depending on the time taken to record the data during a therapy session. In order to analyze one gait cycle, the user may need to select the data for any one gait cycle.

Fig. 4 shows a plot of gait index versus time, increasing linearly from GI 0 up to GI 1000 corresponding to one gait cycle. In actual process, it is hard to obtain the recorded data for the exact numerical values for GI 0 and GI 1000; thus, it needs to be approximated in order to determine the start and end of a gait cycle. In this example, the corresponding time between 78.568s to 81.292s has been approximated to indicate a gait cycle.

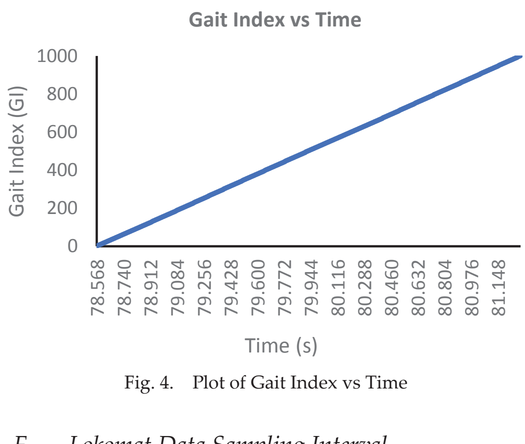

Fig. 4. Plot of Gait Index vs Time

E. Lokomat Data Sampling Interval

The sampling interval for the recorded data though not mentioned by Hocoma, it can be calculated from the time differences between time at a GI and the time at next GI or time differences between time at a GI and the time at previous GI. The authors have calculated this value to be at 0.004s sampling time interval or 250Hz sampling frequency. This value is consistent and fixed at every recorded data interval. So, for a one minute data recording, the data captured can be 15,000 data points which is very big and will require large memory space. In addition, a normal therapy session takes about 30 to 45 minutes.

F. Converting Gait Index Into Gait Cycle

Gait index (GI) is defined in term of numerical values ranging from 0 – 1000. It indicates the position of gait in the gait cycle. The plot shown in Figure 4 as stipulated in [20] is very hard to interpret and gives little information. The only information available from the graph is that GI is increasing linearly within a gait cycle time period. The time axis has been selected where a gait cycle is completed from several cycles.

The gait cycle on the other hand is usually defined in percentage (%). Then, in order to convert the GI into gait cycle or % gait, the formula that can be used is

$$Gait\ cycle = \frac{GI}{1000} \times 100\% \qquad (1)$$

G. Determining the Stride Time

A stride time is defined as time taken in seconds to complete a gait cycle or a period taken over 100% gait cycle. The unit is second (s). To calculate the stride time, the time a 0 gait index and the time at 1000 gait index need to be determined. As the gait index numbers may not be exact at 0 and 1000, user needs to approximate the indices near to 0 and 1000 and take the time at each index. The stride time can be calculated using this formula

$$Stride\ time = time_{GI\ 1000} - time_{GI\ 0} \qquad (2)$$

Referring again to Fig. 4., the stride time is calculated as 2.724s. Multiplying the stride time with the sampling frequency gives about 681 data points in each stride or gait cycle.

III. RESULTS AND DISCUSSIONS

Based on the data shown in Fig. 3., the following figures show the graphs of the profiles for only the right leg obtained with MS Excel while more profiles can actually be plotted. The converted GI into gait cycle is taken as horizontal axis and the joint angles in vertical axis. Similar profiles but with different form can also be obtained for the left leg. Fig. 5. and Fig. 6. show the joint angle profiles for hip and knee which are the same types of profiles obtained by other researches on walking gait studies.

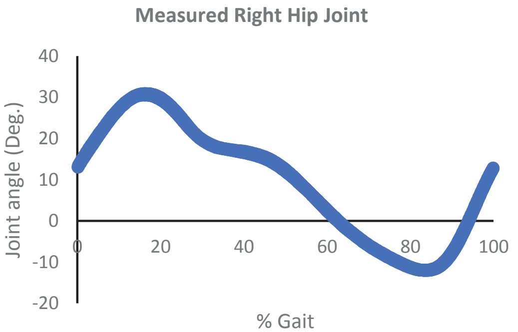

Fig. 5. Right hip joint profile measured on patient

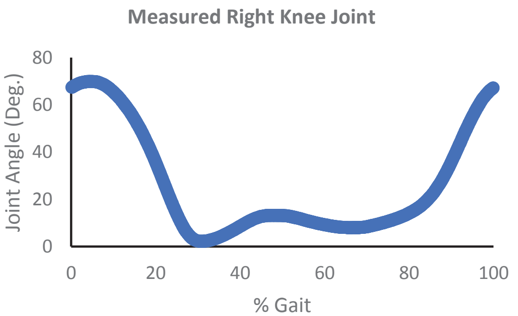

Fig. 6. Right knee joint profile measured on patient

Fig. 7. and Fig. 8. on the other hand show the joint torque profiles for hip and knee measured on the patient. This is the voluntary effort of the patient by producing torque to allow his legs to follow Lokomat predefined gait trajectory during the therapy session.

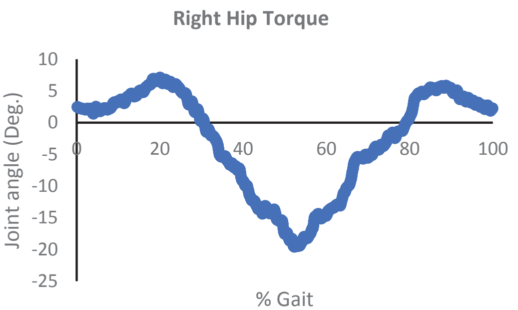

Fig. 7. Right hip torque profile produced by patient

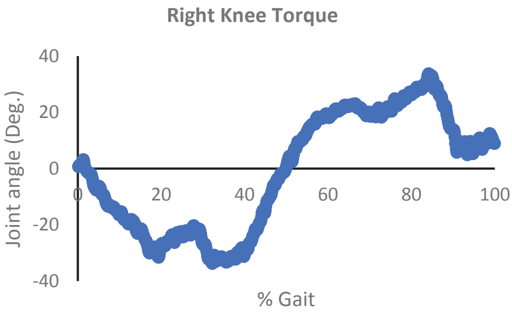

Fig. 8. Right knee torque profile produced by patient

Further utilization on the graphs of Fig. 5.-Fig. 8. and other signals data [21] can be done for CGA according to the therapist or to the researcher needs. The % gait in the horizontal axis can be converted into stride time which is patient specific whilst % gait is independent of type of patients.

CONCLUSION

The approach and the steps shown in previous sections showed on how the recorded data from each Lokomat therapy session can be processed and can be utilized to produce graphs that similar to the graphs used for clinical gait analysis. This is very useful for therapists to access the current stage of recovery for patient undergoing the robotic rehabilitation therapy and for the researchers who are doing research on human biomechanics to understand the effect of certain diseases in causing gait impairment and their recovery. Further work can be done by exporting the data from MS Excel into Matlab workspace for further manipulation as the data can be used together with Matlab Simulink for simulation.

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