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Research Article

DESIGN AND DEVELOPMENT OF THE LOWER LIMB REHABILITATION ROBOT FOR RESTORATION OF NORMAL GAIT IN STROKE PATIENTS

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ABSTRACT:
This paper presents new machine of lower limb rehabilitation robot, called "TU Gait Trainer". The machine has been developed for stroke patients to restore normal gait with trajectory and ankle angle control. While patients were being gotten physical therapy by TU Gait Trainer, their each foot was fastened by foot supporter of the rehabilitation robot and moved follow normal gait pattern by only 1 motor with linkage mechanism which was specific designed for normal gait pattern. During ankles had been moving, TU Gait Trainer was controlling angle of patient's ankles to move in dorsiflexion and plantarflexion posture same as normal gait pattern also. TU Gait Trainer prototype had been made up and getting efficiency data with real patients. The testing results of real patients with TU Gait Trainer are presented. The results show patients got stronger muscle and they got chance to restore normal walking.

Keywords: *Gait, Stroke patient, Rehabilitation, Linkage*

1. INTRODUCTION

Rehabilitation medicine is one of health services which is done for assessment, treatment, and rehabilitation. Moreover, it aims for healthfulness, recurrent prevention and complicacy of general, physical disability and decelerating patients. Rehabilitation is done to recall their physical abilities, not only to help them live well but also live themselves. Some of rehabilitation patients are inborn disability patients, some are musculoskeletal system abnormality patients and orthopedic surgery and stoke patients as well.

Rehabilitation medicine in developed countries is challenging work and common well-known. It reflects the government advertency well because all of rehabilitation patients are handicapped or bad physical fitness patients. Unfortunately, in Thailand, rehabilitation medicine is not got interest from neither government organization nor people so that there are less of rehabilitation doctors and physiotherapists. Furthermore, each hospital abilities are not equal because rehabilitation equipment is very expensive and all of them are imported. At present, potential hospitals are only government province hospitals, hospitals of some universities, military hospitals, or some private hospitals so that many patients cannot reach services thoroughly. Stroke is main illness that has to be treated constantly in order to get repeating that patients will learn and back to live normally.

Currently, inventors design tools or equipment to support walking practicing patients. Physiotherapist workload is

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reduced so that they can take care patients better and thoroughly. There are various types of walking practicing equipment. Each types control lower body part such as hip joint, knee joint and ankle joint to be moved align with walking direction. Each equipment control specific body part differently such as Lokomat [1] and Lopes [2] control hip joint and ankle joint movement, HapticWalker [3], GT1 [4] and Lokohelp [5] control ankle join. There are very less of rehabilitation equipment in Thailand compare with number of patients because medium or small hospitals have not enough budget to buy those expensive imported equipment. Walking practicing equipment design challenges inventors because of combining of both engineering and medical knowledge [6-7] to invent satisfaction rehabilitation tools or equipment. There are new researches about walking practicing equipment nowadays because there are some points to be improved to get most efficiency tools or equipment.

From all above mentioned, are inspiration points of walking practicing equipment improvement project for stroke patients. The purposes of the project are getting most efficiency equipment with low cost in order to distribute it to outreach patients.

2. GENERAL CONCEPT DESIGN

Recently, there are several types of Lower limb rehabilitation robot design concept such as Lokomat, the robot that control hip angle and knee angle with 2 motors follows the normal gait pattern (Fig. 1). The other rehabilitation robots such as Haptic Walker controls ankle movement with 2 Motors follows normal gait (Fig. 2). The both 2 concepts can control ankle movement but Haptic Walker can control ankle angle with add one motor so affect to gait pattern in dorsiflexion and plantarflexion posture [3].

Design concept of TU Gait Trainer (TGT) is the need to move the patients to walk same normal gait pattern exactly so that ankle-controlled type was selected in TGT. TGT uses 1 motor with 8 bar mechanism linkages to generate walking gait pattern as showed in Fig. 3 below.

Fig. 1. Path of Ankle Movement in Lokomat (Experiment).

Fig. 2. Haptic walker [3].

