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IMPROVING ACTIVE DISTURBANCE REJECTION DRC CONTROL FOR ROBOTICS HOME-BASED TO LOWER EXTREMITY REHABILITATION CARE

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A B S T R A C T

This study is intended to be used as a fundamental guideline for developing locally established restoration frameworks for exoskeletons (Robotics), particularly in the event of the COVID-19 pandemic. This work describes a one-degree-of-freedom exoskeleton-leg dynamic demonstration and control recreation (automated knee joined with sitting level). The linear active disturbance rejection control (LADRC) and the corresponding proportional-derivative-integral (PID) controller for position and speed control are the two regulators that make up the control structure. The findings of the MATLAB reconstruction reveal that the proposed regulator (LADRC) has a respectable potential for providing scheduled recovery treatment to reduce appendages, particularly for direction following error. The results of the proposed controller (LADRC) demonstrate quicker reactions with settling time and steady-state error are very small.

1. INTRODUCTION

In the last 20 years, an increasing number of neurological conditions such hemorrhage, spinal cord damage, and Disease were reported for people of all ages. The World Health Organization (WHO) identified "brain hemorrhage" as the third leading cause of weakening worldwide and one of the main causes of over 5 million casualties between 2000 and 2016 due to the development of certain illnesses, The demand for recovery administrations is rising globally. Controlled lower extremity orthotic devices, often known as motorized skeletons, and frequently regarded as aids in rehabilitation and the improvement of human gait. These devices have undergone extensive development and presentation work, and there are still numerous problems that need to be studied due to the inherent demands of flexibility and safe interaction with the user and the environment. The control of these devices is conceivably one of the major approaches for working on their exhibition (Young & Ferris 2017).

The analysts have been addressing existing provokes and prerequisites to configuration, control and develop recovery robots appropriate for home treatment. Subsequently, many at-home recovery gadgets have been planned inside the exploration domain (Aylaret et al., 2021).Additionally, the present state of the global crisis increases interest in robot-assisted restoration frameworks in order to reduce the risk of contamination for both patients and medical care provider organizations (Kimmiget et al., 2020). Robot-helped recovery practice for useful variation of knee joint broadens an extraordinary chance for post-stroke patients. Likewise could be an extraordinary apparatus

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to gauge utilitarian enhancements of muscles and joint movements.

An robotic leg's instrumentation setup is capable of performing accurate location and power estimations as well as being prepared to collaborate with humans (Huanget et al., 2019). More critically, electro-mechanical actuators of the framework can play out an undertaking more than once inside the ideal work area of a joint.The test in this field is to discover suitable control systems for these gadgets, which can be adjusted to the useful abilities of the clients, for a consistent intellectual and physical interaction. Hence, users and exoskeleton should cooperate during restoration, in an instinctive and synergistic way, to permit more normal developments, and work with their contribution for an improvement at their neural versatility. For this reason, diverse control approaches dependent on movement aim have been accounted for to work on the exhibition of the exoskeleton to execute activities that are both fitting for the restoration errand and compares to the client's assumptions (Tuckeret et al., 2015). Due to the dubious components and the inadvertent subject's reactions during walk recovery, the design of an exact control system for a low appendage skeleton framework does not present many challenges. For more than a decade, lower appendage exoskeletons and orthoses have been controlled by typical automated stages.

The purpose of the exoskeleton control is to aid the wearer in partially or completely reestablishing engine function. The majority of these recent publications emphasize the use of conventional PD or PID control techniques. It is well recognized that these regulators are weak to model errors and disturbances (Akhtaruzzamanet et al., 2020). For (Rifaiet et al., 2011), a bounded control force was applied gradually while employing the EICOSI orthosis to regulate a lower appendage orthosis placed to the knee joint for restorative items. Observations revealed a good match between patient joint development and the expected path in a respectable amount of time. It is suggested in Mefoued et al. (2011) to employ a controlled knee-joint orthosis to restore human lower appendage growth, particularly the knee extension of the lower leg.

The control method relied on the Higher Ordering Sliding Mode Control (HOSMC) process. To assess the suitable control law's robustness, testing using conventional PID regulators was conducted. HOSMC's display tends to be more well-liked. To comprehend the regular gait, however, very few scientists have looked at the best control, in particular the linear quadratic controller. Additionally, by approximating the linear time-changing structure and substantially limiting the computational complexity linked to a few nonlinear regulators, LQR as a linear control plan may be utilized for nonlinear framework components (Knee joint model). However, the LQR is the best control strategy and should be used to identify ambiguous exoskeleton components (Castro & Zhong, 2018). However, chattering due to erroneous exchanging is a problem for the sliding mode control (SMC) technique, which can limit against vulnerabilities and boundary vacillations [Wei & Aiguo 2020; Li et al. 2014). Before the concept of active disturbance rejection control (ADRC) recently emerged, there was some work to be done managing the plant's uncertainties, including the affects of disturbances and its obscure components.

Numerous designing tools use it (Parvathy & Asha 2013; Huang & Xue 2014) to overcome these control issues at hand. The basic motion of the human knee, as according to biological traits, is flexion-expansion in the frontal plane. In this approach, the plan of the device knee always has a single absolutely turning DOF (Liet et al., 2019). The advantages of this approach include a reduction in weight and an increase in the complexity of the exoskeleton and control frameworks.

This work introduces the design and control reproduction of a 1-DoF automated limb for knee practice in order to reduce weight. An exceptional seat is attached to the limb so that a disabled person can be seated on it and perform treatments for their knee joints. In this work, an input regulator, which makes up for the absolute unsettling influences by simple linear active disturbance rejection control (ADRC) is intended to balance out knee movement joint controller framework. The paper's contribution of this study can be highlighted by the following points:

- An improved ADRC built by modified the ESO for traditional ADRC depending on desired trajectory response with a one design parameter related to closed-loop poles location.
- The proposed controller satisfied the stability criterion by using pole-placement technique.
- Study the validity of modified ESO for estimation and cancellation by a proper controller law

2. METHODOLOGY

In this section, we introduce the basic concepts behind the knee-joint mathematical model, as well as the ADRC control elements, and develop the suggested controller.

2.1 Knee-joint mathematical model

As shown in Figure 1, which depicts the skeleton is controlled through a controller that transmits power to the lower leg, the relatively lower extremity framework in this article consists of a person wearing an activated orthosis chair that swings in around lower leg. Throughout this framework, the strap synchronizes movement between the two portions and links the exoskeleton to the human leg. The considered dynamic orthosis's mechanics design outline shows that is the exact position of the involved knee joint, in which $\theta = 0$ rad refers to complete leg extension, $\theta = \pi/2$ rad is the resting condition, and $\theta = 3\pi/4$ rad is the maximal leg flexion.

The top and bottom halves of the motorized exoskeleton each have (1DoF). An active segment of a DC brushless motor drives the top portion. Typically, the person leg and the incorporated motorized exoskeleton constitute up the system. The exoskeleton is a piece of machinery that is fixed to the participant's knee using straps and fits properly on that leg. The corresponding models for the shank and orthosis will be derived similarly. It is based on the kinematic concept of materials in rotational:-

$$J\ddot{\theta} = \sum \tau_i \quad (1)$$

Jrepresents the overall inertia, and τ represents the torques applied to every joint's leg orthosis. The lower leg joint orthosis model can be expressed as follows using the Lagrangian formulas (Han 2009; Hala et al. 2012; Kashif et al., 2019):

$$J\ddot{\theta} = -\tau_g cos\theta - Asgn\dot{\theta} - B\,\dot{\theta} + \tau_h + \tau_e \quad (2)$$

Where $\dot{\theta}$ and $\ddot{\theta}$are, respectively, the lower leg angular velocity and acceleration, and θ is the knee joint angle between the exact place of the shank and the fully adjustable location,while τ_e is the desired exoskeleton torque.The solid friction factor, viscosity friction coefficient, gravity torque, and person disturbance torque are denoted by the letters A, B, τ_g, and τ_h. The measurements of the adult limb are listed in Table 1 (Hala et al.,2012; Kashif et al.,2019).

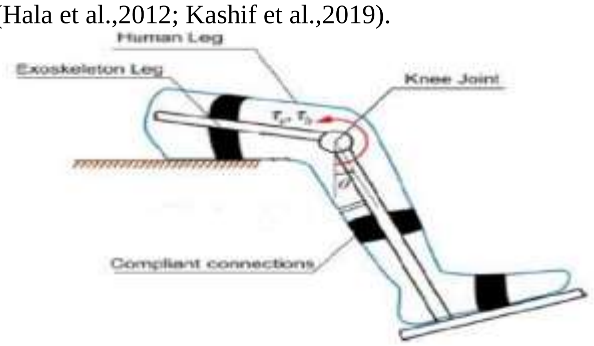

Figure 1. An exoskeleton around the knee

2.2 ADRC design

In the remainder of this work, an ADRC is intended to manage the following issue for the knee joint 1-DoF controller framework presented in the section 2.1 .The outline of the planned control framework is displayed in Figure 2.

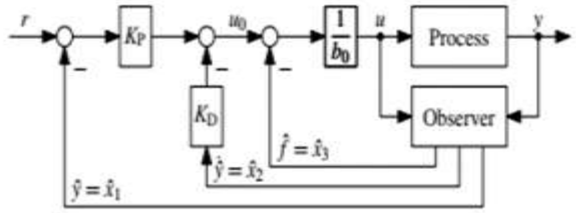

Figure 2. ADRC structure

To prevent overflow and enhance control performance, divide the reference input signal into two parts. The first portion should represent the desired trajectory, and the second should be its derivative. Consider the powerful framework in equation (2) that can be represented by the development of a second order nonlinear conceptual framework:

$$\ddot{\theta} = f(t, \theta. \dot{\theta}, w) + b\tau \quad (3)$$

b is a boundary that is an established one. The abbreviation "f" refers to the combined effect of internal and external influences. In actual situations, it is usually difficult to get an exact mathematical representation of f. ADRC offers a really important solution to this problem. The key idea is that, if f can be evaluated gradually in some fashion, it will typically be dropped using the control action, turning equation (3) into a second integration process. In other words, a time - variant unidentified system of equation 2 is roughly decreased to a continuous - time basic system that may be successfully regulated using, for example, a PD regulator. This ingenious idea is what changes a control problem into an estimating problem. The following is how the suggested layout is presented:-

A- Extended-state observer (ESO)

The structure in equation (2) can be expressed using the state space form shown as: (Han, 2009; Wammeedh et al., 2020;)

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = x_3 + b_o\,\tau \quad (4)$$
$$\dot{x}_3 = \dot{f}$$
$$y = x_1$$

When equation (4) expressed in state-space matrix notation:-

$$\dot{x} = Ax + B\tau + Eh$$
$$y = cx \quad (5)$$

Where

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix},\ B=\begin{bmatrix} 0 \\ b \\ 0 \end{bmatrix},\ E = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix},\ c = [1 \quad 0 \quad 0] \quad (6)$$

The observer of equation (5), in this case takes the form of the most widely used linear Luenberger-like estimator, which is:-

$$\dot{\hat{x}} = A\,\hat{x} + \hat{b}\tau_c + L\,(y - \hat{x}_1) \quad (7)$$
$$\hat{y} = C\,\hat{x}$$

Where,$\hat{x} = [\hat{x}_1 \hat{x}_2 \hat{x}_3]^T$ is the respective vectors representing estimates for y, $\dot{y}$, and f. Since the state vector in equation 4 is expanded to include f and this observer is made to offer an estimate of that, it is known as the ESO. When properly planned and executed, the observer equation (7) will track the plant in equation (5). The pole-placement approach, for instance, can be used to determine the variable vector L (Mefoued, 2014). Let the characteristics equation for the ESO design be as follows for simplicity:-

$$Q(s) = |SI - (A - LC)|$$
$$= (S + w_o)^3 \quad (8)$$

And the observer gains can calculated as:-

$$L = [3\, w_o \quad 3\, w_o^2 \quad w_o^3] \quad (9)$$

There are just two borders in the ESO: b_o and w_o. Engineers are familiar with the former, and it can also be obtained by open-loop system response or ($b \approx b_o$). The final stage is an adjusting parameter that increases the observer's bandwidth. Productivity and noise sensitivity can indeed be significantly compromised by tuningW_o.

The state space equation (4) can be expressed as (Wameedh et al., 2020; Wameedh et al., 2021) to modify ESO for increasing the ADRC performance.

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = -w_c^2 x_1 - 2w_c x_2 + x_3 + b_o\, \tau \quad (10)$$
$$\dot{x}_3 = \dot{f}$$
$$y = x_1$$

Where $w_c$controller bandwidth. The desired closed-loop transfer function given by:-

$$\frac{Y(s)}{R(s)} = \frac{w_c^2}{s^2 + 2w_c s + w_c^2} \quad (11)$$

The modified ESO for equation (10) and related to equation (7) is:-

$$\dot{z}_1 = z_2 + \alpha_1(y - \hat{y})$$
$$\dot{z}_2 = -w_c^2 z_1 - 2w_c z_2 + z_3 + b_o\, \tau + \alpha_2(y - \hat{y})$$
$$\dot{z}_3 = \alpha_3(y - \hat{y})$$
$$\hat{y} = z_1$$

The modified observer gains are calculated as:-

$$\alpha_1 = 3w_o - 2w_c$$
$$\alpha_2 = 3w_o^2 - w_c^2 - 2w_c\alpha_1 \quad (12) \alpha_3 = w_o^3$$

As seen from the equation (12), the first parts of it is the same as equation (9).

B- Controller design

Where estimate of $x_3 \approx f$, it can be get the control strategy :(Han, 2009; Mefoued, 2014)

$$u = \tau = \frac{(w_c^2 r - f)}{b_0} \quad (13)$$

So that reduce equation (3) to simple second order:

$$\ddot{y} = \ddot{\theta} = -2w_c\dot{y} - w_c^2 y + f + b_o\left(\frac{-z_3 + w_c^2 r}{b_o}\right)$$
$$\approx -2w_c\dot{y} - w_c^2 y$$
$$+ w_c^2 r \quad (14)$$

Equation (14) is identical to equation (11), when represent as transfer function. To calculate w_c and w_o , these related to design specifications, specially the settling timeT_s, so that (Chen et al., 2011; Gao, 2003):

$$w_c = \frac{10}{T_s} \quad (15)$$

In this study, if select T_s=0.4sec, then $w_c = 24.5 rad/sec$ and the value of observer bandwidth w_o is calculated as $w_o = 4w_c$ (Gao, 2003). Figure 3 show modified ADRC for any order.

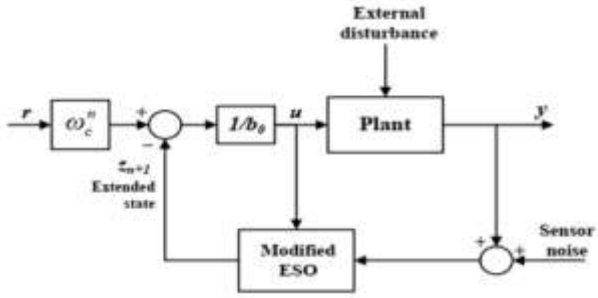

Figure 3. ADRC with modified configuration

3. SIMULATION RESULT AND DISCUSSION

This part considers a numerical simulation to show the performance of the proposed control method. The following conditions are selected for equation (2) (Hala et al., 2012; Kashif et al., 2019):

$J = 0.4\ kg.m^2$,$A = 0.6\ N.m$,$B = 1\ N.m.sec.rad^{-1}$ and $\tau_g = 5\ N.m.$

3.1 Without effect of disturbance

The proposed ADRC and comparing with PID controller were tested by carrying out the simulation in MATLA MathWorks. In this work the desired trajectory of the knee joint is taken as predefined by the doctor is (sinusoidal input) with magnitude (0.5) and frequency (2rad/s)and for general test signal(step input). In this case the performance of the proposed ADRC is compared with classical controller (PID) without external disturbance. The PID controller settings ($K_p = 150$, $K_i = 80$,$K_d = 15$) are calculated by trial and error and some tuning. The observer gains of equation 12 are ($\alpha_1 = 239$,$\alpha_2 = 16501$, $\alpha_3 = 941192$).Figure 4 show the trajectory tracking performance of mentioned controllers for the knee joints for step input and Figure 5 for sin input.

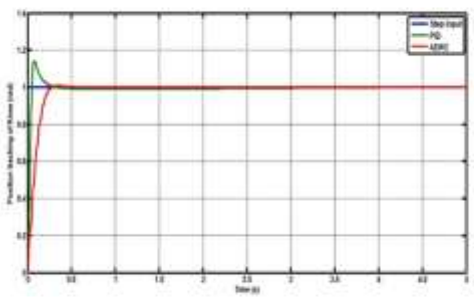

Figure 4. Trajectory tracking comparison between ADRC and PID controller without disturbance for step input

As seen from Figure 4 the maximum overshoot M_p=0.005% for ADRC and M_p=14.4% for PID controller, while the transient response speed for

ADRC is very high ,when compared with PID to reach the steady-state. The root mean square error(R.M.S.E)for ADRC is(0.0024rad),while for PID is(0.982rad). The trajectory tracked by ADRC has best reference tracking than PID controller. For sin wave input as shown in Figure 5, also it is clear that the differences in transient trajectory and appear the improvement of ADRC.

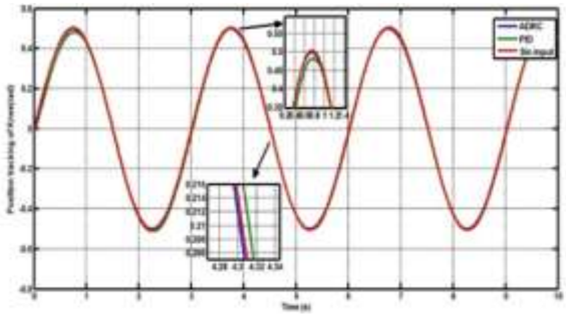

Figure 5. Trajectory tracking comparison between ADRC and PID controller without disturbance for sine input

3.2 With effect of disturbance

We also assess the ADRC and PID control's ability to reject perturbations only with introduction of a permanent disruption. They are all set to produce the very same closed loop response. After attaining steady state, a unit step perturbation of magnitude (5N.m) is introduced to every control loop for a one-second duration. From Figure 6, it is clear that ADRC corrects the disturbance much more quickly, ensuring that its impact on the control variable stays minimal. Though PID controller could also be compensated with high overshot and take more time to reach the steady state. This state also can be conclude for sine input signal as shown in Figure 7.

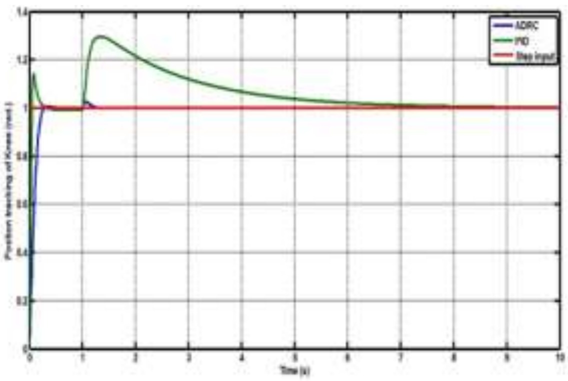

Figure 6. Trajectory tracking comparison between ADRC and PID controller with constant disturbance for step input

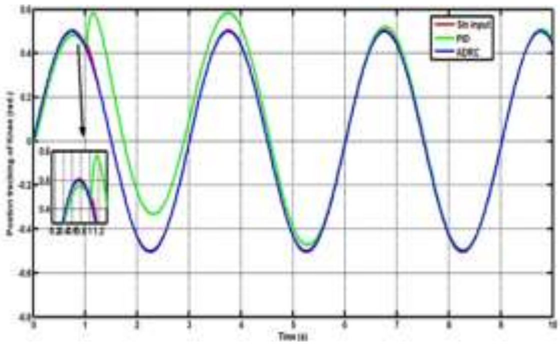

Figure 7. Trajectory tracking comparison between ADRC and PID controller with constant disturbance for sine input

3.3 Validity of ESO

The way to the success of the ADRC is the ESO, which empowers the regulator to effectively make up for the progressions in the dynamics (inertia) or the unsettling influences. To see the adequacy of the ESO, we plot the estimation state (z_3), against its objective (total disturbances), and complete unsettling influences, which is the subordinate of $f(.)$.In Figure 8, it is shown that z_3 tracks, the complete aggravations $f(.)$ intently and R.M.S.E value is (0.07058rad). This permits the control law u(t) to move the plant in Equation 3 to a roughly double integrator, which can be effortlessly controlled with the PD controller .Figure 9 shows the transient trajectory error at force aggravation (sin wave) with magnitude (1) and frequency (0.5rad/s) with R.M.S.E value is(0.004262rad).

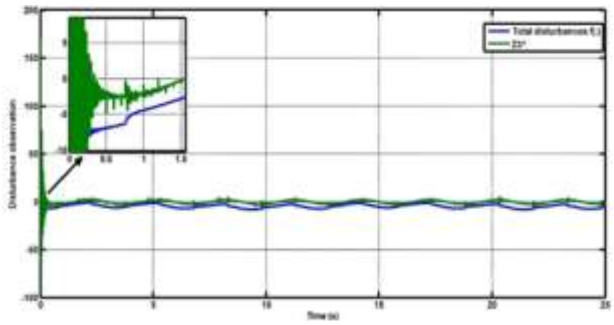

Figure 8. Total disturbance and its estimation

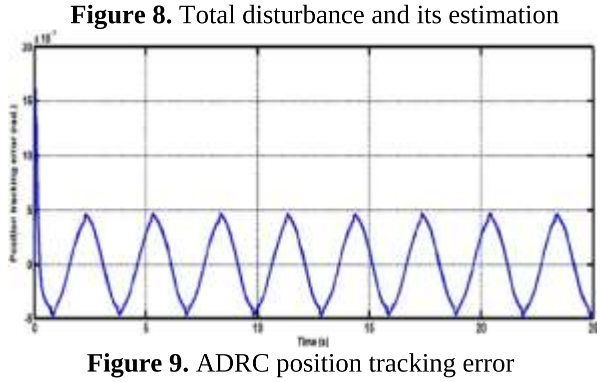

Figure 9. ADRC position tracking error

4. CONCLUSION

This study proposes a dynamic representation and reproduction of an exoskeleton-assisted knee joint exercise recovery system. This paper shows a control scheme for a 1-DoF exoskeleton leg's trajectory tracking. By reproducing for various input kinds, the suggested control engineering's reasonability is evaluated (step, sine). The main goal is to exercise the knee joint with the aid of an exoskeleton, ensuring a consistent and steady movement design. This type of scheduled restoration framework is desired for medical helpful practice in the COVID-19 situation to ensure the separation relationship while providing the types of support to the patients. The fundamental goal of this work is to draw out the advantage of arranging control techniques towards hearty methodology for human help and restoration cycles to make up for changes in the human-orthosis elements. Two different control laws (PID, ADRC) were tested in different operational scenarios. The results reveal that, when compared to the PID controller, the ADRC controller exhibits the least error and the smallest overshoot. When such perturbations are present, the modified ADRC controller performs as desired in respect of position error. Although the estimation error tends to reduce as observer bandwidth rises, this has the opposite effect on control action, which rises as observer bandwidth increases, particularly with step input.For showing the effectiveness of ESO, it is clear that the extra estimated state variable (z_3) can be cancelled the total disturbances (external toque and uncertainties) with R.M.S.E is (0.07058rad) and the error between the reference input(r) and the position trajectory output (y or θ) is almost equal zero, with R.M.S.E is(0.004262rad). This research can be expanded in the future by including new observation techniques or designing additional control systems, either to improve the ADRC or to compare performance (Humaidi et al., 2018a; Humaidi et al., 2018b; Aljuboury et al., 2022; Humaidi & Badr, 2018; Nasir et al., 2022; Alawad et al., 2022; Shaymaa et al., 2022). The suggested controller for 2-DOF of motion, which is used with the Knee-Hip Exoskeleton system, may be expanded in future study.

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