Online-Journals.org

iJOE International Journal of
Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 19 No. 10 (2023) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v19i10.40375

PAPER

Evaluation of Robotic Ankle-Foot Orthosis with Different Actuators Using Simscape Multibody for Foot-Drop Patients

Gowrishankar Govindaraj,
Arockia Selvakumar
Arockia Doss(✉)

School of Mechanical Engineering, Vellore Institute of Technology, Chennai, Tamil Nadu, India

arockia.selvakumar@vit.ac.in

ABSTRACT

Gait cycle plays a major role in human locomotion. Patients with neuromuscular problems are unable to walk normally. Foot drop causes difficulty in lifting the front part of the foot and affects the dorsiflexion (DF) and plantar flexion (PF) motion of the foot. Patient with foot drop must use ankle braces to achieve a normal gait. The existing ankle-foot orthosis (AFO) has its own limitations, as it does not produce adequate PF motion. To overcome this scenario, a study was conducted to analyse the two-degrees-of-freedom (DOF) motion of a robotic ankle foot orthosis (RAFO) with a spring-based series elastic actuator (SEA) and scissor actuator. The objective of this paper is to evaluate the two DOF of RAFO with two different actuators using simscape multibody. The RAFO with actuators were designed using Solidworks, and simulation was carried out using simscape multibody, to analyse the 2-DOF motion. The dynamic motion analysis was carried out using block libraries, bodies, joints, constraints, revolute joints, sensors and a proportional integral (PI) controller. From the simulation results, the total range of motion (ROM) 40° (PF angle of –25° and DF angle of 15°) is achieved by the proposed RAFO with different actuators. Further, based on the results, the input power consumption of spring-based SEA was found to be less than the scissor actuator. Similarly, torque and output power generation of the scissor actuator was found to be greater than spring-based SEA to achieve the normal human ROM. Hence, the designer can choose a hybrid actuator for foot-drop-disorder applications.

KEYWORDS

robotic ankle-foot orthosis, dynamic motion, spring-based SEA, scissor actuator, dorsiflexion and plantar flexion motion

1 INTRODUCTION

The ankle joint plays a major role in human locomotion by providing two degrees of freedom (DOF), namely plantar flexion (PF) and dorsiflexion (DF) motion in the sagittal plane, as shown in Figure 1. The ankle and the actual ankle-foot orthosis (AAFO)

Govindaraj, G., Doss, A.S.A. (2023). Evaluation of Robotic Ankle-Foot Orthosis with Different Actuators Using Simscape Multibody for Foot-Drop Patients. *International Journal of Online and Biomedical Engineering (iJOE)*, 19(10), pp. 156–168. https://doi.org/10.3991/ijoe.v19i10.40375

Article submitted 2023-04-12. Resubmitted 2023-05-12. Final acceptance 2023-05-23. Final version published as submitted by the authors.

range of motion (ROM) are illustrated in Table 1. Due to ageing, trauma and neuromuscular disorder, the ankle muscles shrink and becomes weak, which leads to foot drop. Persons with stroke usually exhibit an inability in producing sufficient ankle PF and DF motion. Persons with impaired movement in the ankle joint, including foot drop, can get benefit from the use of an ankle-foot orthosis (AFO) [1–3]. Active and passive types of AFO are available on the market. A passive AFO is integrated with shank, foot and hinges. In a passive AFO, PF motion is limited due to insufficient energy to lift the foot. In recent research, the passive AFOs have evolved into AAFO by applying torque to the ankle joint to achieve a normal gait pattern and also allow the foot to perform both DF and PF motions [4–6]. A wearable AFO has been used to assist the lower body and help with gait rehabilitation in a variety of studies [7]. Through specific mechanisms, an AFO can regulate movement with specified degrees of freedom. It is possible to perform and support more complex motions using robotics to address lower limbs and ankles. A robotic ankle orthosis can assist the user in regaining full ankle mobility and control during all phases of the gait cycle. In order to improve ankle stability, rehabilitation robotics can be used in several ways, but many of these methods are very labour intensive.

AAFOs with direct-drive actuation systems are large and impractical. Hence different actuation techniques have been suggested to lower the peak input power of the actuator. The well-known series elastic actuator (SEA) principle and its development into the variable stiffness actuator (VSA) are used in current actuator designs. A DC motor and compliant SEA link produce torque at the ankle joint. Based on the properties of the complaint link and the lever arm in a SEA, the applied force and torque can be calculated by inferring the displacement of a compliant link. The SEA configurations in AAFO design can reduce an AAFO's peak input power by 69% compared with the direct-drive option. To maximize the stiffness, a linear spring is positioned between a slider and crank, and other improvements are explained by Hollander et al [8]. The developed AAFO prevents both foot drop and toe drag during the loading response. Most spatial and temporal parameters were also improved [9]. An AAFO has also been developed using an accurate gait-phase detection method to prevent foot drop and toe drag [10].

AAFO actuators have been successfully actuated by a discrete non-linear actuator with reduced the complexity, size, and weight by eliminating lead screws [11].