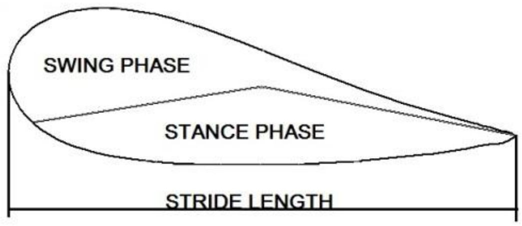

Fig. 3. Pattern ankle movement.

The special mechanism of the gait trainer takes patients' ankles follow normal gait pattern. The stride length can be adjusted to be suit with patients' body. While a patient has been getting the rehabilitation, the ankle will be adjusted by additional mechanism to follow normal gait pattern. This gait trainer has to be work with adjustable weight balancer.

Stroke patients who use gait trainer will get virtual practice that help them to learn walking. Their damaged muscular-nervous system will recover. Finally the patients can walk themselves again [8].

The mechanism controlling should align with gait cycle. The gait cycle has been divided into eight periods, five during stance phase and three during swing phase.

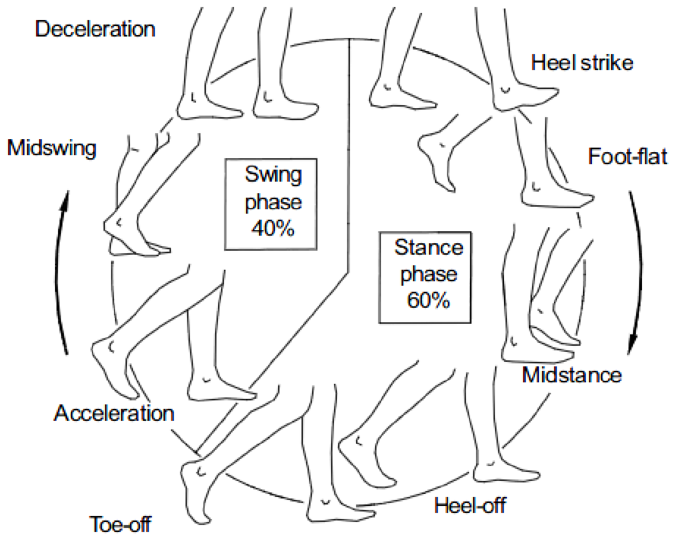

Fig. 4. Describing eight main phase [9-10].

3. Design Lower Limb Mechanism

3.1 Function of lower limb mechanism

Lower limb mechanism, one of the TU Gait Trainer parts, helps stroke patients to practice walking. From the mentioned rehabilitation concept of TGT is the help patient to walk with movement and angle of ankle control. So the design mechanism emphasis on patient's ankle while walking follow normal gait pattern.

3.2 First prototype of lower limb mechanism

Main purpose of prototype1 was the proof of mechanism and controlling concept with real prototype. At first we trialed various mechanism linkages to check feasibility showed sample in Fig. 5 below.

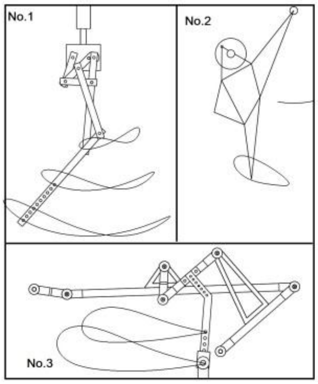

Fig. 5. Trajectory of linkage.

Table 1: Linkage type comparison

TYPE	Trajectory of Ankle	Step Length (mm)	Step Length Adjustment
No.1	Curve Radius	500	Fixed
No.2	Elliptical	500	Fixed
No.3	Curve same Walk on treadmill	500-700	Adjustable

The best mechanism was No. 3, it suited with TGT because the result of ankle's movement agreed with design concept. Before making prototype, the mechanism is checked trajectory movement by Motion analysis module of Solidworks2012. The output result of path movement of prototype1 was showed in Fig. 6.

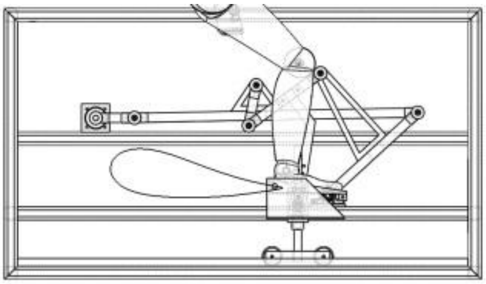
Fig. 6. Simulation trajectory of prototype 1.

Real prototype1 showed path movement was showed in Fig. 7

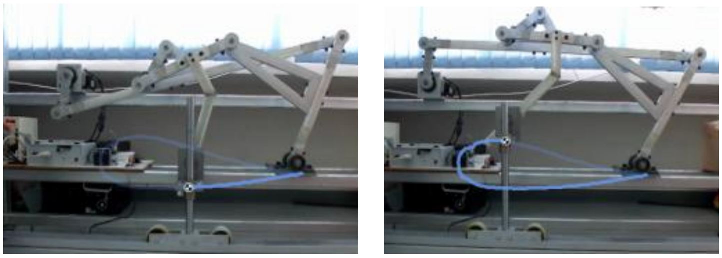
Stance phase Swing phase

Fig. 7. Path movement of prototype 1.

The prototype1 proved that the mechanism agreed with design concept and collected the problems of both mechanical and control part in order to improve in second prototype.

3.3 Second prototype of lower limb mechanism

The second prototype was developed on the basis of prototype1 problems and added mechanism control of ankle angle. There were 2 motors, the first one controlled ankle angle to follow the gait which was trailed on prototype1. And the second one controlled ankle angle to strike most like as real normal walking gait. The prominent point was the less motor usage that still agreed with real walking gait as much as possible. The cost would be reduced. Main structure of prototype2 showed in Fig. 8 The mechanism separated into 2 parts. The first one was Ankle movement and the second one was Ankle angle. The movement of Ankle mechanism composed 8 bar linkage which was moved by servo motor to control position and speed then add 4 bar linkage to get total 12 bar linkage to increase structure strength. For the angle mechanism, used 4 bar linkage which used power screw attach to servo motor to control position of ankle angle. The prototype has been made real prototype as showed in Fig. 9 and result of experimental of movement was showed in Fig. 10.

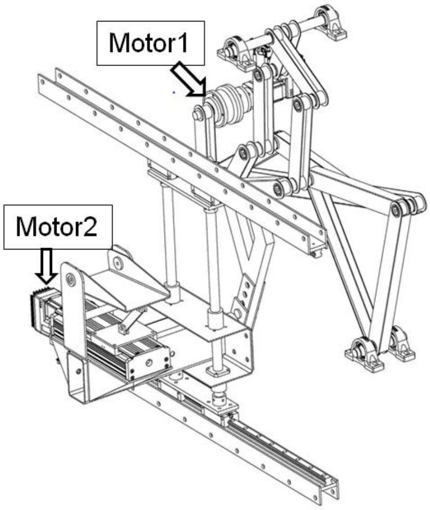

Fig. 8. Main structure of prototype 2.

Fig. 9. Real prototype 2 of lower limb mechanism.

Fig. 10. Result path movement.

3.4 Adjustable stride length

TGT can be changed stride length by changing linkage positions as showed in Fig. 11 for adapted to several of patients. Each position would be change stride length in table 1.

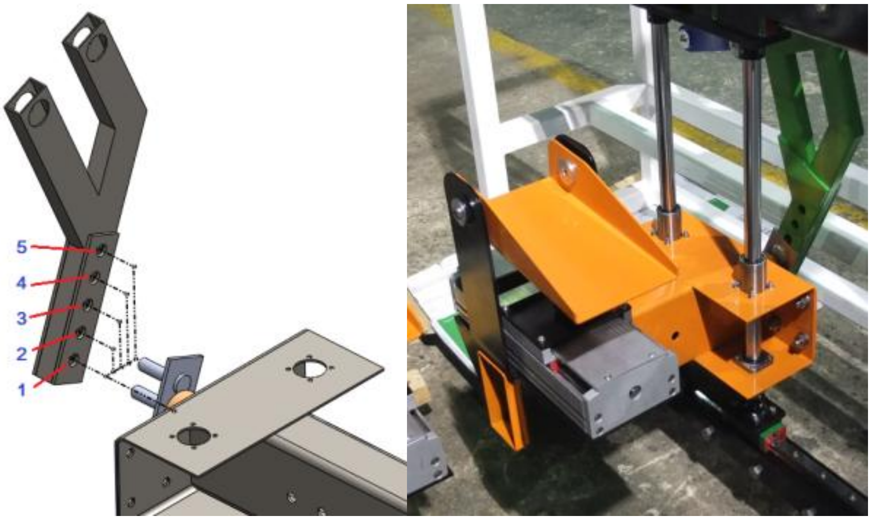

Fig. 11. Stride Length 5 Positions.

Table 2: Stride length with linkage position

Position	Stride Length(mm)
1	631.60
2	606.89
3	582.69
4	557.98
5	534.36

Prototype 2 of TGT used 2 motors that were synchronous control followed gait pattern. One motor was main motor for control ankle movement and another one controlled ankle angle. During TGT was operating, the main motor of both two legs moved set up lack phase starting 180 degree to generate stance phase and swing phase meanwhile but different leg.

The control system was displayed via touch screen display on control box which showed in Fig. 12. Motor positions showed in Fig. 13. The motor control was separated into 2 parts. Motor no. 1 and 4 controlled left side and right side consequently. Motor no. 2 and 3 controlled ankle angle to comply with the movement of motor no. 1 and 4. The conclusion of motor working relations were in the table no. 2.

Fig. 12. Control box.

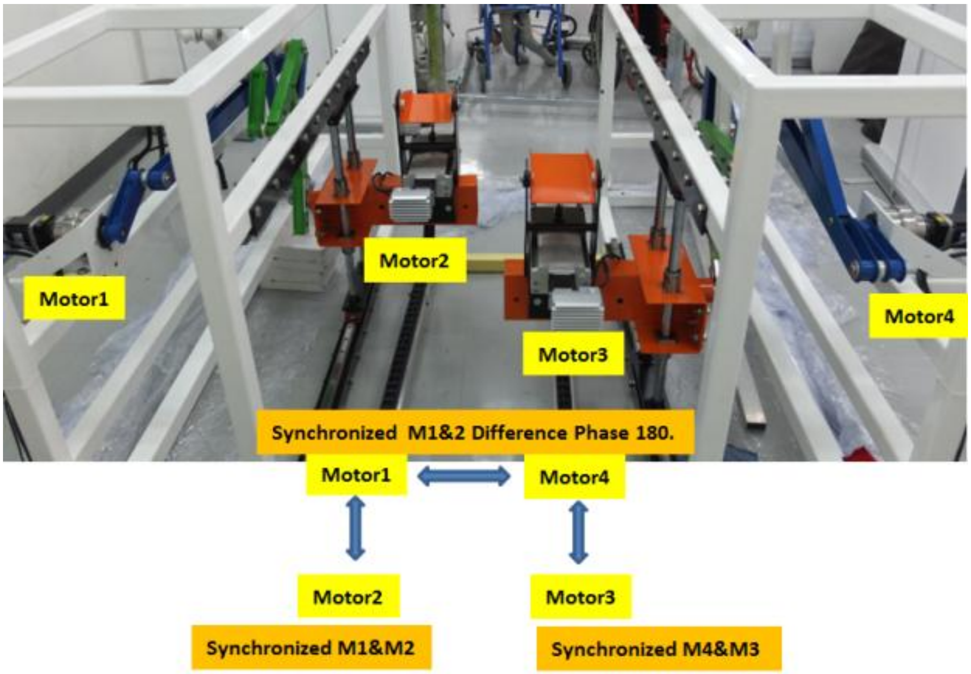

Fig. 13. Motor positon in TGT.

Table 3: Detail control concept motors of TGT

Motor No.	Control	Leg Side	Syn1	Syn2
1	Path	Left	O	□
2	Angle	Left	O	-
3	Angle	Right	Δ	-
4	Path	Right	Δ	□

Syn1 means motor movements are synchronized by Path and Angle controlling of each leg.
Syn2 mean Motor1 and Motor4 moved at the same time but different leg side and starting point offset phase 180 degrees.

O = Motor1(main) synchronized Motor2(follower)
Δ = Motor4(main) synchronized Motor3(follower)
□ = Motor1(main) synchronized Motor4(follower)

3.5 Completed TU gait trainer (TGT)

Main component of TGT consist of 5 parts (Fig. 14) are

1. Lower limb Mechanism
2. Body Support and Sling
3. Harness and Belt
4. Control System
5. Other and Accessory

At present, lower limb mechanism parts had been completed prototype 2 and installed to TGT to set up all parts. At first setting condition, we tried operating with healthy subject. (Male, Height: 170 cm. Weight: 69 kg. in Fig. 15) This experiment was done for checking mechanism of TGT. It worked normally as control algorithm and there was not any unsafe point to patient.

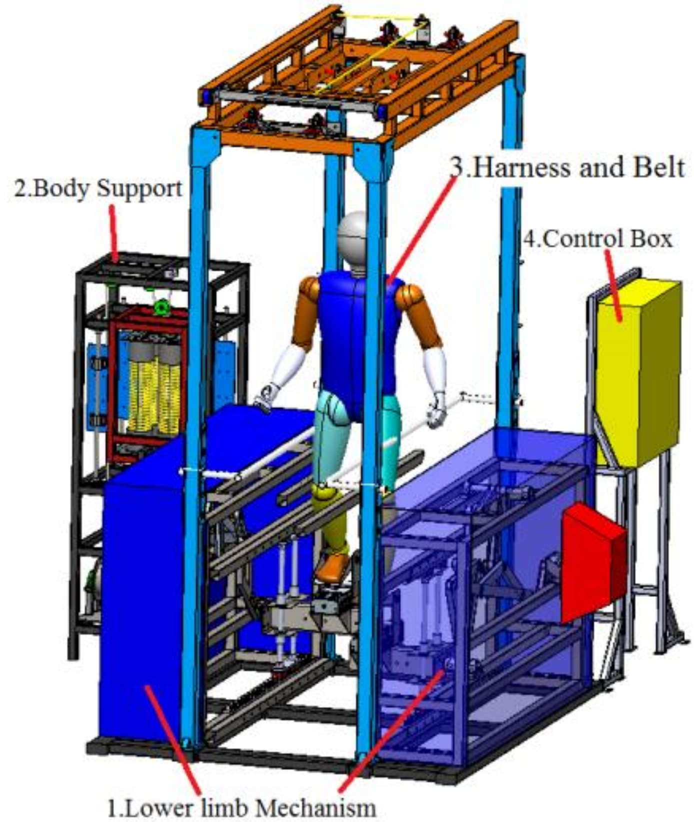

Fig. 14. The main component of TGT.

Fig. 15. Test TGT full set in healthy subject.

When finished the test in a lab, then installed all equipment at local area, Nakornpathom province, to test with patients. (Fig. 16)

Fig. 16. Installed TGT at local hospital Nakornpathom provice.

5. Clinical Test

Tested TU Gait trainer with 3 stroke patients shown detail in table 3.

Table 4: Details of patients who had participated

No.	Sex	Age	Data-PreTest				Period	Type
			Side	Weight	Hight	HR		
1	Male	66	Rt.	51	160	89	3 yrs	Hemorrhagic
2	Male	63	Lt.	65	175	72	1.5 yrs	Hemorrhagic
3	Female	57	Lt.	65	152	67	1.5 yrs	Hemorrhagic

Rt. = Patient stroke of Right leg
Lt = Patient stroke of Left leg
Period = The period that the patient had stroke.

The test compared walking development between before and after using TGT. Test period was 4 weeks 3 days per week. (Fig. 17)

Fig. 17. Test TGT with stroke patients.

From result of 6-minute walk test in table 4, the patients got better development obviously (average 58.4%, Max 67.9, Min 42.2) and from graph (Fig. 18), the patient could walk smoothly.

Table 5: Result of 6-minute walk test (m)

Patient	Week0	Week2	Week4	% Growth
1	189	220	284	65.1
2	211	268	280	42.2
3	140	180	200	67.9
Average				**58.4**

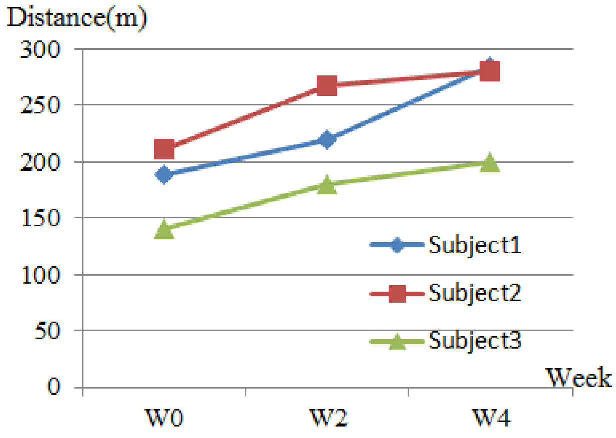

Fig. 18. Graph showed 3 patients develop walk ability in 4 weeks.

6. Advantage

This gait trainer would reduce physiotherapists workload and helped them to service more patients. The patient development tended to be better. However, there are many treatment factors that effect to the result but this gait trainer is one of the main factors. The advantages are;

1. Reduce expensive imported machines from foreign countries.
2. Support local clinics or hospitals where have not enough budget to buy imported machines.
3. To be prototype of gait trainer development.
4. Reduce physiotherapist workload.
5. The physiotherapist can control patient posture.
6. The patient can practice in virtual walking pattern.

7. Conclusions

TU Gait Trainer has developed for the need to distribute to all areas and reduce therapist work load of stroke patient practicing. At present, TGT has just completed first prototype which agree with design concept of using only one motor to control path movement same as real gait walking and control ankle angle for help patient learning foot action on ground. The testing result show walking ability of patient is stronger. Future work, we will describe more detail in clinical test and develop any points recommended with TU Gait Trainer.

In commercial term, TGT must be improved not only easy usability but also user friendly appearance. The cost of prototypes and few orders is quite high but competitive price to import models. It is cheaper about 1.5-3 times.

8. Acknowledgement

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REFERENCES

[1] Hidler, J., Wisman, W. and Neckel, N. Kinematic trajectories while walking within the Lokomat robotic gait orthosis, Clinical Biomechanics, Vol. 23, 2008, pp. 1251-1259.

[2] Veneman, J.F., Kruidhof, R., Hekman, E.E.G., Ekkelenkamp, R., Asseldonk, E.H.F.V. and Kooij, H. Design and evaluation of the LOPES exoskeleton robot for interactive gait rehabilitation, IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol. 15(3), 2007, pp. 379-386.

[3] Schmidt, H., Hesse, S., Bernhardt. R. Safety concept for robotic gait trainers, Annual International Conference of the IEEE EMBS, 2004, pp. 2703-2706.

[4] Schmidt, H., Werner, C., Bernhardt, R., Hesse, S. and Krüger, J. Gait rehabilitation machines based on programmable footplates, Journal of Neuroengineering and Rehabilitation, Vol. 4(2), 2007, pp. 1-7.

[5] Freivoge, S. Schmalohr, D. and Mehrholz, J. Improved walking ability and reduced therapeutic stress with an electromechanical gait device, J. Rehabil Med, Vol. 41(9), 2009, pp. 734-739.

[6] Winter, D.A. The Biomechanics and Motor Control of Human Movement, 3rd Edition, John Wiley & Sons, 2004.

[7] Hamill, J. and Knutzen, K.M. Biomechanical Basis of Human Movement, 3rd Edition, The people republic.

[8] Westlake, K.P. and Patten, C. Pilot study of lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke, Journal of Neuroengineering and Rehabilitation, Vol. 6(18), 2009, pp. 1-11.

[9] Vaughan, C.L., Davis, B.L. and Connor, J.C.O. Dynamic of Human Gait, ISBN: 0-620-23558-6, Mills Litho, Cape Town, 1999.

[10] Philips, J.W. The Foot Functional Foot Orthosis, ISBN: 0-443-049991-2, Longm, 1995.