Design and additive manufacturing of wrist therapy devices for people with muscle disorders

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Abstract. In this modern era, Indonesia is faced with MEA (ASEAN Economic Community). According to data from the Indonesian Ministry of Health as many as 95 degree of medical devices in Indonesia are still imported products. Health problems also occur in many industries. Muscle injuries in the wrist are ranked 3 with 14.3 percent of workers who have suffered muscle injuries. One of the rehabilitation activities that can be done is physiotherapy. Physical therapy devices are widely available, but wrist therapy devices are still expensive and difficult to obtain in Indonesia. Therefore, it is necessary to develop a device, so that can be produced domestically at low prices. One technique that can support the developing of rehabilitation device is additive manufacturing. This technique has been widely applied in rehabilitation sector, for example to create finger orthosis and adaptive aid tools used by therapies. It is very suitable for rehabilitation sector, because it can create tools that accurately follow a patient's unique anatomy. This study produces a device that can move patient's wrist flexion and extension, with maximum range of motion 70 degree from normal position. The whole design produces a weight of 0.8 kg which can be categorized as portable.

1. Introduction

Physiotherapy is a form of health service that aims to develop, maintain and restore the body's movements and functions, which experience aging, injury or disease [3]. In general, the physiotherapy process to improve joint function uses devices such as Continuous Passive Motion (CPM), which is a machine equipped with an external motor device and is used to train injured body parts [1]. According to data for 2019, Prof. Orthopaedic Hospital Dr. R. Seoharso Surakarta treated 10,796 injured patient's surgery or without surgery, which required recovery (physiotherapy). Due to the limited physiotherapy facilities, postoperative patients and patients without surgery must queue to get the chance to receive physiotherapy services. Meanwhile, according to the World Confederation for Physical Therapy (2017), the golden period for surgery patients using assistive devices is 7 days postoperatively and the time needed to perform recovery is for 4 to 6 weeks depending on the severity [6]. This shows that the availability of physical therapy devices is really needed.

Additive manufacturing can build 3D objects by adding material layer by layer, both materials made of plastic, metal, or concrete [2]. This technology is better known as 3D printing as one of the attractive alternative technologies because it has many advantages. Additive Manufacturing can make 3D things with a shorter time and more affordable costs compared to the old way [5, 9]. Additive Manufacturing technology also has a high level of design flexibility, considering that in the design of this therapy device, many modifications will be made, because the design must be in accordance with anthropometry and also be able to perform functions as planned [10].

2. Methodology
The primary elements of this study comprise an anthropometric measure of Indonesian hands, simulation of devices range of motion, Identification of Design Alternatives, construction design with CAD program, 3D printing, the development of Arduino-based control system, Assembly of all parts.

2.1. Anthropometric measure of Indonesian hands
The concept of wrist therapy device design uses anthropometric data in Indonesia with 95th percentile. Percentile 95 was chosen to accommodate 95% of all users of the device and also if used by people with small sizes the tool will not experience a decrease in function.

2.2. Simulation of devices range of motion
At this stage will be explained about the mechanical system design stage tool to suit needs. The wrist part connects the bone in the forearm, the radius and the ulna with the metacarpal bone in the hand. In the work system there is a string pull rope that connects between the main part and the handle that serves to move the handle.

2.3. Identification of design alternatives
At this stage a morphological chart will be formed, and an alternative determination will be made. In conducting the formation of a morphological chart, the first step is to determine the function attributes used.

2.4. Construction design with CAD program
Additive manufacturing stage is the stage of printing 3D objects from designs that have been created using CAD software. The 3D Printing process is used to make a prototype of the device.

2.5. 3D printing
The 3D Printing process uses the Prusa i4 III-8 Printer using PLA material. Stages that must be done before the 3D Printing process include the slicer software setup process and the 3D Printer management process. The process of setting the slicer software is used to determine the location of the object and adjust the factors that affect the printing results. The process of setting up the 3D Printer is used to ensure the 3D Printer can function properly.

2.6. Arduino-based control system
At this stage will be explained about the design of a series of control systems that are used to transmit commands to the actuator and also the programs used so that the tool can run in accordance with the functions that have been planned.

2.7. Assembly of all parts
At this stage will be explained about the design of wrist therapy devices that have been successfully developed. Prototype of a design therapy tool that was developed using materials such as polylactic acid (PLA).

3. Results and discussion
3.1. Anthropometric measure of Indonesian hands
The concept of wrist therapy device design uses anthropometric data in Indonesia with 95th percentile as shown in Table 1. The 95th percentile is chosen to accommodate 95% of all users of the device and also if used by people with small size the device will not experience a decrease in function.

Table 1. Anthropometric measure of Indonesian hands.

Dimension	Length (mm)
Hand length	183
Metacarpal length	101
Metacarpal width	81
Thumb hand width	99
Thumb width	47
Hand Metacarpal width	33
Grip to hand at horizontal position	767
Elbow to tip of finger	473
Forearm width	77

3.2. Simulation of devices range of motion

The design process is done using SAM software. The design of the fingers and thumb is adjusted to the ROM which is able to be reached by the human hand in performing flexion hyperextension movements as shown in Figure 1.

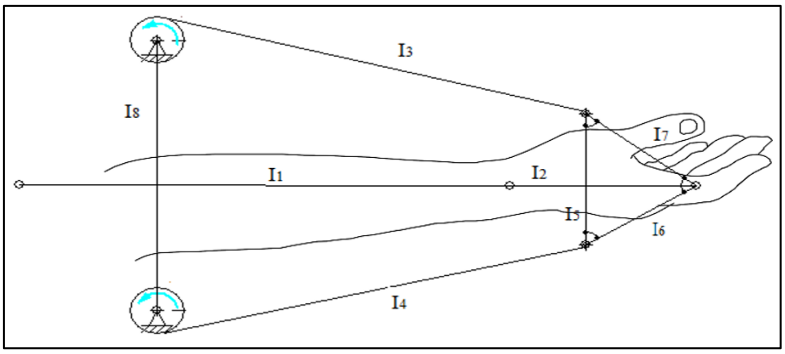

Figure 1. Mechanism of device design movement.

Adjustments are made to the design because at the end point I8 lies on the actuator where the chassis width must be adjusted so that it can be disassembly and there is enough space to position the electronic circuit. Adjustments will also be made to the hand brace section I5 because this section requires a stronger structure so that the design is made thicker so I5 length is obtained. For the length of the rope I3 and I4 will be calibrated first, adjusting the elbow length to the finger of the user. Trial and error are done to get the length of I5 and I8, then the length of I5 is 70 mm and the length of I8 is 140 mm. Furthermore, the tool flow simulation is performed to determine the range of motion of the design when motion and hyperextension occur as shown in Figure 2.

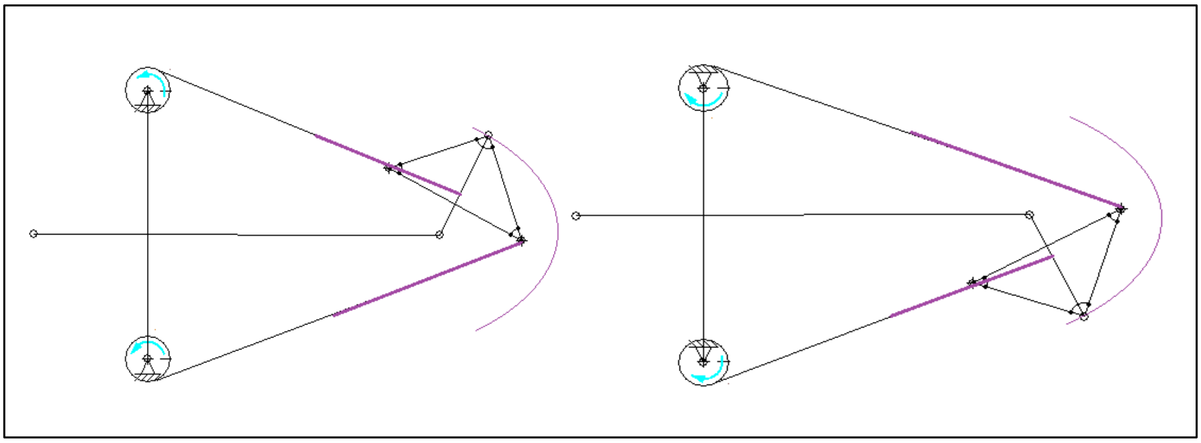

Figure 2. (a) flexion, (b) extension.

In the simulation design on SAM software, the maximum range of motion for flexion and hyperextension is 70 degree. In the picture above also shows that the mechanism of design motion can produce movements that resemble the shape of an arc. It can be concluded that the movement mechanism produced by the design can resemble the movement of the human wrist joint.

3.3. Identification of design alternatives

This morphological chart will be used in determining design alternatives. In conducting the formation of a morphological chart, first determine the function attributes used. The following are the function attributes used on the morphological chart as shown in Table 2.

Table 2. Function attribute.

Main Function	Parameter Function
Activating control	Controlling the device
Moving actuator	Generate mechanic movement
Drive	Continuing the kinetic force of the actuator

Furthermore, an alternative preparation phase will be carried out using the morphological chart method. The morphological chart method allows to obtain various alternative designs. The data used is the result data from internet searches and discussions with experts in the field of machinery as shown in Table 3 and Figure 3.

Table 3. Alternative parts.

Function	Alternative	
Controlling the device	On board	Wireless
Generate mechanic movement	Electric	Pneumatic
Continuing the kinetic force of the actuator	Lead Screw	String

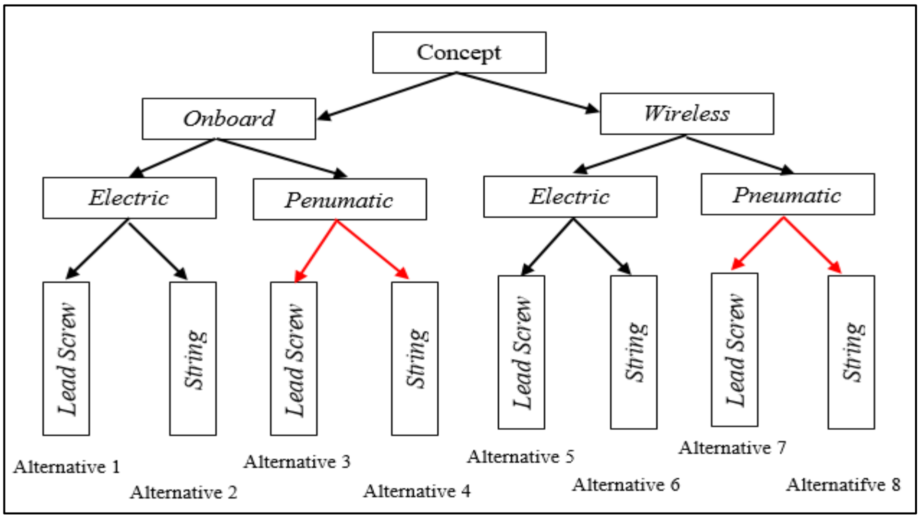

Figure 3. Decision tree alternative.

The value of each alternative will be calculated using the performance value and cost of each alternative based on the results of the previous stage. The calculation of the value of each alternative uses the basic formula of the value engineering method, which is a comparison between the value of performance compared to cost Table 4.

Table 4. Alternative ranking.

Alternative	Value	Rank
Alternative 1	7.42×10^{-7}	4
Alternative 2	1.79×10^{-6}	1
Alternative 5	1.11×10^{-6}	3
Alternative 6	1.66×10^{-6}	2

Then it can be concluded that the design of alternative 2 has the best value compared to other alternatives. Because the design already has a better value than other alternatives, then the chosen alternative will be used as a parameter in the formation of tool development at a later stage.

3.4. Construction design

Based on the design requirements that have been obtained, the design can be made according to existing design requirements. The design was made using Autodesk Inventor 2017. The design created consisted of chassis design, hand brace design, and support parts.

3.4.1. Arm chassis. This part is useful as the main support part of the arm, this part will also be a place for electronic and Arduino circuits as shown in Figure 4.

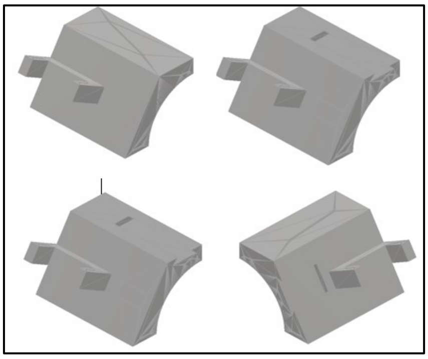

Figure 4. Arm chassis.

3.4.2. Hand brace. This part is useful as a hand grip, will be connected from the servo motor by cable so that the hand can move outward and inward as shown in Figure 5.

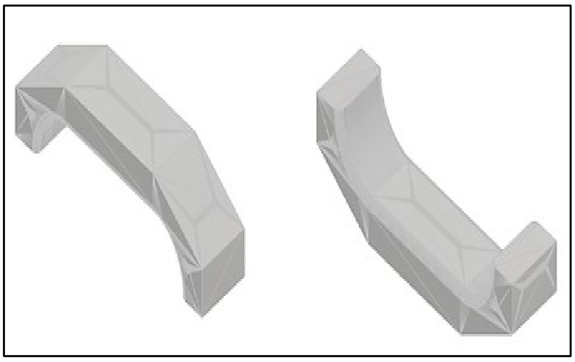

Figure 5. Hand brace.

3.4.3. Supporting parts. There are some parts that are useful as supporting parts with various functions, such as a connector, locking, and battery compartment as shown in Figure 6.

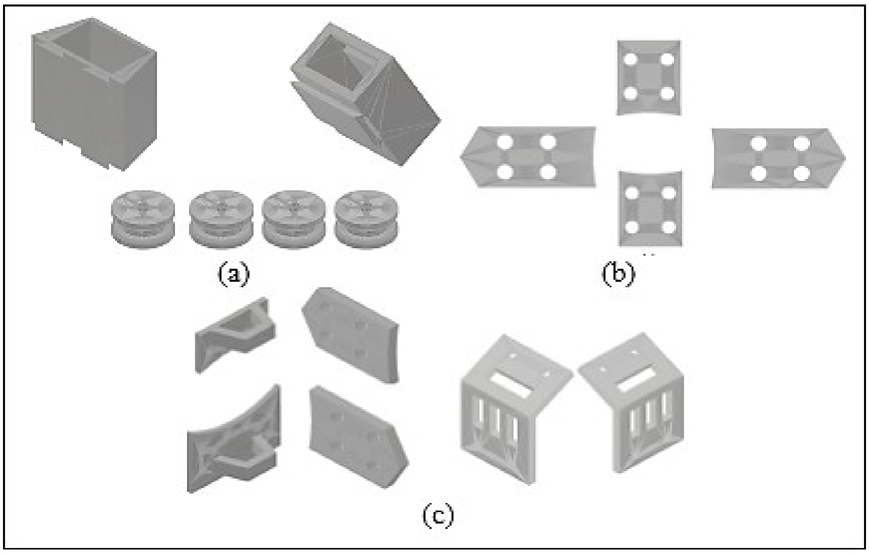

Figure 6. a) battery holder and servo mount, b) front lock, c) rear and hand brace lock.

3.4.4. 3D printing. The 3D printing process uses the Prusa i4 3D Printer with PLA material. The printing process is carried out using PLA material with an extruder temperature of 210^{0}C and a bed temperature of 60^{0}C. The layer height used is 0.2 mm with grid-shaped infill / filling. Extruder speed used is 40 mm / s. The printing process uses raft support and printing base [8]. The printing process uses support because there are parts of the object that hang so they need a support base. In addition to making adjustments to the software, hardware settings are also required namely the 3D Printer machine. The settings on the 3D printer are done manually by inserting the material into the extruder, adjusting the height of the bed in accordance with the height of the extruder so that the printing results match and regulating the temperature and try the initial position of the extruder [7]. The material that has been inserted into the extruder is certain to be able to come out well from the extruder and the position of the extruder is in accordance with the position of the bed so the printing process can begin as shown in Figure 7.

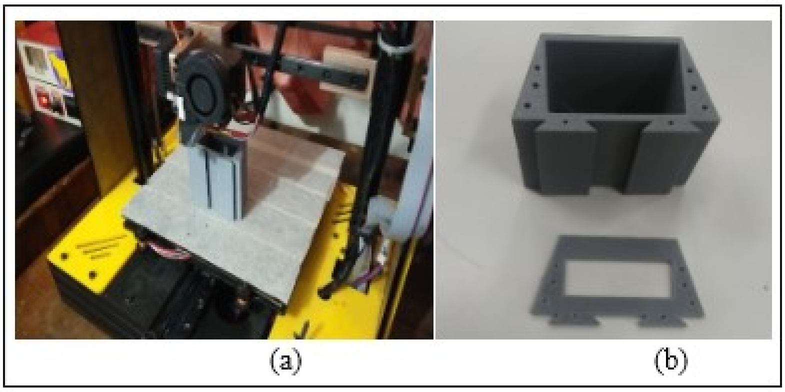

Figure 7. a) 3D print process, b) 3D print result.

3.5. Arduino-based control system.
The main controller used is the Arduino Uno microcontroller, this component will be made into the brain where the origin of control commands derived from the programming language will be transmitted all components. Next there will be two buttons that serve as input to the Arduino uno. The actuator used is a servo motor, the input signal from the button will be transmitted to the actuator so that the servo motor can move according to what has been programmed. The power source is in the form of one 9V battery box and four AA batteries, 9V batteries are used to deliver power to Arduino while AA batteries to servo motors. Components used to connect all other components to form a series of jumper wire as shown in Figure 8.

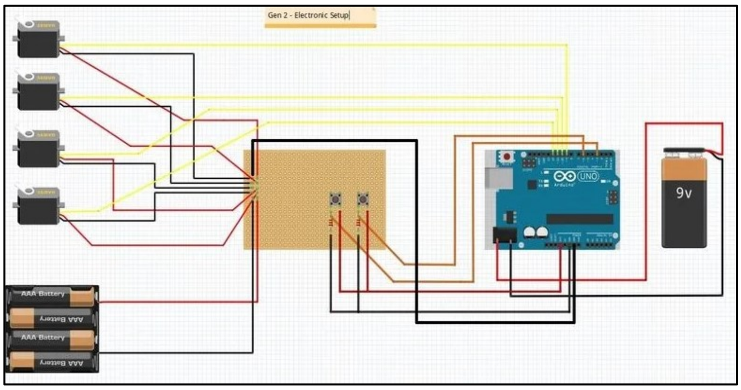

Figure 8. Arduino circuit design.

In the picture above it can be seen that the four servo motors as actuators use power that comes from AA batteries while Arduino comes from 9V batteries. Two buttons as inputs are connected to pin digital numbers 2 and 6 on Arduino, while four servo motors as output actuators are combined on pandigital numbers 9, 10, 11, and 12 on Arduino Uno.

The next step is designing the Arduino Uno programming language. The programming process is done using Arduino IDE software. The final result expected from the program is if the top button is pressed, then the upper servo motor will move 70^0 and if the bottom button is pressed, then the bottom motor will move 70^0, just like human wrist range of motion.

3.6. Assembly of proposed device

Prototype of a design therapy device that was developed using materials such as polylactic acid (PLA). Based on its material properties, PLA has a density level of 1.24 g / cm3. This material is a plastic material so that it can produce a light weight and is easily formed. As a whole the design produces a weight of 0.8 kg [4,8]. The following is the result of the development of a wrist therapy device design that has been successfully created as shown in Figure 9.

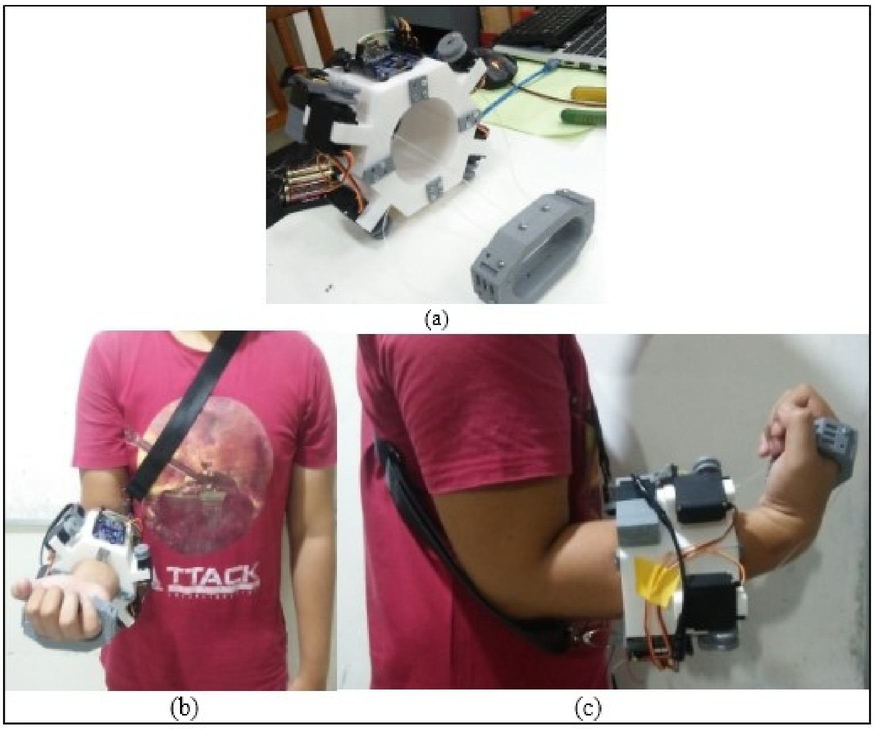

Figure 9. (a) Design result, (b) Example instalment, (c) Flexion movement.

3.7. Mechanism test

Tests conducted are testing the movement of the hand brace. The human hand can perform basic movements in flexion extension with a certain range of motion. Tests carried out using a control system that has been developed for this tool in the previous stage, namely the concept of the design of a driving mechanism with 4 actuators. The four actuators are used to pull the wrist, where the two upper actuators are for flexion movements and two lower actuators are for movements.

Testing is done by pressing the button in the controller. There are two buttons on the controller, the upper button will make the two upper actuators move according to the program, while the buttons below will make the bottom two actuators move according to the program. Furthermore, the string will move and pull the hand brace to form flexion and extension motion. Hand brace pulled by the string allows the hand to make flexion and extension movements. In flexion, the metacarpal can reach an angle of 70^0 from normal conditions. Same as, upper button, the results of the next test show the bottom actuator moves to pull the hand brace so that it can perform extension movements. In the extension movement, the metacarpal can reach an angle of 70^0 from normal conditions.

4. Conclusions

In this study, we try to develop the device that gives maximum full-function effectivity and low-cost design, these devices also design to be portable compared to the other existing device. Result of this study produce a device that can move patient's wrist flexion and extension, with maximum range of motion 70^0 from normal position. The whole design used PLA as material, this device produces a weight of 0.8 kg which can be categorized as portable. The physiotherapist is no required to run this tool, anybody even the patients itself can operate this devise easily at any places. This therapy device is expected to help the physiotherapist in carrying out the rehabilitation process. The proposed system used platform integrated with Arduino Uno. Utilization of additive manufacturing technology will facilitate the process of making this device by speeding up the time of manufacturing and maintaining the total cost relatively inexpensive. Therefore, the design by applying the addictive manufacturing process is able to assist in the manufacture of physical therapy device in an effort to restore muscle function as before which can be done independently, with making time that is faster and with affordable costs.

5. References

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