Fig. 1. Movements of the ankle joint

Table 1. Human ankle ROM, AAFO

Ankle Movement	Human Walking	Human (max)	AAFO (max)
Plantar flexion motion	20º	50º	25º
Dorsiflexion motion	15º	20º	15º

Regenerative braking is the process where the applied force of a motor, absorbed by the ankle joint, is stored as energy in the spring until it is required. Regenerative braking has been accomplished using an SEA arrangement [12]. For a 65-kg user, the AFO with SEA design can generate 50% of the ankle joint's power at a mass of 0.5 kg [13]. Convens et al. developed an actuator that combines a series elastic actuator and a resettable overrunning clutch. This reduces the driving motor's peak power and energy consumption by removing the load from the motor and storing energy in the spring during the stance phase [14]. Parallel elastic actuators (PEAs) are used to decrease the load of the motor by placing the spring parallel to the motor. The use of PEA and SEA in combination is used to lower peak input power and energy, and this topic has been the subject of extensive research. By employing an SEA and PEA combination, the peak mechanical input power was reduced by 70% [15]. According to research by Liu et al., the use of a unidirectional parallel spring reduces the peak input power by 74.3% when compared with the direct-drive option. When a SEA is included, the peak power reduction further increases by 0.08% [16].

Variable stiffness actuators are made to allow actuator stiffness to match the needed output force/torque requirements. In comparison to the original SEA, VSA is made use of several linkages, revolving discs, and springs. These arrangements are more complicated than SEA [17]. In VSA, an ankle joint is attached to one of the two links; both the springs are driven by linear springs. The difference between the two links generates a torque. For a total weight of 1.5 kg, this design produces 25 Nm of torque. In unpowered ankle exoskeletons, barrel-based VSA is used, in which fixed and rotating plates are attached with tensile springs. When the top plate rotation increases, the stiffness decreases. To control accurately the swing phase-to-toe contact, the authors proposed a design that varies the ankle joint stiffness [18]. In VSA and SEA designs using a four-bar mechanism, the assistive torque is applied using a slider-crank configuration. Whenever the driven and connecting links are aligned, the crank-rocker four-bar mechanism reduces the torque of the motor to zero [19].

An innovative AFO with two degrees of freedom has been developed [20]. Using the geared five-bar spring system, a new actuator for active prosthetic foot was developed. The series elastic with a geared five-bar (SGFB) actuator mimics the ankle biomechanics and uses less electrical power than the SEA actuator for low ROM [21]. An SEA can be used to implement force and impedance control in a manner similar to biological systems [22]. A scissor lift mechanism's dynamic behaviour was simulated using commercial software. In simulations, the design almost mimics a real-time application, and the simulation data can also be used to improve the design [9]. Three springs are used to form a variable gravity compensation mechanism for scissor lifts. Adding springs to the motor that is used to lift the load can reduce its torque requirement [23]. The results obtained for AAFO from a simscape multibody encourages further research on various topics, such as creating a control system for SEA. Impedance control of SEA was performed by adding a PID controller with various blocks [24]. An ankle-foot orthosis based on a platform of end effectors was investigated for the rehabilitation of DF and PF of the ankle. Further, the PI showed good performance with regard to torque control [25]. Matlab and Simulink software was used to simulate the transient response of the research model using a PID controller [26–27].

Based on the literature survey, it is understood that SEAs are widely used to control the AAFO orthotic joint stiffness and damping during PF and DF ankle motion with low ROM. Also, VSA and PEA are used to control the motion of AAFOs.

2 MATERIAL AND METHODS

In this study, an RAFO is proposed with two different actuators, i.e., SEA and scissor actuator. The proposed research work is carried out by modelling the RAFO using solid works and the simulation is carried out with a simscape multibody to evaluate 2-DOF motion DF and PF.

