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Advantages of Series Elastic Actuator Controller Design: A Review

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Abstract: **-** The goal of this study is to offer an operational model for a group of elasticity actuation which could satisfy the morphological and payload criteria of industrialised cooperative robotic tyrants Flexible actuation defy the maxim that "stiffer is better" in machine layout, whereas being widely advertised because its benefits like excellent pressure loyalty, exceptionally low resistance, decreased abrasion, and a broad power regulation bandwidth. For integrated monitoring of robotics in broad spaces, Sequential Stretch Actuators (SEAs) are especially appropriate. We describe the output-feedback torque management approach for SEAs, that employs a form of filtering to predict mobility indicators and systemic aggregated disruptions, to address parameter uncertainties and external disturbances. By doing this, the controller's resistance to system uncertainty is strengthened. Projects that employ series elasticity actuators, especially position control, can frequently have performance constraints as a result of poor controller design. However, because of its low impedance, great force fidelity, and built-in shock resistance, SEAs are perfect for a wide range of applications. Legged robots, exoskeletons, robotic arms, haptic interfaces, and adjustable suspension are some of these uses. We also demonstrate that the control process and controller types for SEAs differ depending on the application of the SEA. In this study, we aim to compare and analyse six existing controller theories or control type designs for SEAs that have been previously published. We will cover topics such as the design of mechanical systems, choice of actuators, motors, and drive systems, and power transfer from actuators to moving parts.

Keywords: Series elastic actuator, Impedance control, PID control, Force control.

I. Introduction

Series elastic actuators consist of an elastic component that connects to the mechanical energy source output. This architecture has various advantages over rigid actuators, like low mechanic output resistance, endurance for influencing loads, a larger peak voltage production, and passively electrical energy storage. These actuators are more effective and adaptable in a variety of applications because to the use of an elastic element. The process of transforming an energy source into mechanical force and motion is known as actuator. An actuator is a mechanism or device that converts energy. Actuators with transmissions include a hydraulic piston and an electromagnetic motor [1]. Except for some exceptions, the robot actuation system generally fails to generate accurate forces within the robot's joints. Some of the factors that can cause inaccuracy in a robot's position are friction, stick-slip, backlash in transmissions, and cogging in motors. These events can also cause force noise However, when it comes to controlling the trajectory or the robot's position, force noise is minimized by the mass of the robot and the low-pass filter. This is because the mass of the two components makes the noise in the output [2]. In most cases, force noise can be a problem when it comes to performing tasks that require good force control. Developing force-controlled actuators that are both powerful and safe involves considering various factors such as power density, force bandwidth, and mechanical output impedance. However, in practical applications, these actuators often suffer from low performance, stability, and safety issues due to the limitations they face. The key parameters are important for great power-controlled actuators: force data transfer capacity, mechanical result impedance, dynamic reach, power thickness, and power thickness. The first three measures are linked, and an improvement in one usually leads to an improvement in the others [3]. According to Pratt and Williamson (1995) [4], engineers often aim to create a stiff connection between an actuator and its load in order to enhance precision, stability, and position control bandwidth. However, this can lead to unwanted side effects such as noise, friction, and torque oscillations. In contrast, Pratt and Pratt (1998) [5] argue that a non-rigid interface is usually required when humans interact with machines [6]. Sequential elastic actuators (SEAs), as reported by Pratt et al. (2004), were employed in the creation of an instrument to boost a knee joint's strength [7]. The same actuator, as described by Blaya and Herr (2004), powers an ankle-foot prosthesis made especially to treat drop-foot illness [8]. The distinctive qualities of series elasticity actuators, that render them ideally suited for human-machine interaction, are widely known. These characteristics include force management, impedance control with low impedance potential, impact absorption, minimal friction, and a broad bandwidth. Robinson et al. (2006); Sensing and Weir (1999); [9][10]. The SEA used to improve muscle strength is an actuator with an elastic element and a structure in which the motor torque is transmitted to the mechanism

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via an elastic element such as a spring [11]. The elastic element is designed to measure force based on displacement and to have external compliance characteristics. High-torque motors can be used in industrial robots, but in the case of muscle-strengthening robots or humanoids, the volume and capacity of the motors are limited. According to [12], the foundation for the SEA concept is the inclusion of an elasticity component across the speed of the motor and the load. The spring's fluid behavior is employed to establish a link between the load that is placed force and the assessment of deformation caused by elastic. The addition of flexibility provides an essential advantage of transforming a torque control problem of SEAs into a position control challenge by sensing the torque via the elastically deformed shape of the internal spring of the SEA. Furthermore, the transmission mechanisms were rigid and could not be reversed [12]. Robotic systems have proven to be useful in traditional heavy industries where the working environment is clearly defined and there is minimal interaction between the systems and people. They offer benefits such as precision, speed, and repeatability [11][12]. However, as the manufacturing industry moves towards producing smaller batches of customized products with shorter lifecycles, the use of robots in production has become more common. Additionally, robots are increasingly being used in domestic settings and need to be adaptable to unstructured environments and human needs [12]. To this point, many torque controllers have been developed in an effort to provide SEAs with precise and dependable torque tracking performance. There were several of them, including a class of PID-based controllers [13,14]. When it comes to SEA, the driving actuator is considered a source of torque, position, or velocity [15]. In both of these two scenarios, position or velocity feedback in the inner loop of a cascaded-PID controller architecture is typical, with torque feedback in the outer loop. The fractional-order PID (FOPID) controller, which is illustrated in [16], was created to be more adaptable and efficient than traditional ones. To increase the robustness of torque control in SEA systems, some designers have resorted to a class of disturbance observer (DOB) instituted controllers, notwithstanding the popularity of PID-based controls because to their simplicity [17]. Therefore, the design of these controllers can be quite complex. Alternatively, some have utilized adaptive control methods to handle unknown SEA system parameters [18-20], but these methods don't account for external disturbances. Lastly, several sliding-mode controllers (SMCs), including conventional SMC [21] and integral SMCs (ISMCs), offer yet another approach to tackling uncertainties and disturbances in SEA systems. However, the discontinuity in SMCs invariably causes chattering, which should be avoided in controller design [22]. In order to address the chattering problem, the SMC-based force controller's robustness is sacrificed to obtain a smoother control signal. Previous research has proposed a robust motion controller for SEAs, but it requires complicated analysis and controller design, limiting its practical use [23]. In SEAs, the force control objective is to achieve the intended spring deflection, which is treated as the force control goal. To improve force control performance, precise position control must be In SEAs, the planned spring deviation is viewed as the power regulation target, and achieving it is the pressure regulation target. Accurate positioning control must be applied at the motor to increase force control performance. Using conventional SMC, a trustworthy position controller is built to minimize disturbances and enhance the motor's performance during position control. [24]. It's crucial to be aware of the suggested controller's limitations even though they enhance the performance of SEA motion control applications. The format of this essay is as follows. The series elastic actuator model is described in Section 2. The Dynamic and Control Force of the Series Elastic Actuator is explained in Section 3 in detail. Table 1 in Section 4's Comparison of Series Elastic Actuator is used. Section 5 comes to an end.

MODEL OF THE SERIES ELASTIC ACTUATOR

A direct current engine, a ball screwdriver, and a stretchy coupler make up the configuration of a SEA as defined by Robinson and colleagues in 1999 (see Fig. 1). Through a lock nut attached to the wrench, a cylindrical screwdriver transforms the base's axial movement from the engines' rotation. A series of springs have been placed between the structure and the output effector to regulate the pulling power and resistance of the activator. Springs collapse and provide pressure to the load via the resultant effector whenever the nut oscillates back and forth when the motor is turned on. A linear sliding sensor can measure the amount of power and the impedance. (Potentiometer) that is mounted on the support platforms of the springs. The sensor generates a voltage signal that corresponds to the deformation of the springs when the potentiometer cursor moves along with the nut support platform. The force applied to the load can be calculated based on Hooke's law ($F = kx$) [25].

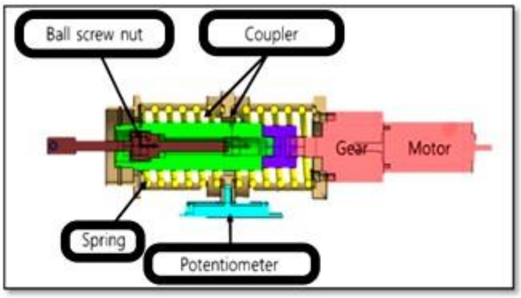


Fig.1 The series elastic actuator Configuration [25].

The dynamic characteristics model of the SEA [25] and shown in the below following Fig. 2.

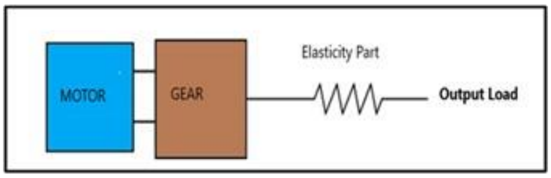


Fig.2 Series elastic actuator model [25].

The schematic representation of a group of elasticity actuator in Fig. 3 shows how it is topically equivalent to any other motion actuator that has a load gauge and closed to the outside world control system. Yet, the conforming element causes two-part disparities. First, it's impossible to ignore spring's superior storage of energy. Second, it can be challenging to include a compliant load-bearing sensor into a small actuator. Nevertheless, successful small designs have been created. By appropriately raising the control gain, the entire loop gain of the actuator can be kept within suitable stability margins. This enables series elastic actuators to have low output impedance, to be resilient to changing loads, and to tolerate shock loading. Additionally, for the actuators to produce clean force, the improved controller gains significantly lessen the impacts of internal stiction and other transmission non-linearities.

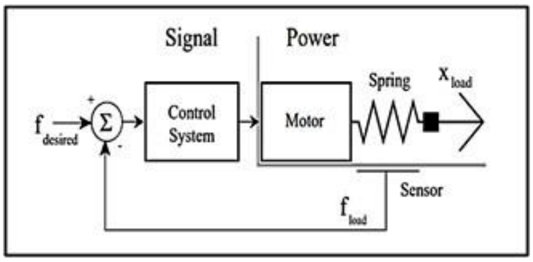


Fig **.**3 Series elastic actuator block diagram.[25]

II. DYNAMIC AND CONTROL RANGE OF THE PRESSURE ELASTIC ACTUATOR

This section will present the series elastic actuator's mathematical model.(SEA), which has been researched in the past.

The following definition applies to the SEA model:

$$m_m\ddot{x} + b_m = F_m - F_l \qquad (1)$$

Where:

$$F_l = k(x_m - x_l) \qquad (2)$$

Where k is the elastic spring constant, xm is the linear position of the linear screw nut, xl is the load position, mm is the motor mass equivalent, bm is the damper coefficient, Fm is the force generated by the motor, Fl is the output force, and bm is the damper coefficient [26].

The force and velocity restrictions of the DC motor must be taken into account in order to calculate bm, the damper coefficient [27]. The following is how these parameters can be related:

$$b_m = {F_{max}}/{V_{max}} \qquad (3)$$

Where the maximum forces and velocities for the DC motor are (Fmax) and (Vmax), respectively.

The transferred function representation may be used to determine the force pushing the load, (Fl), which is a function of (Fm) and (xl), as follows:

$$F_L(s) = \frac{F_m(s)}{\frac{m_m}{k}S^2 + \frac{b_m}{k}S + 1} \quad (4)$$

Considering the preceding presumptions, it is possible to determine the representation for the state space of SEAs as follows:

$$\dot{x}(t) = A_P x(t) + B_P u(t) \quad (5)$$

$$y(t) = C_P x(t) + D_P u(t) \quad (6)$$

Additionally, think about the potential effects on plant input of parametric uncertainty and actuation external interruptions. All of these disturbances combine to form one disturbance, w(t) [26,27].

$$\dot{x}(t) = A_P x(t) + B_P u(t) + B_p w(t) \quad (7)$$

Where u(t) is the control input, y(t) is the measured output, and x(t) represents the state.

The disturbance, friction at the spring and linear screw, mass at the motor, and mass at the screw are additional factors.

The force management of the series elastic actuator requires a transfer function between the output displacements and the input force, as shown in Fig. 4. When a heavy load is applied, this transfer function is achieved [25].

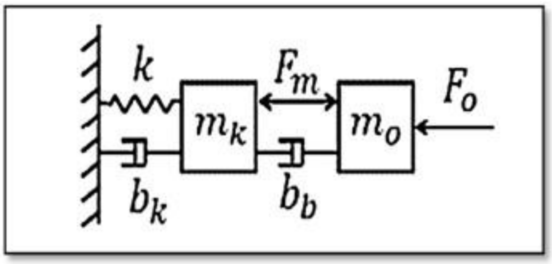
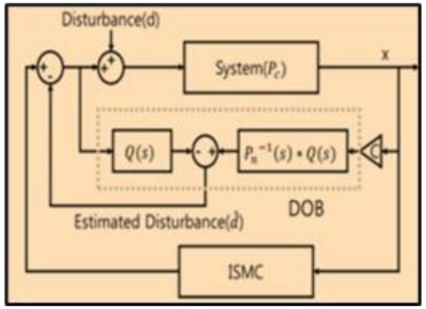
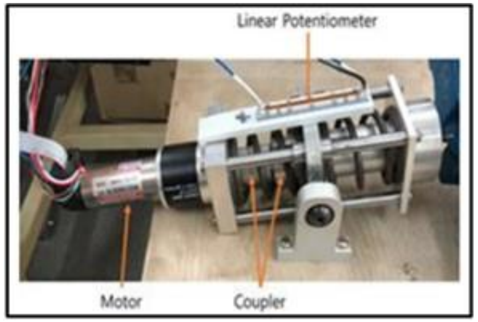
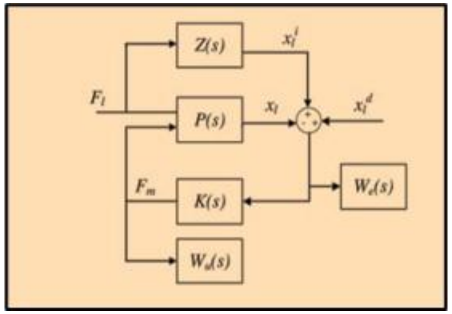
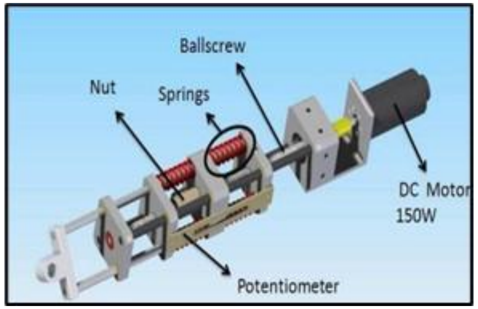


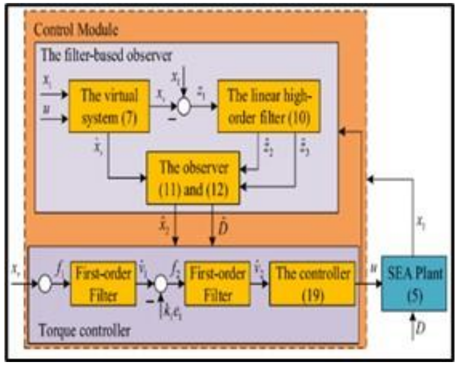
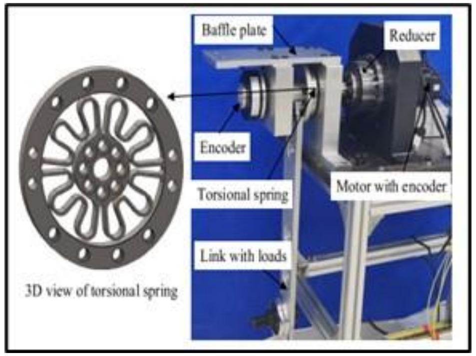
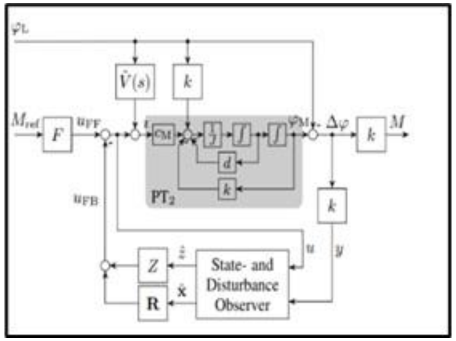
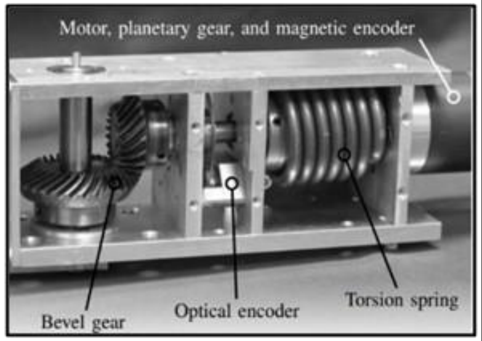
Fig.4 Series elastic actuator model with applied load.[25]

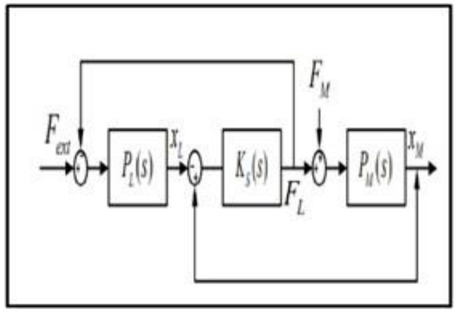
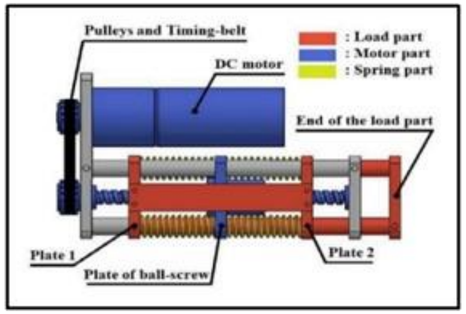
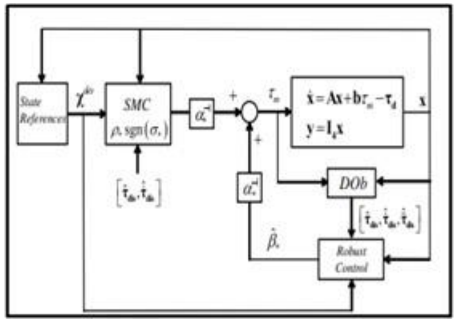
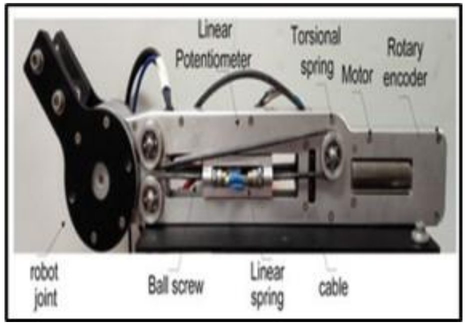
When the screw movement is restricted due to the output load's high resistance, the force that is being applied to the load can be described as follows using the preceding figure:

$$f_o = f_{m_k} + f_{b_{eff}} + f_k = m\ddot{x} + b_{eff}\dot{x} + kx \quad (8)$$

TABLE I. A COMPARISON OF CONTROLLER OF SERIES ELASTIC ACTUATOR: DESIGN, ACTUATOR AND POWER TRANSMISSION

No.	**Controller Type**	**Controller Design**	**Actuator &Power Transmission**	**Advantages**
1	**Robust Control Using ISMC & DOB (disturbance observer) [25]**			Effective implementation of the state feedback controller by the robust controller by combining it with integral sliding mode control (ISMC) as a nominal controller. This integration allows the controller to operate without being affected by disturbances. The SEA's control performance is enhanced by adding a disturbance observer, which allows it to handle a wider range of disturbances and reduces the chattering phenomena by lowering the gain of the variable control input.
2	**Robust Force and Impedance control [26]**			The aggregated perturbation of the system and the velocity indicators are estimated using a filtering technique to increase the controller's robustness in the face of system uncertainty. This strategy renders the torque controller a solid basis for multi-level control frameworks. Furthermore, our time-domain controller relies on the dynamic surface approach, which eliminates the need for derivatives of the commanded reference, rendering it independent.

3	**Robust output Feedback torque [28]**			The torque controller's use of filtering techniques, it is a perfect basis for multi-level control frameworks because of its ability to assess velocity signals and system outages. Thus significantly improving the controller's robustness against uncertainties in the system. Furthermore, we adopted a dynamic surface approach to ensure that our time-domain controller is not reliant on any derivatives of the commanded reference.
4	**Model Based Control of Sequence Pliant Actuators [29]**			The controller is designed around a straight-line model of the actuator, which can be simplified to a PT2 element through the use of a disturbance compensator. This approach facilitates a straightforward process for developing a state space controller, enabling easy selection of controller parameters. Because of the straightforward modeling and controller design, selecting the appropriate controller parameters is simple and intuitive, resulting in excellent results.

	PD Controller [30]			When driving at high speeds, the driver experiences reduced forces thanks to compensation for both forces (inertial and external). This results in a more comfortable driving environment. However, due to motor vibrations and high-speed disturbances, the system response may exhibit slight oscillations. To mitigate this issue, a new control algorithm and mechanical design for the SEA may be necessary to reduce vibrations.
	A controller for sliding force and orientation [31]			Positioning and management of an array of acoustic actuator (SEA) is a difficult challenge because of that SEA's fourth-order dynamics and the existence of both matching and unpaired perturbations. The underwater environment can correctly follow intended trajectories and interact safely with unexpected and dynamic surroundings because to a suggested robust motion controller, which can assist overcome these difficulties.

IV DISSUCTION THE SET OF FLEXIBLE ACTUATOR'S CONTROLLER PERFORMANCE

This study explains and compares six existing designs of series elastic actuators that have been published in various publications. Three topics are covered in the discussion: (i) design and mechanical systems, (ii) actuators in relation to motor and drive mechanism choices, and (iii) power transfer from actuators to moving parts.

Reliable Management of Sequence Flexible Actuator by Leveraging Deal ISMC and DOB, Changwon National University, Korean is the set of elasticity actuation that is being analyzed in this article. The interference monitor is integrated with ISMC and used to the SEA in this article to expand the permissible range of the disturbance and decrease input chattering of the integral sliding mechanism management. The linear system with disturbance is shown by the state equation below [25].

$$\dot{X} = AX + B\,(u + d) \qquad (9)$$

Where x represents the system's overall state, u represents the input, and d represents the input disturbance
The threshold frequency of Q (s) is set to 5 [Hz] and the coefficient Q (s) employed in the disturbance detector is a second order low-pass filter, however the estimated disturbance of the DOB may be mirrored to a wide range of disturbances [25].

$$Q(s) = \frac{w_c^2}{s^2 + 1.414 * w_c^2 + w_c^2} \qquad (10)$$

Hardware configuration of the control system of the SEA is shown below Fig .5

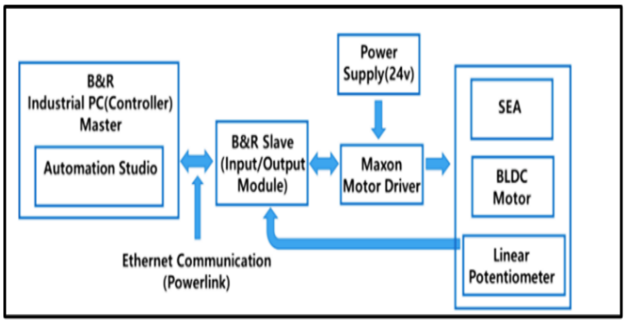


Fig.5 Control system for SEA hardware configuration [25]

And explain the control performance of a robust control system signal that mitigates the input chattering of the ISMC is shown in the Fig.6.

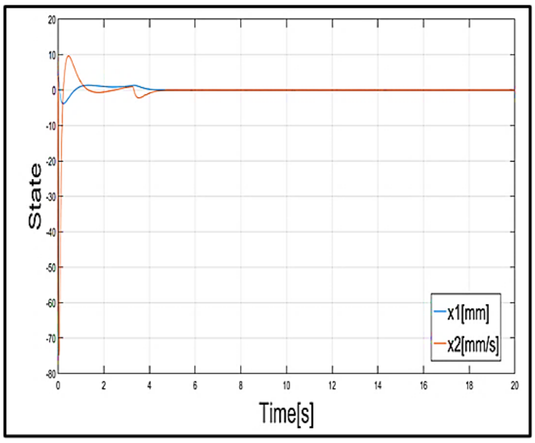


Fig.6 State response of Robust Control [25]

(ii) The institution of So Paulo, situated in So Carlos, Brazil, is conducting research on the creation of reliable strength and resistance control methods for series elastic actuators (SEAs). Similar to the one described in

Robinson et al.'s (1999) study, a SEA is illustrated in Fig. 7. Power driver EPOS 70/10 (Maxon Motor) and software created using Borland Builder C++ (26) were both used for controlling the system [26].

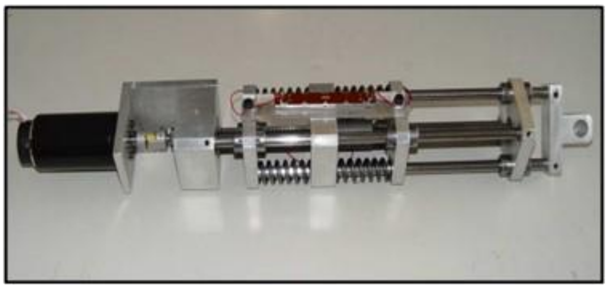


Fig 7**.** Series Elastic Actuator [26]

Thus, as illustrated in Fig. 8, that depicts the facility P(s) and the supervisor K(s), the structure of the diagram represents the power management system.

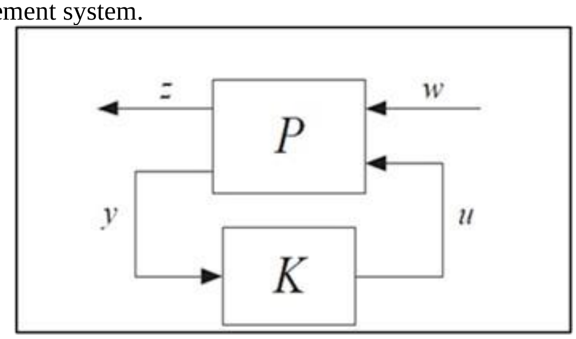


Fig.8 The structure of the diagram for the force control system [26]

Yet, the augmented system P(s)'s state-space forms reconstruct the management system within the present-day realm as follows:

$$\dot{x}(t) = Ax(t) + B_1 w(t) + B_2 u(t) \quad (9)$$
$$z(t) = C_1 x(t) + D_{11} w(t) + D_{12} u(t) \quad (10)$$
$$y(t) = C_2 x(t) + D_{21} w(t) + D_{22} u(t) \quad (11)$$

Therefore; when designing the robust controller, the nominal model and carefully chosen weighting functions are taken into account to enhance controller performance as shown in Fig.9.

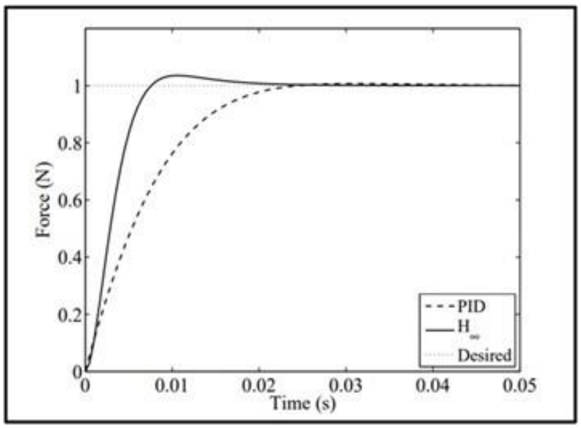


Fig.9 The robust controller and the PID controller.[26]

The plant being studied has internal input signals (u) and external input signals (w), as well as output signals that are measured (y) and regulated (z). From the results of the research, it was found that the end effector's position could successfully track outside pressures and exhibit the necessary susceptibility. The environmental assessments (Series Elastic Actuators) attached to the exoskeleton will eventually be equipped with the suggested controls, allowing their movement to be monitored. These actions are outlined in greater detail in the sources referenced, specifically [32]-[38].

(iii) At Harbin Institute of Technology in China, researchers aim to achieve torque control over a wide frequency range using multi-level control frameworks for series elastic actuators (SEA). The operator structure may be hierarchical in a multi-drive machine like an automated arm, for instance [39]–[42]. To rotate the load through a torsional spring as part of the SEA's dynamic operation, a motor is driven. The driving torque for the load throughout this operation is the elastic torque brought on by the spring's deformation. For visualization, see Fig. 10.

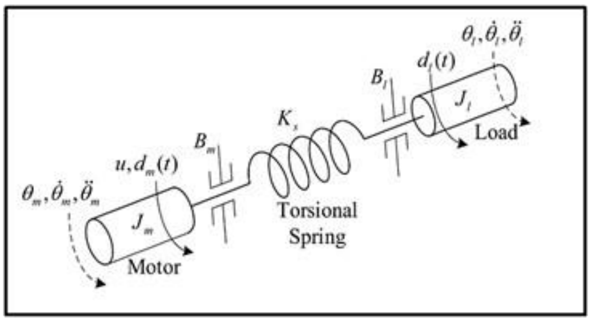


Fig.10 The SEA dynamic process's schematic diagram.[28]

Fig .9 illustrates the SEA with a two mass-spring-damper system, modeled as:

$$J_m\ddot{\theta}_m + B_m\dot{\theta}_m + \tau_s = u + d_m(t) \quad (12)$$

$$J_l\ddot{\theta}_l + B_l\dot{\theta}_l = \tau_s + d_l(t) \quad (13)$$

And the output torque of the series elastic actuator, which as follows:

$\tau_s = k_s(\theta_m - \theta_l)$ (14)

To achieve precise control of joint torque in multi-rigid-body systems, a higher-level controller is used to command the joint torque of subordinate lower-level joint controllers. A resolving dynamics model is employed to accomplish this, with each lower-level controller specifically.

(iv) At the Technics Universidad in Darmstadt, Germany, researchers have presented several designs and controllers for series elastic actuators. Actuators that incorporate a spring between the motor and the load are designed to decouple their dynamics and prevent shocks from affecting the drive train. By using the spring as a torque sensor, the force control problem can be transformed into a position control problem. The researchers conducted an analysis of the system's behavior in open and closed loop conditions, and evaluated the impact of compliance on the controller and overall performance. The SEA block diagram depicted in Figure 11 assumes ideal gear properties, including linear spring stiffness (k) and damping (d), and the ability to operate the motor in a current controlled mode. In addition to the original sources [48-59], it is worth considering the practical implications of these findings, such as the potential benefits for robotic systems that require precise control over force and position.

A. Preparing Your Paper

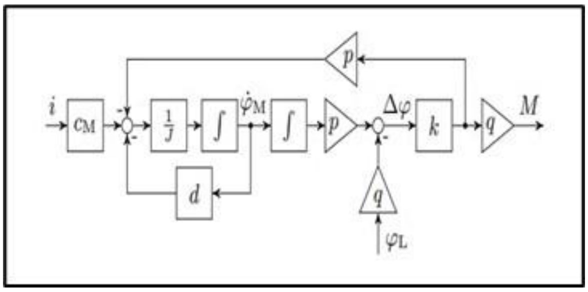


Fig.11 The structure of the diagram of the sequence flexible actuator [29]

Thus, the system's only components are the motor and the gear, and the equation of motion is:

$$J\ddot{\theta}_m(t) = c_m\iota(t) - M_d(t) \quad (15)$$

We used a constant current (i(t) = I) to drive the engine in order to calculate the damper strain (md). The vehicle kept speeding up until it reached a final velocity that was influenced by the damper strain (md) as well as the current I. The test results are shown in Fig. 12, where it is clear that the suggested controller had outstanding behavior with little overrun.

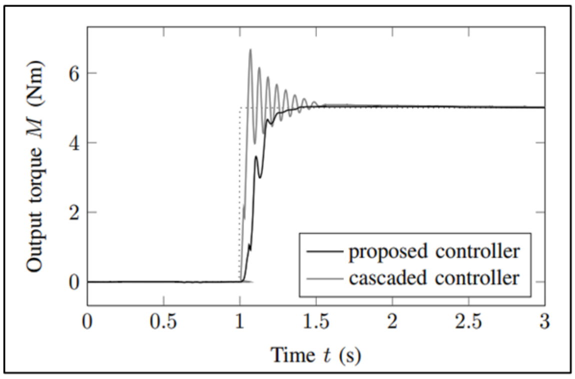


Fig.12 Step response of the closed loop system [30]

(v) At Pusan National University in Busan, Korea, researchers have developed a mechanism called SEA to improve driver stability. In a research to build an active suspension system that might be fitted in the model to improve vehicle security, this approach was adopted. The SEA's cushion functions as a low-pass filter (LPF) while operating normally, efficiently removing high frequency disruptions [60]–[63].

The Series of Flexible Actuators (SEA) is a kind of operator that uses a ball screw to transform rotational movement into a straight line. A dynamic rendering of the SEA's translational movement is shown in Fig. 13 to help clarify its behavior.

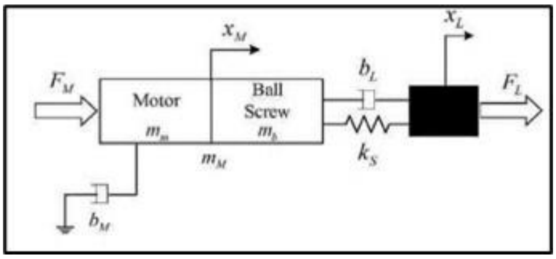


Fig.13 The translational motion of the SEA according to the dynamic model.[30]

The overall weights of the DC motor and ball-screw, expressed in (mm) and (mb), accordingly, are included in the dynamical model employed in the present research. Whereas the weight of the part's movement is indicated by (xL), the DC motor's height is denoted by (xM). The direct current (DC) motor's dampening factor is (bM), while the weight's damping factor is (bL). Last but not least, (kS) denotes the straight springs characteristic. The sequential elasticity actuator (SEA) is an adaptable structure that includes two crowds, despite its strength.

Researchers have employed a two-mass dynamic model [64], which may be thought of as a synthesis of the motor, spring, and load systems, to study its dynamics. The dynamic equations for these systems can be expressed using the following equations:

$$m_M \ddot{X}_m + b_m \dot{x}_m = F_m + F_L \quad (16)$$

$$F_L = k_s(x_m - x_l) \quad (17)$$

$$m_l \ddot{x}_l + b_l \dot{x}_l = F_L - F_{ext} \quad (18)$$

In which FL, FM, and Fext, accordingly, stand for the forces impacting on the springs, the forces produced by the engine, and the exterior forces impacting on the SEA's loading component.

Fig. 14 combines the SEA and PD control block diagrams to depict the construction of the SEA controller for the active system.

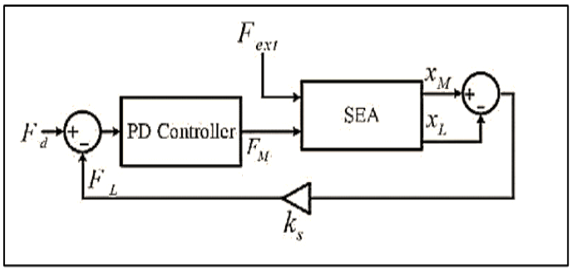


Fig.14 Block diagram of SEA controller.[30]

A PD system with proportionate and differentiated advancements, Kp and Kd, was used in the current investigation [65–68]. The torque generated by the DC motor (FM), which is the controller's output, may be written as follows:

$$F_m = (F_d - F_l)(k_p + k_d s) \qquad (19)$$

Simply put, the torque produced by the direct current (DC) generator in the SEA is reflected in the transmitter's results, referred to as FM. In order to account for outside influences, the processor uses the disparity between FD and FL as an input; as a result, FD remains constant at 0. The response signal FL to the actuator is computed using the final displacement of the load plate and the spring constant. Future study might examine if decreasing vibration necessitates both a new mechanical design for the SEA and a new control algorithm [69-73].

(vi) A strong movement regulator for environmental assessments (series elastic actuators) has been created by the Polytechnic of Illawarra in Australia combining two cutting-edge management approaches, DOB (disturbance observer) and SMC (sliding mode control). Researchers were able to build useful dynamic models for position and force control applications by considering all external disturbances as fictional disturbance variables. Series elastic actuators (SEAs) have attracted more attention recently because of their potential advantages in the physical robot-environment interface, such as increased safety and high-fidelity force control [74–77]. SEAs have been used to develop exoskeletons, humanoids, and other complex robotic systems, as well as compliant industrial robots. [78-79]. SEA is built with a spring or other flexible mechanical part between the actuator and connection specifically to ensure compliance in physical interactions. While the compliant mechanical component enhances the physical contact between the robot and its surroundings, it also makes the mechanical design and motion control issue more challenging, particularly in position control [80-81]. The durability and efficiency of the SEA might significantly deteriorate in practice as a result of this compliance, which also renders SEAs more susceptible to disturbances than naturally robust stiff actuators with high gear ratios [82–84]. The vast majority of prior research on SEAs has been devoted to solving force/impedance control issues and examining prospective applications, such as cooperation between humans and robots.

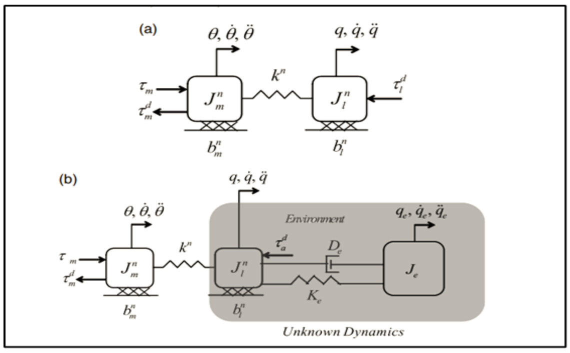


Fig.15 Dynamic models of SEA. (a) Free motion. (b) environment interaction.[31]

The dynamic model of SEA, which is used for position and force/impedance control, is based on a mathematical derivation. Unlike the scenario depicted in Figure (14a), SEA does not directly interact with the environment. The dynamic model equation is as follows:

$$J_l^n \ddot{q} + b_l^n \dot{q} = \tau_s^n - \tau_l^d \qquad (20)$$
$$J_m^n \ddot{\theta} + b_m^n \dot{\theta} = \tau_m - \tau_s^n - \tau_m^d \qquad (21)$$

$$\tau_s^n = k^n(\theta - q) \quad (22)$$

In this study, an innovative mobility operator for series elastic actuators (SEAs) is described which makes use of both the sliding mode control and disruption observers (DOB). In the help of this administrator, environmental assessments may precisely follow intended trajectories and safely interact with unpredictable and turbulent situations. The suggested mobility administrator, in contrast to conventional approaches, is appropriate for a variety of sophisticated autonomous machines, including conforming humanoid being manufacturing robots, and external skeletons.

Exotic skeleton humanoid being and collaborating manufacturing robots are just a few examples of robotic devices driven by SEAs that may use the controllers presented in this paper. Experiments were carried out to assess the position and force control in order to confirm the efficacy of the sliding mode motion controller. As mentioned in the citations, the position and force controllers were created by combining DOB and SMC approaches. [85-89].

V CONCLUSION

This investigation's goal was to grow a strong motion controller for SEAs by utilizing different controller types. To create useful dynamic models for position and force control applications, any disturbances were combined into imaginary disturbance variables. Our objective is to create an accurate output-feedback traction regulation technique for SEAs which is capable of handling unpredictability of parameters and outside disruptions. We use a filtration approach for estimating velocity signals and system lumped disturbance in order to increase the robustness of the controller. In order to guarantee that our time-domain regulator is unaffected by any variants of the ordered reference, we also use a dynamic surface technique. This adaptable torque controller can play a crucial role in multi-level control schemes. Our proposed torque controller has two major applications. First, it can be used in an impedance control system that outperforms conventional cascaded-PID methods in terms of impedance tracking capability. Second, it can be integrated into a multi-level control framework for complex systems. SEAs (Series Elastic Actuators) benefit from elastic parts that can handle impact loads, have low mechanical output resistance, store energy passively, and produce more peak power. To achieve these advantages, it's essential that the spring can withstand loads while avoiding excessive stiffness. When the spring is too stiff, it results in high system impedance, which can impede optimal performance. Therefore, finding the right balance in spring design is crucial for optimizing the performance of SEAs. In the conclusion, we demonstrate that the utilization of the SEA affects the control process and controller types on series elastic actuators. According to the above mentioned research, several regulator types can improve the functioning of the repeated elasticity actuation (SEA).When designing SEA, it's crucial to carefully select linear actuators and the type of transmission to achieve the desired level of torque. Using a linear actuator as the primary driving force for moving the output load presents an exciting avenue for further research on SEAs.

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