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CONCEPTUAL DESIGN FOR ROBOT-AIDED ANKLE REHABILITATION DEVICE

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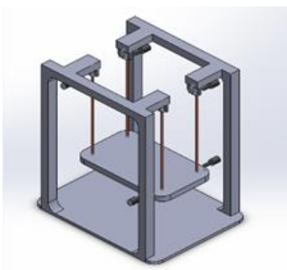
Graphical abstract



Abstract

Ankle injury is one of physical injury that can happen whether in sports or in domestic accidents. The injury can take from weeks to months to recover and requires physiotherapy treatment for effective recovery. Currently, there are established treatments for ankle rehabilitation in hospital such as endurance training and range-of-motion training. However, the success of rehabilitation for ankle injury directly depends on physiotherapy administered by experts. This conventional therapy treatment requires patients to frequently visit to hospital which is tedious and costly. To solve this, researchers have introduced a number of robot-aided ankle rehabilitation devices which has been developed in the last decade. However, those devices are bulky and do not designed for portability and configurability – which is an important feature for patients undergoing rehabilitation at home. In this paper, we proposed a concept based on robot-aided ankle rehabilitation device to assist patients undergo rehabilitation procedures. We focused on all patients' need especially based on important features such as portability and configurability of the device. Standard design process were followed including concept generation and concept selection according to all relevant criteria using Morphological Charts and Pugh Method. A Pulley Driven Cable Based Parallel Mechanism robot-aided ankle rehabilitation device has been selected based on selections from 5 different concept design generated. We show that a design based on parallel mechanisms should provide the needed portability and configurability. This result provides an insight for a portable and configurable robot-aided ankle rehabilitation device.

Keywords: Ankle rehabilitation, conceptual design, robot-aid devices

Abstrak

Kecederaan buku lali diantara kecederaan fizikal yang boleh berlaku samada didalam sukan ataupun didalam kemalangan domestik. Kecederaan ini boleh memakan masa diantara beberapa minggu hingga beberapa bulan untuk pulih dan memerlukan rawatan fizioterapi untuk pemulihan yang berkesan. Pada masa ini terdapat rawatan yang ditubuhkan untuk pemulihan buku lali seperti latihan ketahanan dan rawatan pergerakan. Walaubagaimanapun, kejayaan pemulihan ditentukan oleh rawatan fizioterapi yang dilakukan oleh pakar. Pemulihan konvensional ini memerlukan penglibatan pesakit ke hospital dimana ia agak mahal dan membebankan. Untuk menyelesaikan masalah ini, penyelidik memperkenalkan beberapa peranti robot pemulihan buku lali dimana ia telah dibangunkan selama beberapa dekad yang lalu. Walaubagaimanapun, peranti tersebut adalah terlalu besar dan tidak direka untuk menjadi mudah alih dan kebolehupayaan untuk mengkonfigurasi dimana ia adalah ciri yang penting untuk pesakit yang sedang menjalani rawatan pemulihan didalam rumah. Di dalam artikel ini, kami mencadangkan konsep peranti robot pemulihan buku lali untuk membantu pesakit yang sedang menjalani prosedur pemulihan. Kami fokus kepada semua pesakit terutamanya berdasarkan ciri seperti mudah alih dan kebolehupayaan untuk mengkonfigurasi peranti tersebut. Proses piawai rekaan diikuti oleh penjanaan konsep dan pemilihan konsep di mana ia merujuk kepada semua kriteria yang releven menggunakan Carta Morfologi dan Kaedah Pugh. Peranti Robot Pemulihan Buku Lali mengunakan Mekanisma Selari yang dikawal oleh takal telah dipilih berdasarkan 5 rekaan konsep berbeza yang telah dihasilkan. Keputusan ini telah memberikan dorongan untuk menghasilkan peranti robot pemulihan buku lali yang mudah alih dan berkeupayaan untuk mengkonfigurasi.

Kata Kunci: Pemulihan buku lali, Rekaan konsep, Peranti bantuan robot

1.0 INTRODUCTION

Ankle joint is one of many complex joint in human lower limb bone structure and helps to maintain body balance during movement [1]. However, if people 'overdo' their movement during playing sports, the ankle has tendency to be injured. This can be proven as ankle injury is one of the most common sports injuries [2]. Domestic accidents can also contribute some cases of ankle injuries [3]. In fact there are estimated 23,000 cases relating to ankle injury in United States and in New Zealand there are 82,000 new claims and 17200 ongoing claims related to ankle injury were reported to Accident Compensation Corporation (ACC) in year 2000/01 [1]. Additionally, it has been reported that 24 out of 70 type of sports injury are relating to ankle injury. This statistic shows both athletes and non-athletes can be affected by potential ankle injury [4].

Ankle injuries can take a long time to recover depending on the condition of the injuries and method of treatment. Usually, if condition is too severe the injured ankle would need 4 to 26 weeks to recover [2]. With introduction of mobilization of ankle under form of ankle exercises, the treatment can encourage the recovery of ankle injury more effectively instead of leaving the injured ankle to recover by itself [2].

In conventional method for rehabilitation, patients are using simple tools to treat ankle injuries such as elastic wobble boards, roller foams and elastic bands [3]. However, there is need for improving the treatment of ankle injuries which is aimed to improve the results of physiotherapy. This can be done by introducing several automated devices that can help to increase the effectiveness of ankle rehabilitation treatment such as Fisiotek 2000 (Rimec) or Kinex KA2TM.

However, these automated equipment are limited by low portability, lack of configuration, high cost and bulky [3]. Additionally, some of the devices are limited to a single function in which are only helping ankle joint to rehabilitate in one direction only which is not effective for full recovery [5]. This hinders possibility for the injury to be treated at home.

There are several existing robot-aided ankle rehabilitation devices that have been introduced that is aimed to help patients to undergo rehabilitation at home which is aimed to counter the problem experienced by conventional devices that are being used in ankle rehabilitation [5-7]. Similarly by introducing robot-aided ankle rehabilitation devices, the workload of the physiotherapist can be reduced into a supervisory role during treatment.

However, the problems of portability and configurability are still not being addressed. In this project, we proposed a concept for robot-aided ankle rehabilitation device that can fulfill both features of configurability and portability. With portability features, the proposed device can be used at home thus reducing total dependency of the treatment at the hospital. In addition with configurability features, the proposed device can cover most of ankle rehabilitation exercises which it can be operated under as a single unit.

This paper introduces the design of a robot for ankle rehabilitation based on the important feature such as portability and configurability. Portability helps patients to move the equipment from one place to another. Configurability helps patients to undergo different treatment exercises under the same equipment without dependency of additional equipment to be fully healed ankle injury. Using engineering design tools such as Morphological chart and Pugh Method, these tools will help to ease the process during designing the concept. Based on the results, the selected design concept has satisfy the requirements for ankle rehabilitation procedures.

This paper is organized as follows: Existing robot-aided ankle rehabilitation device described in Part 2.0. Part 3.0 introduced the ankle joint's motion and structure. The Conceptual Design method such as morphological chart and Pugh method will be described with selected concept design in Part 4.0. Part 5.0 show the results of the concept design selection and finally Part 6.0 is discussion.

2.0 EXISTING ROBOT-AIDED ANKLE REHABILITATION DEVICES

The aim of robot-aided ankle rehabilitation device is to encourage treatment at home which is helping patients to reduce the dependency of the treatment solely at the hospital. For example of the mentioned robots are Adaptive Wearable Parallel Robot by Jamwal *et al.* and Ankle rehabilitation robot by Yoon *et al*. which are shown in Figure 1 [6, 7].

Ankle rehabilitation robot with four degrees of freedom (Figure 1) is consisted of two upper platforms and three limbs driven by four pneumatic actuators. This robot is designed by Yoon *et al*. [6]. The robot has additional features which allow ankle and foot motions including toe and heel rising. This device can be used for ROM or range of motion, muscle strengthening and proprioceptive exercises required in the ankle rehabilitation program due to reconfigurable nature of this robot. With additional DOF or degree of freedom, the device anticipated to be more flexible in application and has wide range of exercises for ankle rehabilitation treatment.

Despite the robot has ability to configure to several variety of ankle rehabilitation exercises, the problem of portability is not being stressed as use of hydraulic and pneumatic technologies which deemed unsuitable for domestic environment especially at home. It is noisy and hard to control. Pneumatic system requires additional device such as compressor in order to implement the system.

Adaptive Wearable Parallel Robot is a three DOF (Figure 1), wearable-based pneumatic driven ankle rehabilitation robot designed by Jamwal *et al*. [7]. The actuators of the robot are placed parallel to the shinbone. The robot consists of 2 parallel platforms which represent a "U" shaped top platform for leg support and also a moving platform at the bottom used to activate foot and ankle of the patients. Also, the robot is compatible with the ankle motions as it uses PMA or pneumatic muscle actuators which also light in weight.

Although the robot is using PMA instead of conventional pneumatic actuators which are light weight and has greater power-to-weight ratio compare to electromagnetic actuators. In addition, PMA has low impedance which allows back drivability [7]. The system still requires external equipment such as air compressor which hinders the portability of the robot.

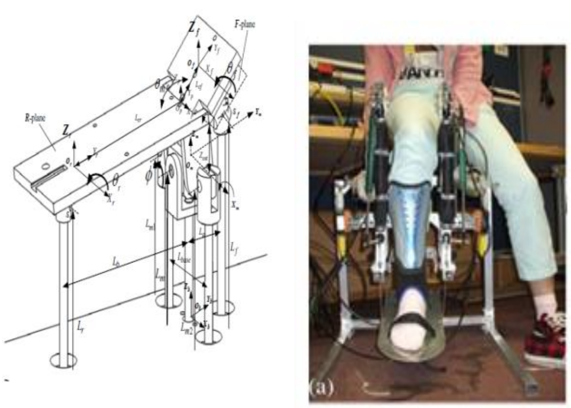


Figure 1 4 D.O.F. Ankle rehabilitation robot by Yoon *et al*. and Adaptive Wearable Parallel Robot by Jamwal *et al*. [5,6]

While there are existing robot-aid ankle rehabilitation device that have been developed in recent years, important factors such as configurability and portability are not stressed by these researchers. For example, they are still using pneumatic actuation which is unsuitable for portability and the devices are limited to a certain exercises such as balance training. With configurability feature, ankle rehabilitation devices can support most of ankle rehabilitation exercises.

3.0 ANKLE JOINT MOTION, STRUCTURE AND INJURY

Ankle joint is one of the unique features of human joint that can revolve under 3 axes. With this features, human can able to perform several movement using ankle joint such as walking, running and jumping. Figure 2 below shows tips of shinbone and fibula together with astragal made up the ankle joint structure. Complex movement of the ankle joint is unique as it can rotate under any direction under limited range of motion depending on different individuals.

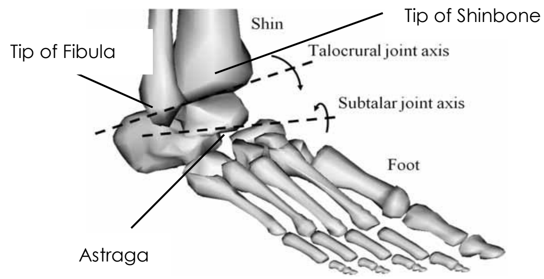


Figure 2 The structure of the ankle joint [3]

The rotation of ankle joint rotates around the three axes of the coordinate system shown in Figure 3 below. The ankle is fixed with Cartesian coordinate and axes x, y and z represent rotating pivot under three different directions. Thus, this motion can be described into three different rotating movements under three axes (x, y and z) in Table 1. There is a limit for each motion according to characteristics of human ankle construction which is measured in degrees (°). The ranges of each motion described are listed in Table 1 below according to Liu *et al*. [5].

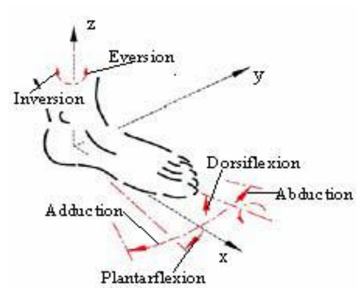


Figure 3 Type of ankle rotation on the xyz – axis [5]

Table 1 Ranges of angle for ankle motion [3]

Axes	Name of the Motion	Range of Motion
X	Inversion	14.5° - 22°
	Eversion	10° - 17°
Y	Dorsiflexion	20° - 30°
	Plantarflexion	37° - 45°
Z	Adduction	22° - 35°
	Abduction	15° - 25°

There are three types of ankle injury such as ankle strain, ankle fracture and the most common type of ankle injury is ankle sprain. Ankle sprain can cause a stretch or tear of a ligament as the result from a fall or an outside force that dislocates the surrounding joint from its normal alignment [8]. Rehabilitation of ankle sprain requires long term recuperation which is depended on the state of injury [3]. This gave some motivations to the researchers to develop a robot-aid ankle rehabilitation device that can help patients to recuperate ankle injury at home without moving in and out from the hospital for treatment.

4.0 CONCEPTUAL DESIGN

There are 2 main stages of conceptual design involved in this process which are Morphological chart as a method to generate the concept design and Pugh Method as a method to select the concept design [9, 10].

4.1 List of Criteria for Generating Concept Design

The criteria are selected based on features that are needed to be included for designing a suitable robot-aided ankle rehabilitation device. Based on literature review there are 5 criteria such as Mechanism, Actuation, Type of Platform, Sensors and User Interface which are selected according to in the literature [9, 10].

To address the issues of configurability, mechanism design, actuation system and user interface plays a major role into this design. For example, using a ball joint is easier for a user to configure the structure of the robot mechanism compare to chains/belts as its DOF is limited. While portability is determined by mechanism and actuation system. For example pneumatic actuator requires extra equipment such as compressor compare to electrical actuator to operate. With additional weight and the user has to require more than 1 equipment to carry, this factor hinders portability. Example for this statement is the electrical actuator requires no additional equipment compare to pneumatic actuator which requires compressor or filter to operate the actuator. Three of the latest existing robot-aided ankle rehabilitation devices are chosen for reference for the criteria such as Adaptive Wearable Parallel Robot, Four D.O.F. Ankle rehabilitation robot and ARBOT [7, 8, 11].

1. **Mechanism** – This type of criteria is chosen to determine lifting or transmission of power from the actuators to the foot platform. This feature will determine the simplicity and complexity mechanical operation of the robot. Currently, Jamwal *et al*. used cable-based while Yoon *et al*. used cylinder-based mechanism. Saglia *et al*. used capstan drive which are consist of lateral pulleys under each linkage [6, 7, 11]. Examples of potential for the design are: Gears and Shafts, Belts, Chains, Cables (Pulleys), Spurs, 2-way Cylinder, Spring Loaded Mechanism and Swing Arm Quick Return Mechanism. This selection can be a combination of two or more types of mechanism.

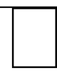
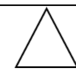
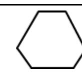
2. **Actuation** – This type of criteria is chosen to determine specification of the actuator that will be used for proposed robot-aided ankle rehabilitation devices. According to Saglia *et al*. robot-aided ankle rehabilitation device only requires 2 rotational degree of freedom which is suitable for proprioceptive ankle exercise [11]. However, some of robot-aided ankle rehabilitation device use 3 d.o.f and even 4 d.o.f. in their design [6, 7]. In the current robot-aided ankle rehabilitation devices, both Jamwal *et al*. and Yoon *et al*. are using pneumatic based actuators due to large power-to-weight ratio suitable for designing robot-aided ankle rehabilitation devices while Saglia is using electrical linear actuator [6, 7, 11]. For example: Solenoids, Linear motor, Hydraulic Cylinder, Pneumatic Cylinder and Rotary motor.

3. **Type of Platform** - This type of criteria is chosen to decide shape of foot platform of the proposed robot-aided ankle rehabilitation devices. Both Jamwal *et al*. and Yoon *et al*. are using rectangular shaped foot platform while Saglia *et al*. used circular shaped platform [6, 7, 11].

4. **Sensors** – This type of criteria is chosen to decide type of sensors that will be used for the proposed robot-aided ankle rehabilitation devices in purpose of controlling the movement and safety of the robot. Jamwal *et al*. used linear potentiometer, load cells and transducers. Saglia *et al*. use optical encoder for positioning of every end effectors of the robot [7, 11]. While Yoon *et al*. used pressure sensor [6]. For example: Force Transducer, Strain Gauge, Limit Switch, Proximity Switch, Visual, and Load Cell.

5. **User Interface** – This type of criteria is chosen to decide type of patient's interface of the robot-aided ankle rehabilitation device. Both Jamwal *et al*., Yoon *et al*. and Saglia *et al*. have used PC as selected interface [6, 7, 11]. For example: PC, Remote Control (Wireless Transmission), Control Panel connected to the robot.

Table 2 Morphological chart

Parameters	**Solutions**				
	1	**2**	**3**	**4**	**5**
Mechanism	Shafts and Gears	Peaucellier Cell	Belts	Pulleys	Chains
	Spur Gears	4-Bar Linkage	Spring Mechanism	Slider Crank	Internal Gear
	Cams	Swing Arm Quick Return	Rack and Pinion	Helical Gears	Robotic Arm
	Ball Joint	Screw Mechanism	2-way Cylinder	Lever mechanism	Magnetic Levitation
Motion (Actuation)	Pneumatic Cylinder	Solenoids	Linear Motor	Hydraulic Cylinder	Rotary Motor
Shape of Platform					
Sensors	Force Transducer	Strain Gauge / Load Cell	Limit Switch	Proximity Switch	Visual-aid
	Encoder	Accelerometer			
User Interface	PC	Remote Control (Wireless Transmission)	Control Panel (Wire Connection)		

4.2 Concept Generation Drawing

Using design concept generation tool such as Morphological Chart in Table 2, we have produced about 5 concept designs based on the criteria from the morphological chart in Figure 4 below. However, this is not drawn to scale as parametric element will be considered later during the embodiment design [9, 10].

Design A is a 4PS (Prismatic-Spherical) DOF platform based robot-aided ankle rehabilitation device. This robot is using 2 springs on the back side of the robot. The actuator is using screw mechanism DC linear motor on the front side of the robot. Additional central strut can be applied for balancing exercise. The current position of the Design A can be used both sitting and standing mode. The robot will use proximity sensor to detect the movement of the robot. Additional sensors can be applied such as force sensor which is to detect resistance of the patients' foot and accelerometer which is to control the position and movement of the robot. User Interface selected will be the PC.

Design B is a 3RSS (Rotational-Spherical-Spherical) robot-aided ankle rehabilitation device. The current position of the Design B robot can be used both standing, sitting and even sideways movement mode without need for reconfiguration. The robot will use rotary encoder to detect the movement of the robot. Additional sensors such as force sensor and accelerometer will be used for controlling motion and resistance of the robot. User Interface selected will be the PC.

Design C robot is a 4 DOF Pulley Driven Cable Based Parallel Mechanism Robot-aided Ankle Rehabilitation Device. The robot is using 4 cable pulleys using rotary DC Motor. The rotary motor will pull the cable through pulleys attached on the top of the platform. Normally this robot will be used for sitting type ankle exercise but the robot can be added with 2 additional configuration such as balancing (additional central strut) and additional central strut attached for stability and resistance sideway motion exercise. Sensors such as force sensor and accelerometer will be used for controlling motion and resistance of the robot. User Interface selected will be the PC.

Design D is a Hybrid (Serial-Parallel) Robot-aided Ankle Rehabilitation Device. The robot can be used both standing mode (if central strut is attached) and sitting mode. The robot will be expected to perform important ankle rehabilitation exercise such as endurance training and potentially resistance training. The robot will use proximity sensor and encoders for serial robot to detect the movement of the robot. Additional sensors such as force sensor and accelerometer will be used for controlling motion and resistance of the robot. User Interface selected will be the PC.

Design E is a 2 DOF Rotational Robot-aided Ankle Rehabilitation Robot. The current position of the robot can be used both sitting and standing mode. All 2 DC motors will drive on the each side of the robot. The robot will use encoder to detect the movement of the robot. Additional sensors such as force sensor and accelerometer will be used for controlling motion and resistance of the robot. User Interface selected will be PC.

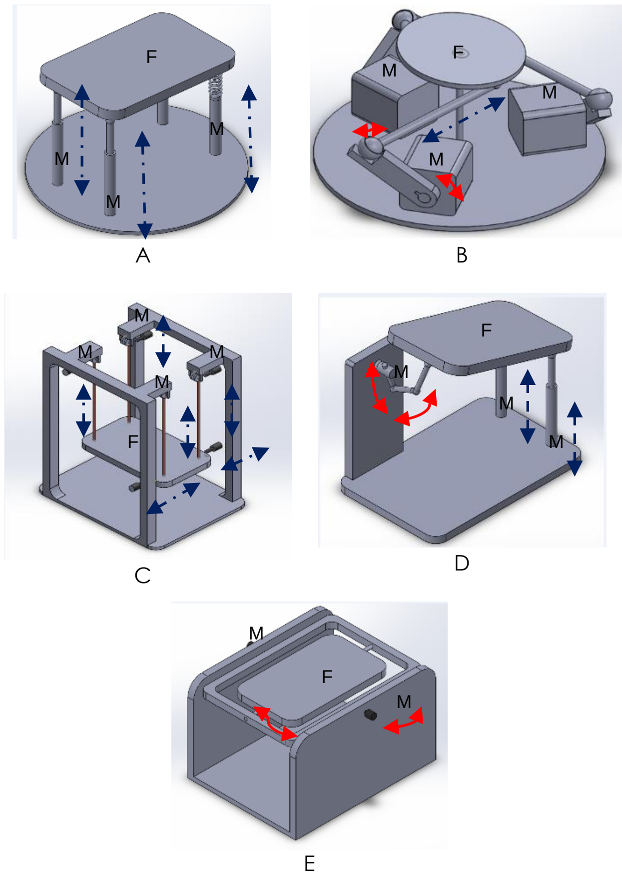


Figure 4 Concept Design A: The radial arrow (solid) indicate rotational movement of the robot while straight arrow (dashed) indicate linear movement of the robot. The 'M' indicates the position of the actuator while 'F' indicates the foot platform

4.3 Concept Selection

Then concept designs are needed to be determined using decision-matrix method or Pugh method. This method will be used to select one of 5 generated concept designs using weighted criteria selected in the Pugh Table. For reference design or datum we will use an existing design from Rutgers Ankle design [12]. Additional current robot-aided ankle rehabilitation device such as MecDEAR and NUVABAT will be added for validating the criteria for concept selection [13, 14]. Generally, Pugh Method is using three-point scale (-, + and S), under this situation this method can be expanded using a seven-point scale for wider range of selection. For example:

- +3- the best than
- +2 - much better than
- +1 - better than
- 0 - equal to
- -1 - worse than
- -2 - much worse than
- -3 - the worse than

This is a list of criteria for Pugh Method concept selection:

1. **Easy Maintenance** – This criteria is determined by looking at the type of actuator or mechanism. If actuator or mechanism has direct physical contact between each other usually it can contribute friction. This can contribute easy wear and tear. Example from existing design such as MecDEAR which is built under simple mechanism [13]. This simplicity allows less actuation involved in operating the robot which is easier to maintain rather than complex mechanism robot.

2. **High Maneuverability** – This benchmark is determined whether the concept mechanism can be able to maneuver and the ability of back drivability. The simpler the mechanism, the easier for the robot to maneuver. Example from existing design is MecDEAR and NUVABAT which have ability to move back and forth, without need for major readjustment thus they are better for maneuverability criteria [13, 14]. According to J.A.Saglia, simple kinematic is important to prevent mechanism failure and to limit cost, and suggested 2 DOF ankle rehabilitation robot [6]. Ideally it is better for a robot to produce exactly 3 DOF motion which is the same as the DOF motion of the ankle. This selection will fulfil most of important ankle rehabilitation exercises relating to passive and resistive treatment [3].

3. **Easy to Use** – This criteria is selected whether users can use the robot easily in terms of user interfacing. This factor can be determined by assembling every part of the robot and type of mechanism for the robot that needed to be encountered where simple mechanism is easier to use compare to complex mechanism. Example from existing design is MecDEAR where the mechanism is simple to control as it is built to fulfill one DOF [13].

4. **Low Cost** – This factor is selected by looking at the assumption cost of the concept selection. Usually more complicated mechanism for assembling contributes low marks for the Pugh Method. Example from existing design is MecDEAR which is a robot is simple in design with limited range of motion [13]. Complex mechanical device usually require a lot of cost in fabricating compare to a simple mechanical device.

5. **Re-Configurable** – Configurability is an ability for a robot that can be adjusted according to the ankle rehabilitation exercise whether the user is using manual or automatic adjustment. For example, if a patient wants to switch from range of motion exercise which is consist most of Eversion/Inversion and Dorsiflexion/Plantar flexion to balancing exercise which is consist most of Abduction/Adduction. He or She can configure the structure of the robot by placing central strut below

the platform as he or she will stand on the foot platform. The ability of reaching the certain motion of the ankle will be measured in degrees (°). Example from existing design is Yoon *et al*. which the robot can be configured to 3 main ankle exercises including heel toe raising [6].

6. **High Portability** - This benchmark is chosen based on portability of the conceptual design. This will be evaluated whether the robot can be functioned without the need of an additional equipment. Also, ease of assemble or dissemble can contribute the major factor for the design's portability. According to the literature, ideal estimated weight of the robot is between 5 to 15 kg. Additionally, the ideal estimated size of the robot between 30 x 30 x 30 (cm) to 50 x 50 x 50 (cm) [5-14]. Ideally, best portability is where the design can reach the minimum size and weight which is under 30 x 30 x 30 (cm) and under 3 kg as the weight of Anklebot weighs about 3.6kg [15]. However, in conceptual design stage, only qualitative measurement will determine the outcome of concept selection of the robot while quantitative measurement will be decided later under the embodiment design. Example from existing design such as MecDEAR which is operated by electrical actuator which allows the robot can be operational as a single unit [13].

7. **Safety** – This benchmark will be considered based on the ability of the design to be safe for patients. For example, if the platform of the robot turns more than expected, there will be a limit switch or a sensor that will able to stop the movement quickly. Examples from existing design are Jamwal *et al*. and Yoon *et al*. are they both are using sensors such as linear sensor and load cell to make sure that their robot are operating safely [6, 7].

8. **Fulfillment of ankle rehabilitation exercises** –This criteria will be looked based on the ability of the design operate to fulfill the ankle exercises by overcoming the mechanical restrictions. Example from existing design is Yoon *et al*. in which the robot has ability to fulfill most of ankle rehabilitation exercises such as balancing and ROM [6].

Table 3 Pugh method table

Measurement Criteria	Concepts						
	Weightage	DATUM	A	B	C	D	E
Easy Maintenance	10	R	1 (10)	1 (10)	0 (0)	-1 (-10)	2 (20)
High Maneuverability	10	U	1 (10)	-1 (-10)	1 (10)	2 (20)	2 (20)
Easy to Use	10	T	2 (20)	0 (0)	1 (10)	-1 (-10)	2 (20)
Low Cost	5	G	2 (10)	2 (10)	1 (5)	-2 (-10)	2 (10)
Re-Configurable	15	E	2 (30)	2 (30)	1 (15)	2 (30)	0 (0)
High Portability	15	R A	2 (30)	2 (30)	2 (30)	1 (15)	2 (30)
Safety	10	S N	1 (10)	-1 (-10)	1 (10)	-1 (-10)	2 (20)
Fulfillment of Ankle Rehabilitation Exercises	25	K	1 (25)	0 (0)	3 (75)	2 (50)	0 (0)
Overall Score	100	L	145	60	165	75	120
Ranking	-	E	2	5	1	4	3

5.0 RESULTS

According to Table 3, concept C is the best concept compare to other design concepts. Concept C scores 165 points compare to the nearest design which is 145 points. This design has scored greater in terms of fulfillment of ankle rehabilitation exercises and portability.

6.0 DISCUSSIONS

Overall, from concept generation and concept selection, Concept C is chosen due to its portability and most importantly concept C has ability to fulfill most of ankle rehabilitation exercises. Using pulley systems give mechanical advantage to the weight of the patients. Electrical actuator is selected due to portability of the design as electrical actuators don't require additional devices such as pneumatic compressor or hydraulic tank. This makes the design can be operated under a single unit and it can be moved by one person. Major differences between existing designs with design are portability where the proposed design is using electrical actuator instead of pneumatic actuator which allows the device to be operated under a single unit. In terms of configurability, the proposed design allows device to be configured with variety of ankle exercises thus allowing the device to fulfill most of ankle rehabilitation exercise compare to other existing robots. With combination of these two features, this design will help to pave the way the rehabilitation treatment is held at home. Additionally, this will allow the long-term ankle rehabilitation treatment to be performed at home instead of depending on the treatment at the hospital.

7.0 CONCLUSION

Based on Pugh method, a Pulley Driven Cable Based Parallel Mechanism Robot-aided Ankle Rehabilitation Device is selected for ankle rehabilitation based on ability of fulfilling most of ankle rehabilitation exercises and contributes high marks on configurability although it scoreless in portability compare to other design due to simplicity of the other design without need to manually reconfigure the robot. However, to fulfill most of ankle rehabilitation robot, we have to sacrifice the simplicity of the design. In doing so, patients can perform most of needed ankle rehabilitation exercise without need of secondary equipment.

In the next stage, embodiment design will be implemented on the selected concept design. Embodiment design involves modelling which involves kinematic and dynamic analysis. Additionally, this stage will decide suitable parameters of the robot such as weight, height, length and determined workspace. With simulation, movements of projected design can be analyzed for its feasibility. This simulation will help to move this project towards fabrication and testing with patients or healthy subjects.

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