2.1 Conceptual design of different actuators of RAFO

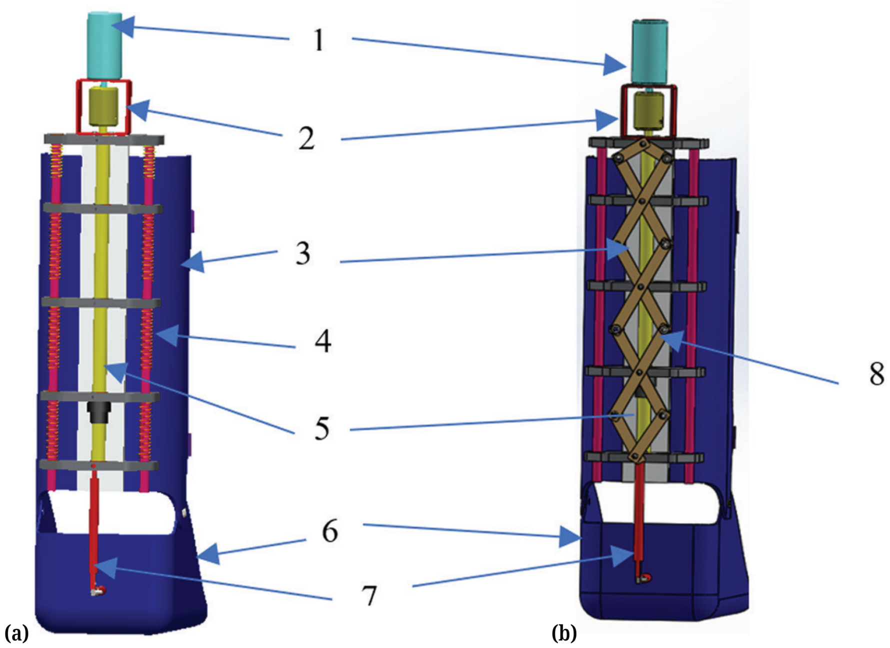
The conceptual model of RAFO is carried out in two stages. In the first stage, the standard AFO parameters are taken as reference and designed with the foot, shank, hinges and strap. In the second stage two different actuators, spring-based SEA and scissor actuators, are designed based on the standard AFO.

2.2 Design of spring-based SEA

A spring is used in the SEA because it mimics human locomotion by storing the energy during DF and releasing it during PF motion. To regulate DF and PF motion, the SEA is regulated by interfacing a DC motor and power supply. The SEA consists of a DC motor, shaft, connector, ball screw, springs, lever and sliding guides. This assembly is interfaced to an AFO, in which the rotating motion of the ball screw is converted into the linear motion of foot. Hence, the stiffness of the spring is directly associated with SEA mechanical impedance to obtain the desired angular position as an output. The 3D model of RAFO with SEA is shown in Figure 2a.

2.3 Design of scissor actuator

A scissor mechanism is to lift the heavy loads in the vertical direction. The scissor actuator consists of a DC motor with shaft, ball screw, sliding guides, scissors and lever. In this model, two types of scissors are employed in two sizes: a three-hole flat plate and a two-hole flat plate, respectively. The scissor actuator is interfaced with the AFO. The 3D model of the RAFO with scissor actuator is shown in Figure 2b.



1 DC motor, 2 connector, 3 shank, 4 spring, 5 ball screw, 6 foot, 7 lever, 8 scissor

Fig. 2. 3D model of RAFO with (a) spring (b) scissor

2.4 Physical modelling of RAFO

The individual parts of solidworks models are imported to simulink as an XML file and the Sim mechanics components are used for physical modelling. The model is designed for mechanical systems with joints, linkages, rigid bodies, forces and torques. Similarly, using block libraries, constraints, sensors and actuators are modelled. These libraries have building blocks that describe mechanical systems with any number of rigid bodies and joints that can be used to represent translational and rotational degrees of freedom.

2.5 Motion analysis of RAFO with different actuators

Ankle motion analysis is carried out using a simscape multibody. The corresponding parameters, such as PF and DF angles, input power consumption, torque and power generation, are observed. Based on the requirements, the exact mechanical structures, electrical motors and control systems required for the motion of RAFO are identified. In this research work, a proportional integral (PI)-based feedback controller is used to control the ankle motion of RAFO with respect to set point values KP and KI, which are values to reduce PF and DF angular positions error.

RAFO with spring-based series elastic actuator. The PI controller supplies the input voltage to the DC motor based on the set point values KP and KI (normal human PF angle of –25° and DF angle of 15°). According to the input voltage, the DC motor rotates the ball screw. Based on the rotation of the ball screw, the sliding guides move up and down and achieve linear motion either by compressing or expanding the springs. The linear motion of sliding guides develops a force over the lever, which moves the lever up or down. Finally, the movement of the lever controls the dynamic motion of the foot. The ankle motion of RAFO with spring-based SEA is visualised in terms of animation through mechanics explorer, as illustrated in Figure 3.

RAFO with scissor actuator. The components of the scissor actuator are the same as spring-based SEA, except the springs are replaced by a scissor mechanism to control the ankle motion. The scissors are placed over static and sliding guides. The movement of sliding guides with a scissor mechanism is used to produce linear motion. Similarly, the force acting on the lever is used to lift upward or downward, as shown in Figure 4.

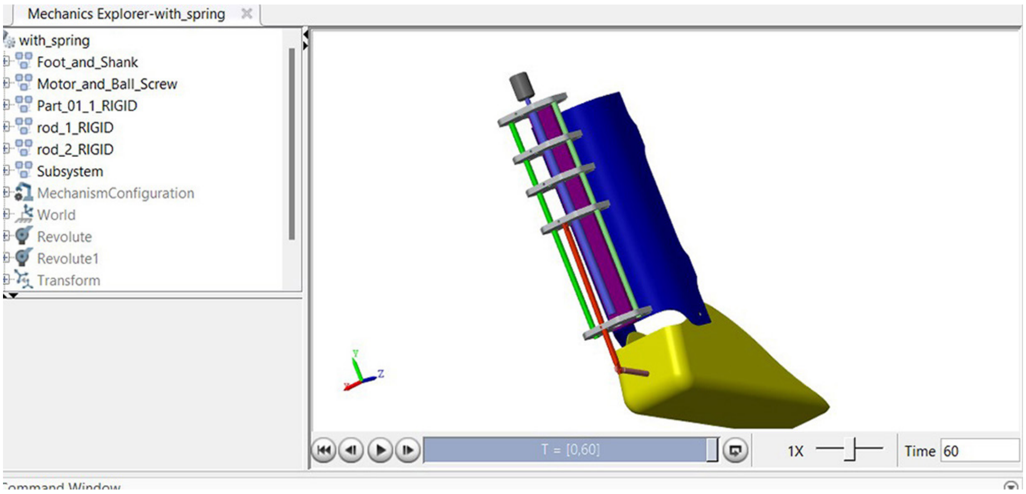


Fig. 3. Spring-based SEA in mechanics explorer

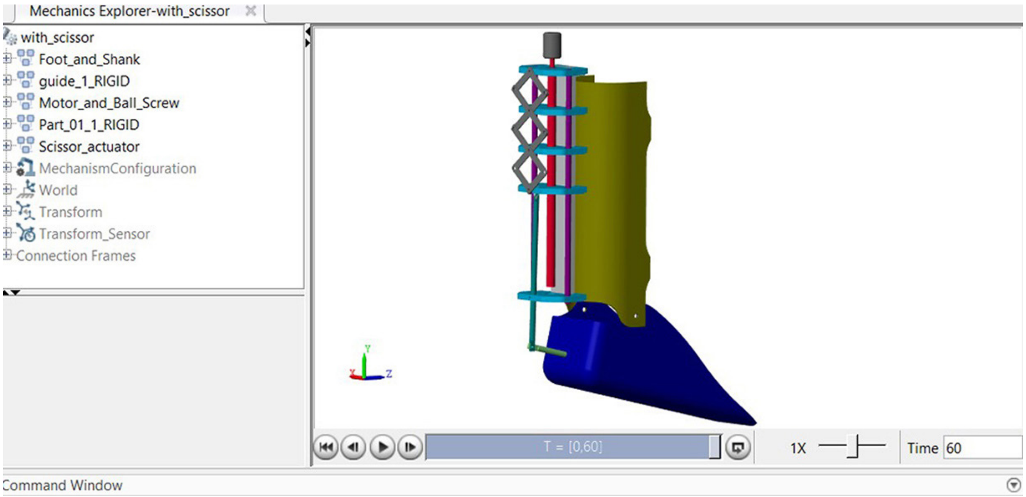


Fig. 4. Scissor actuator in mechanics explorer

3 RESULTS AND DISCUSSION

Figures 5 and 6 represents the block diagrams of RAFO with a spring-based SEA and scissor actuator developed using simscape multibody. The simulations are carried out for the proposed RAFO actuators, and the required PF and DF angles are obtained for the given set point values, as shown in Table 2. The dynamic motion of RAFO with various actuators is observed in mechanical explorer, and the corresponding parameters of the ankle motion are viewed graphically using the scope, as shown in Figures 7 and 8, respectively.

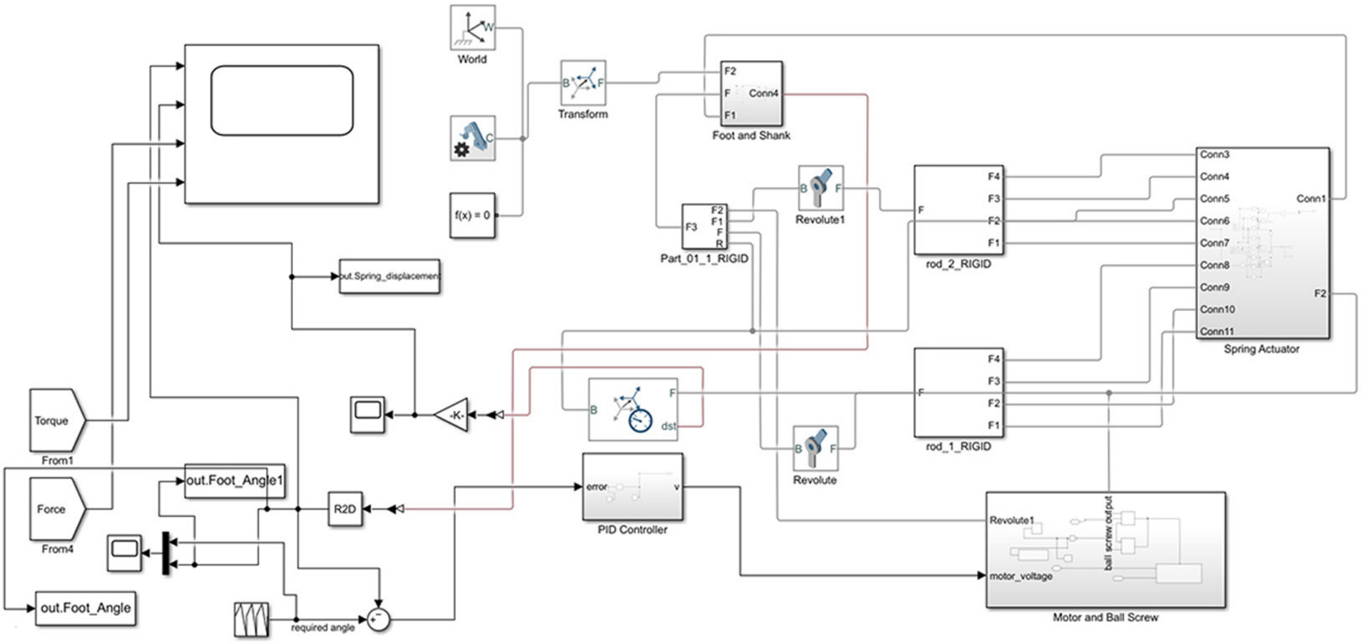


Fig. 5. Simscape multibody model of RAFO with spring-based SEA

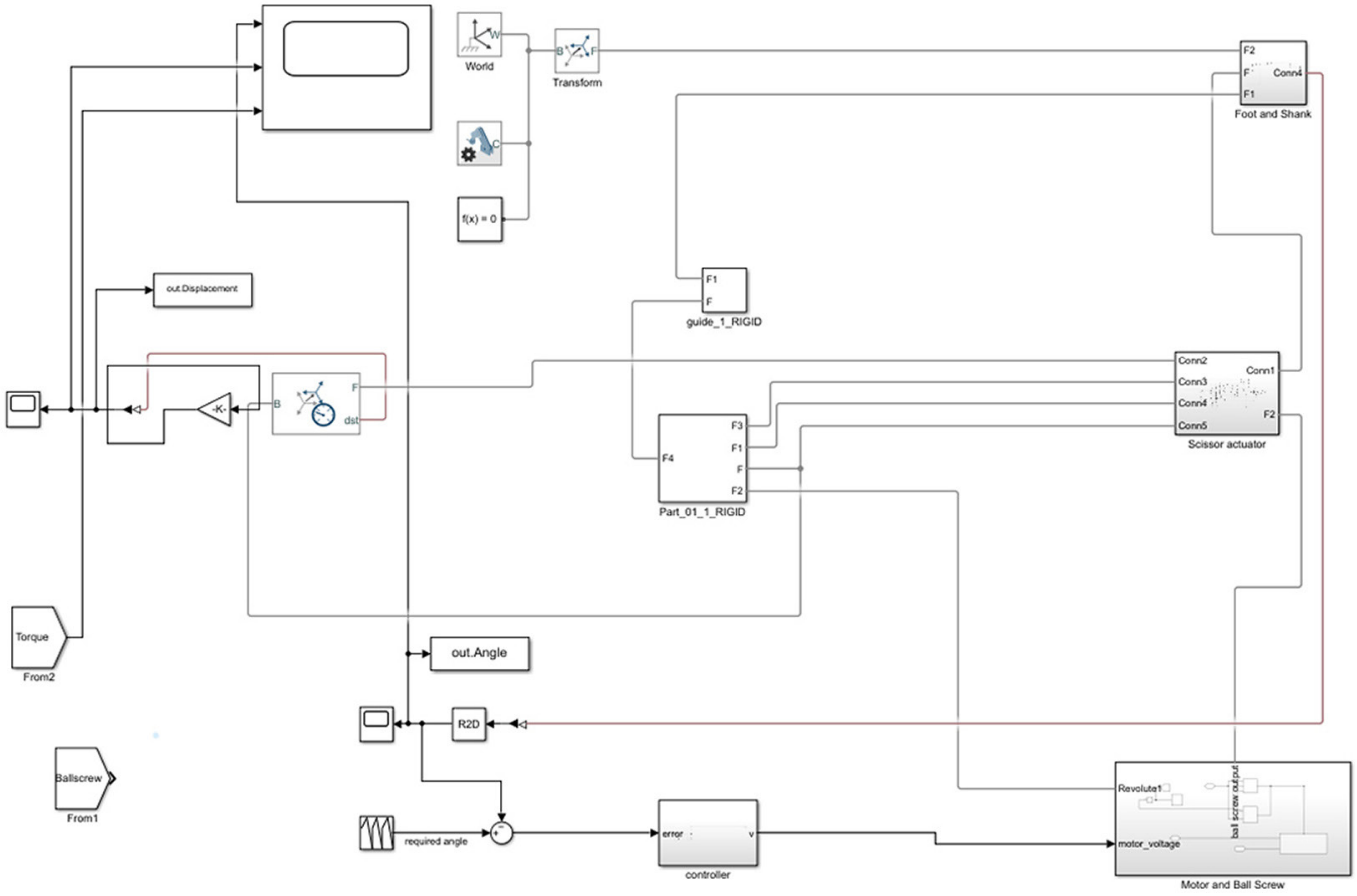


Fig. 6. Simscape multibody model of RAFO with scissor actuator

The simulation of RAFO with spring-based SEA and scissor actuator is conducted based on set point values of PF and DF ankle motion. A PI controller is used to control the ankle motion by tuning KP and KI values randomly, and the corresponding values are shown in Table 2. The desired values of PF and DF ankle motion for spring-based SEA are achieved by tuning KP and KI value as –4 and –1.5, and for scissor actuator values as –3 and –1.5, respectively.

Table 2. Simulation results of RAFO with different actuators

RAFO with Different Actuators	Plantar-Flexion (deg)	Dorsiflexion (deg)	Input Power Consumption (W)	Torque (Nm)	Power (W)	PI gain	
						KP	**KI**
Spring-based SEA	–18	22	72	–1.5 to 6	24.5	–1	–1
	–25	18	72	–1.5 to 6	24.5	–1.5	–1
	–24	17	72	–1.5 to 6	24.5	–2	–1
	–24	16	72	–1.5 to 6	24.5	–2.5	–1
	–25	15.5	72	–1.5 to 6	24.5	–3	–1.5
	–25	15.5	72	–1.5 to 6	24.5	–3.5	–1.5
	–25	15	72	–1.5 to 6	24.5	–4	–1.5
Scissor actuator	–27	17	96	–1.2 to 11.5	46	–1	–1
	–25	16	96	–1.2 to 11.5	46	–1.5	–1
	–24	16	96	–1.2 to 11.5	46	–2	–1
	–24.5	16	96	–1.2 to 11.5	46	–2	–1.5
	–24.5	15.5	96	–1.2 to 11.5	46	–2.5	–1.5
	–25	15	96	–1.2 to 11.5	46	–3	–1.5

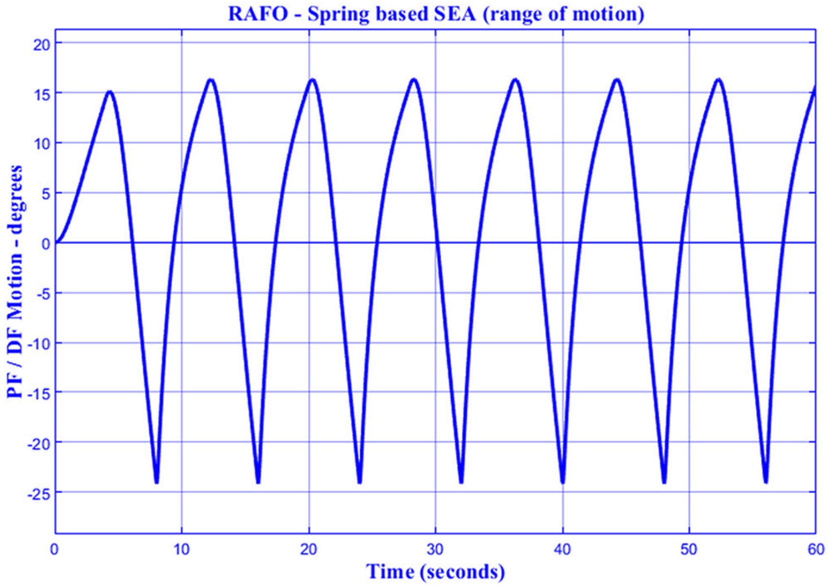


Fig. 7. PF/DF motion versus time for RAFO with spring-based SEA

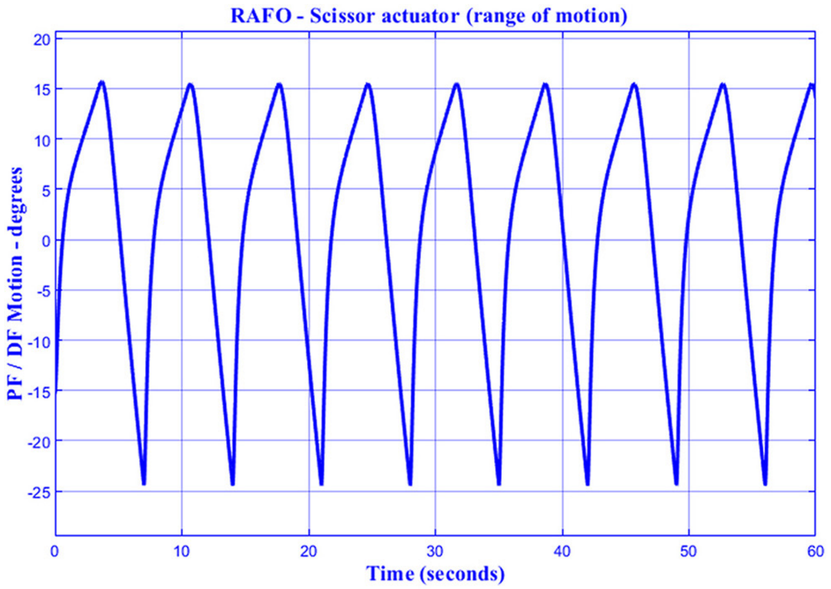


Fig. 8. Ankle motion versus time for RAFO with scissor actuator

From the simulation results, the total ROM of 40° (PF angle of –25° and DF angle of 15°) is achieved by the proposed RAFO with different actuators. The input power consumption, torque generation and power generation of the spring-based SEA actuator is found to be found to be 72 W, 7.5 Nm and 24.5 W. Similarly for scissor actuator the values are found to be 96 W, 12.7 Nm, and 46 W. Figures 9, 10 and 11 compare the spring-based SEA and scissor actuators with respect to input power consumption, torque and output power to achieve DF and PF ankle motion.

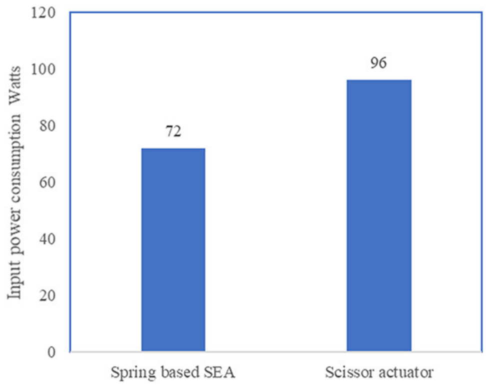


Fig. 9. Input power consumption by spring-based SEA and scissor actuator

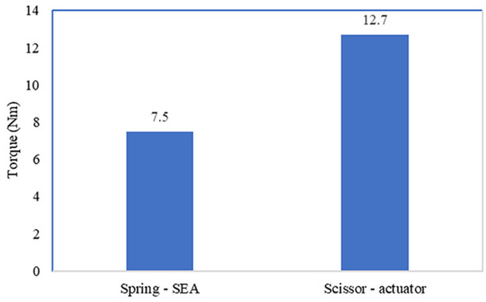


Fig. 10. Torque generated by spring-based SEA and scissor actuator

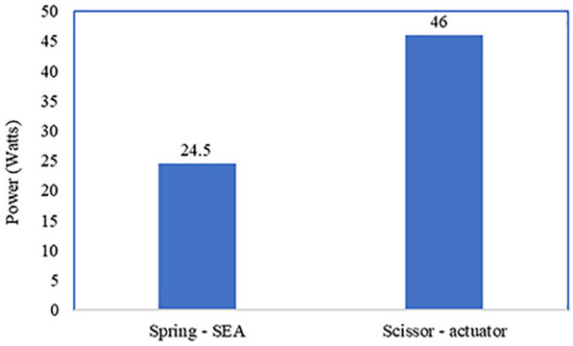


Fig. 11. Power generated by spring-based SEA and scissor actuator

4 CONCLUSION

In this research work, a comparative study is conducted over the performance of RAFO with spring-based SEA and scissor actuators. Based on the simulation results the followings points are concluded,

1. Both RAFOs achieve the normal ROM of the human ankle, i.e., PF motion of 20° and DF motion of 15°.
2. The input power consumption for the spring-based SEA is 33% lesser than for the scissor actuator.
3. The torque produced on the scissor actuator is 69% greater than on the spring-based SEA.
4. The power generated across the scissor actuator is 88% greater than across the spring-based SEA.

This study indicates that the torque and the power generated by the scissor actuator are higher than by the spring-based SEA, but the input power consumption for the scissor actuator is higher than for the spring-based SEA. Based on the above results a RAFO with hybrid actuator (spring with scissor) is proposed in order to reduce the input power consumption and increase the torque and power generation across ankle.

5 DECLARATIONS

Acknowledgement: The authors would like to appreciate the effort of the editors and reviewers. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of interest: The authors confirm that there is no conflict of interest to declare for this publication.

Funding: The authors received no financial support for the research, authorship, and publication of this article.

6 REFERENCES

[1] Moltedo, M., Baček, T., Verstraten, T., Rodriguez-Guerrero, C., Vanderborght, B., and Lefeber, D. Powered ankle-foot orthoses: The effects of the assistance on healthy and impaired users while walking. J. Neuro engineering Rehabilitation 2018; 15(86). https://doi.org/10.1186/s12984-018-0424-5

[2] Adiputra, D., Nazmi, N., Bahiuddin, I., Ubaidillah, U., Imaduddin, F., Rahman, M. A. A., Mazlan, S. A., and Zamzuri, H. A review on the control of the mechanical properties of ankle foot orthosis for gait assistance. Actuators 2019; 8(10). https://doi.org/10.3390/act8010010

[3] Frisoli, A. Wearable robots. Technol. Rev 2004; 10(7), pp. 70–73.

[4] Anas, M. N. An instrumented insole system for gait monitoring and analysis. International Journal of Online and Biomedical Engineering 2014; 10(6), pp. 30–34. https://doi.org/10.3991/ijoe.v10i6.3971

[5] Serrao, P., Dhimole, V. K., and Cho, C. Effect of ankle torque on the ankle–foot orthosis joint design sustainability. Materials 2021; 14, p. 2975. https://doi.org/10.3390/ma14112975

[6] Gowrishankar, G. and Arockia Selvakumar, A. Detection and manipulation of pneumatic walking assistive device using integrated system and ANN classifier. Solid State Technology 2020; 63(6).

[7] Malcolm, P., Lee, S., Crea, S., Siviy, C., Saucedo, F., Galiana, I., Panizzolo, F. A., Holt, K. G., and Walsh, C. J. Varying negative work assistance at the ankle with a soft exosuit during loaded walking. Journal of neuroengineering and rehabilitation 2017; 14(1), p. 62. https://doi.org/10.1186/s12984-017-0267-5

[8] Sridar, S., Nguyen, P. H., Zhu, M., Lam, Q. P., and Polygerinos, P. Development of a soft-inflatable exosuit for knee rehabilitation. In 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2017; 3722–3727. https://doi.org/10.1109/IROS.2017.8206220

[9] Jungyoon Kima, Sungjae Hwanga, Ryanghee Sohna, Younghee Leeb, and Youngho Kim. Development of an active ankle foot orthosis to prevent foot drop and toe drag in hemiplegic patients: A preliminary study. Applied Bionics and Biomechanics 2011; 8, pp. 377–384. https://doi.org/10.1155/2011/530375

[10] Sungjae Hwang, Jungyoon Kim, Jinbock Yi, Kisik Tae, Kihong Ryu, and Youngho Kim. Development of an Active Ankle Foot Orthosis for the Prevention of Foot Drop and Toe Drag, Intl. Conf. on Biomedical and Pharmaceutical Engineering 2006.

[11] Benjamin DeBoer, Ali Hosseini, and Carlos Rossa. A discrete non-linear series elastic actuator for active ankle-foot orthoses. IEEE Robotics and Automation Letters.

[12] Xiloyannis, M., Cappello, L., Khanh Dinh, B., Antuvan, C. W., and Masia, L. Design and preliminary testing of a soft exosuit for assisting elbow movements and hand grasping. Biosystems and Biorobotics 2017; 15, pp. 557–561. https://doi.org/10.1007/978-3-319-46669-9_92

[13] Polygerinos, P., Galloway, K. C., Sanan, S., Herman, M., and Walsh, C. J. EMG Controlled Soft Robotic Glove for Assistance During Activities of Daily Living. 2015 IEEE International Conference on Rehabilitation Robotics (ICORR) 2015; 55–60. https://doi.org/10.1109/ICORR.2015.7281175

[14] Thalman, C. M., Lam, Q. P., Nguyen, P. H., Sridar, S., and Polygerinos, P. A Novel Soft Elbow Exosuit to Supplement Bicep Lifting Capacity. 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS, 2018. https://doi.org/10.1109/IROS.2018.8594403

[15] Bharadwaj, K., Sugar, T. G., Koeneman, J. B., and Koeneman, E. J. Design of a robotic gait trainer using spring over muscle actuators for ankle stroke rehabilitation. Journal of biomechanical engineering. 2005; 127, pp. 1009–1013. https://doi.org/10.1115/1.2049333

[16] Shorter, K. A. The design and control of active ankle-foot orthoses. PhD Dissertation, University of Illinois, 2011.

[17] Hamill, J., Knutzen, K. M., and Derrick, T. R. Biomechanical basis of human movement. 4th ed. Lippincott Williams and Wilkins, USA, 2015.

[18] Nurhanna Zulaikha Ishak, Shahrol Mohanmaddan, Annisa Jamali and Schnichiro Yamamoto. Experimental Analysis of Ankle Foot Orthosis Using Pneumatic Artificial Muscle. Asian-Pacific Conference on Medical and Biological Engineering, 2021; 118–125. https://doi.org/10.1007/978-3-030-66169-4_16

[19] Leung, J and Moseley, A. Impact of ankle-foot orthoses on gait and leg muscle activity in adults with hemiplegia: Systematic literature review. Physiotherapy 2003; 89, pp. 39–55. https://doi.org/10.1016/S0031-9406(05)60668-2

[20] Abhishek Agrawal, Sai K. Banala, Sunil K. Agrawal, and Stuart A. Binder-Macleod. Design of a Two Degree-of-freedom Ankle-Foot Orthosis for Robotic Rehabilitation. International Conference on Rehabilitation Robotics, Proceedings of 2005 IEEE. https://doi.org 10.1109/ICORR.2005.1501047

[21] Dong, D., Ge, W., Convens, B., Sun, Y., Verstraten, T., and Vanderborght, B. Design, optimization and energetic evaluation of an efficient fully powered ankle-foot prosthesis with a series elastic actuator. IEEE Access 2020; 8, pp. 61491–61503. https://doi.org/10.1109/ACCESS.2020.2983518

[22] Bruno Jardim, