Force Adaptation Algorithm for Finger Exercise Using Kuka Youbot

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***Abstract*— The comfort and safety is still a major impact in designing a rehabilitation robot. This paper presents an adaptive control strategy algorithm for rehabilitation robot using KUKA Youbot for human finger. The algorithm is designed to handle the safety and comfort criteria during finger rehabilitation using finger force feedback. Two algorithms are developed to handle two different types of exercises for patient's finger. These algorithms are tested in VREP simulation software. The spring damper system is used to simulate the human's finger along with finger's mechanical properties. Both algorithms used forced feedback to adapt the limitation of a patient's finger. The 5 Nm was set as a safety threshold force that human can handle. The result shows that the algorithm has an ability to follow the safety criteria and can adapt the limitation of a human finger.**

***Index Terms*— Adaptation; force feedback; finger exercise; rehabilitation; KUKA Youbot.**

I. INTRODUCTION

The application of robots in rehabilitation can be classified as assistive and therapeutic [1], and it was designed to facilitate, rebuild muscle strength and the recovery of lost limb functionality [2–4]. Most of the wearable robot, i.e. exoskeleton is an assistive oriented application and is used to assist human to perform the motion in activities of daily living (ADL) [1,3,5,6]. In contrast, the therapeutically oriented robots are used to regain the patient capabilities and to recover the weak or lost function of human muscle or limb [1].

Controlling the robot in rehabilitation application is different with conventional robot application [7]. It is because the functionalities between these two types of the robot are different. The objective of rehabilitation robot is to encourage the patient to make a movement and at the same time to ensure that the movement is correct [7]. So that the selected exercises performed by the patient provoke motor plasticity, and, therefore, improve motor skills recovery [8].

Many methods are used for adapting in rehabilitation robot control strategies such as impedance-based [9], admittance based [10], feed-forward based [11] and neural network based [12]. The impedance control method has been widely used in rehabilitation robot due to its ability to maintain the human-robot interaction force below safe levels and controls the position of the actuator of the robot to map the patient movement [13,14].

Some researchers have addressed the effectiveness of impedance control strategies in rehabilitation robot, and it was shown that the torque control technique is more efficient to use in human-robot interaction when to deal with non-linear of the feedback input [12].

The impedance control strategy has a huge benefit in rehabilitation exoskeleton type robot because the additional force sensor can easily integrate and also the structure of exoskeleton robot is kinematically mapped to the human body.

However, most of the method mentioned so far limits on the discussion to fingers rehabilitation. The finger rehabilitation application is slightly different comparing to other rehabilitation. Patient suffer finger impairment due to after stroke survived or physically accident injuries (broken, dislocated, etc.). Grivas et al. [15] mentioned that the finger repositioning surgical is required if the finger injury due to a broken or dislocated are immobilized longer than three weeks. This is because the broken fingers are usually treated in a straight position, and it can be difficult to bend the finger once it has healed. Exercises such as tendon glides, blocking exercises and grip strengthening can improve finger bending after a fracture [16].

Based on this motivation, this paper presents two new algorithms for physical fingers stretching exercise using Kuka Youbot. The algorithms are designed based on constrained-induced training strategy concept that addressed in [8]. The proposed algorithm handles human-robot interactions in such way to avoid the uncomforted manner and to ensure the safety to reach its final position. Unlike others adaptation method that used adjusted controller's parameter to adapt patient's limitation, this algorithm adjusts the reference trajectory to adapt with the patient's limitation.

This paper begins with a system overview and action algorithm are describes in section 2. In section 3, the simulation setup and result of the method are presented. Finally, the conclusion of the adaptation algorithm and future works that still need to be addressed are discussed in the last section.

II. SYSTEM OVERVIEW

This section discusses the system overview and adaptation algorithm for the proposed system. Figure 1 shows the implementation of KUKA Youbot for finger rehabilitation. The purpose of exercise algorithm can be in flexion or extension finger direction. For the simulation, the extension direction exercise will be discussed. Figure 2 show the KUKA Youbot system block diagram. The system consists of prescribed action function and function selector as input with two feedbacks (force and position).

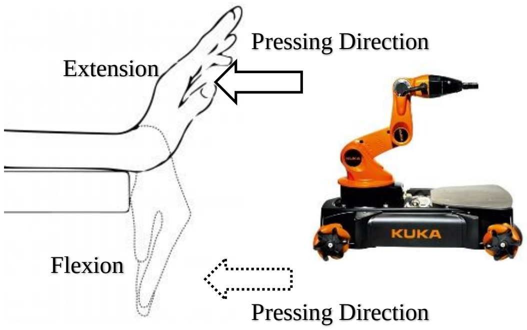

Figure 1: Implementation of KUKA Youbot in physical finger rehabilitation

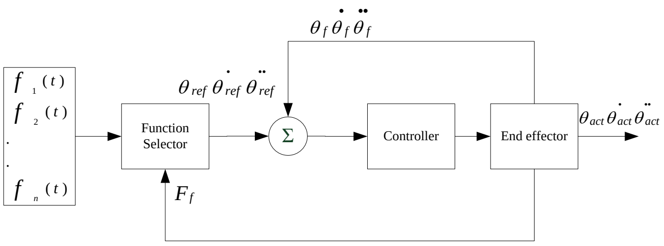

Figure 2: KUKA Youbot rehabilitation system block diagram

A. *Function Selector*

The function selector in Equation (1) is used to select the appropriate action function based on the threshold value and exercise to be executed. Equation (2) shows the value parameters in cubic polynomial trajectory generator as shown in Equation (8) that used to execute the joint before any action algorithm take action. In this paper, the discussion of two action functions for two different types of exercises, push-pull and push-stop-push action algorithm. The priority of these algorithms is to ensure the safety and comfort of the patient.

$$f_{(n)} = \begin{cases} f_1 & F_{TH} > F_f \\ f_2 & F_{TH} \leq F_f \\ f_3 & F_{TH} \leq F_f \end{cases} \tag{1}$$

$$f_1 = \begin{cases} a_0 = \theta_0 \\ a_2 = \dfrac{3}{{t_f}^2}(\theta_f - \theta_0) \\ a_3 = \dfrac{-2}{{t_f}^3}(\theta_f - \theta_0) \end{cases} \tag{2}$$

$$f_2 = -f_1 \tag{3}$$

$$f_3 = \begin{cases} a_0 = \theta_i \\ a_2 = \dfrac{3}{{t_{fi}}^2}(\theta_{f(i)} - \theta_i) \\ a_3 = \dfrac{-2}{t_f i^3}(\theta_{f(i)} - \theta_i) \end{cases} \tag{4}$$

Where;

$$\theta_{(i)} = \theta_{f(i-1)} + \Delta\theta \tag{5}$$

$$\theta_{f(i)} = \theta_i + \Delta\theta \tag{6}$$

$$t_{f(i)} = t_{f(i-1)} + \Delta t \tag{7}$$

B. *Reference Trajectory Generation*

Cubic polynomial trajectory planning is used to control each joint of Kuka Youbot finger manipulator. The trajectory is used as a reference trajectory before action algorithms take effect during exercise. The cubic polynomial can provide smooth motion for each joint (no via-point required for this exercises). Equation (8) shows the cubic polynomial equation

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \qquad F_{TH} > F_F \tag{8}$$

There are four unknown parameters as shown in equation (2). To find the parameters there are four boundary conditions of initial and final position and velocity must be satisfied as shown in Equation (9)

$$\begin{aligned} \theta(t_0) &= \theta_0 \\ \dot{\theta}(t_0) &= v_0 \\ \theta(t_f) &= \theta_f \\ \dot{\theta}(t_f) &= v_f \end{aligned} \tag{9}$$

The measured of exerting force is happening at all the times during exercise. The feedback force (FF) on the finger is measured and comparing it to the threshold value (FTH). The function of this threshold value is to ensure the safety and comforts of the patient [17].

Algorithm 1

Figure 3 shows the push-pull algorithm for the KUKA Youbot robot. The force sensors are placed on top of damper system (represent as human finger) and at manipulator end effector (gripper). The measuring of force (force finger, FF and force gripper, FG) are evaluated all time during the exercise. During the action algorithm, when the FF (FF = -FG) exceeded the FTH, the equation (3) will be executed and the position of Youbot end-effector will turn back to its starting position. The algorithm is behaving in such way because we want to ensure that the safety and comfort of the patient rehabilitation process at all time.

Algorithm 1 push-pull adaptation approach
F_th = a
Damper_Height (max) = b
Damper_Height (min) = c
while (Damper_Height > Damper_Height (min)
Damper_Height (new) = Damper_Height – 0.01
F = Fsensor
if (F<F_save)
move robot to Damper_Hight = Damper_Height (new)
end if
if (F>Fsave)
move robot to Damper-Height = b
break
end if
end while

Figure 3: Push-pull algorithm

Algorithm 2

Figure 4 shows the push-stop-push adaptation algorithm. During the process, the rehabilitation robot tries to get the desired end position of the finger (Zdesired). Any contact with patient's finger will affect the torque causing the increase and decrease velocity of the robot end effector. When this occurs, equation (4) will be executed. Manipulating this behavior, the robot will push the patient's finger step by step and hold the position for a while before continuing pushing until it reaches the final position.

Algorithm 2 push-stop-push adaptation approach

```
F_save = a
Damper_Height (max) = b
Damper_Height (min) = c
while (Damper_Height>Damper_Height (min)
      F = Fsensor
      if (F>F_save && Damper_Height>Damper (min))
            move robot to Z_pos = Z
            stop (1s)
      end if
      Z = Z_damper (max) -0.01
end while
```

Figure 4: Push-stop-push algorithm

III. RESULTS AND DISCUSSION

This section contains two parts. The first part covers the simulation setup for Kuka Youbot in VREP simulator while the second part is discussion on the result from VREP simulation using two action algorithms in VREP simulator.

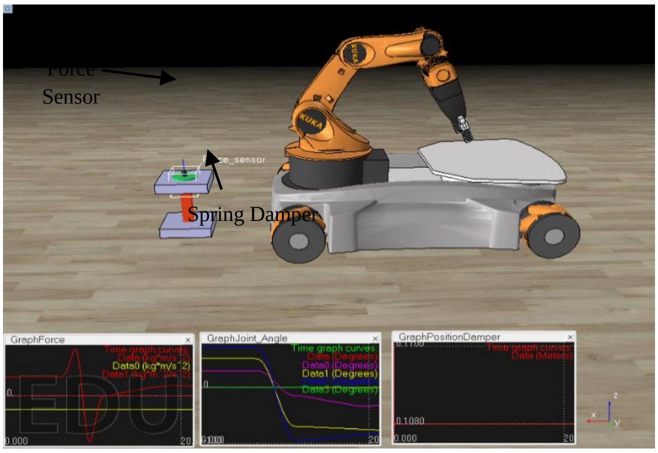

Figure 5: VREP environment simulation setup

A. Simulation Setup

In this simulation, the KUKA Youbot robot is used to demonstrate the force adaptation algorithm for human finger during rehabilitation. The algorithms are tested on VREP simulation software. Figure 5 shows the simulation setup for KUKA Youbot in VREP. For the simulation, the spring-damper system is used to represent human finger. Table 1 shows the spring-damper coefficient for the middle finger that adopts from [18].

Table 1
Mechanical Parameter For Middle Finger Data Based On [18]

Patient	Spring Constant N/m	Damper Coefficient (N*s/m)
Young	491.5	4.61
Elderly	628.4	4.21

The force sensor is placed on the top of spring-damper to measure the applied force from KUKA Youbot to spring-damper system during the simulation. The threshold force (FTH) is set to the value of 5 Nm. This value represents the maximum force that a human finger can handle without incurring any uncomfortable pain for our simulation.

B. Simulation Result

Figure 6 shows the simulation result for the algorithm 1 and Figure 7 shows the simulation result of the algorithm 2. The simulation shows the general safety behavior for both algorithms based on force adaptation that implemented in both algorithms. Based on the results, the KUKA Youbot robot tried to adapt the limitation of the spring-damper (represent one human finger).

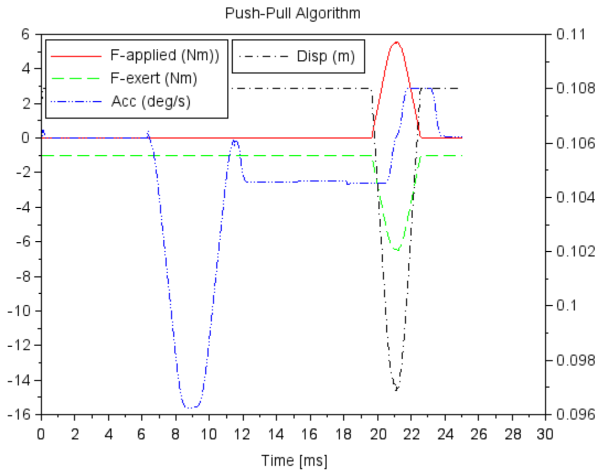

Figure 6: Result for first algorithm

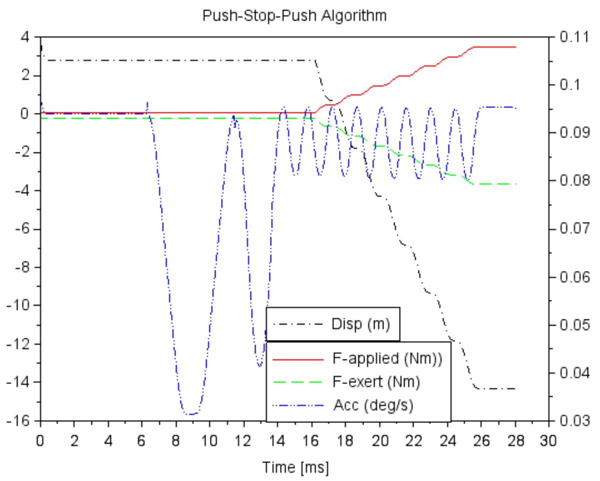

Figure 7: Result for second algorithm

In this situation the maximum painful force, FTH is set to 5 NM. This value is not representing an actual painful force for human finger and only for a simulation purpose. The Youbot stop pushing the damper and back to its original position before pushing the spring-damper (refer to an oval dash area) as shown in Figure 6. This algorithm result shows that it has an ability to adapt any force limit which has been set before the rehabilitation exercises started. However, in a real application of rehabilitation, the Fth is varied between human due to physical parameters such as weight, finger size, age, and also the types of injuries.

Based on the result as shown in Figure 7, the Youbot tries to the target position by step until it reaches target position of spring-damper. From the result, it shows that the robot behaves such that way to reach a final position in a less painful manner by increasing the time to reach the target position. This gives time to the patient to adapt painful during the rehabilitation process. However, in the real application the position and force exert in rehabilitation may differ due to the patient finger and finger physically.

IV. Conclusion And Future Works

In this paper, we present a methodology to solve the problem of force adaptation during rehabilitation using the push-pull and push-stop-push algorithm. We also demonstrate that the simulation result has an ability to adapt the uncertainties of human reflect force during rehabilitation and safety condition for the patient's finger. This algorithm still needs improvement before it can be used in real rehabilitation proposed. Some concerning questions such as, how many exerts force that patient can finger during the exercise. In this simulation, all the forces values are all assumptions and not real exact values for human. Other question like, how to select the prescribed training automatically, adapt and modification of prescribed training based on patient limb limitation also has to be considered.

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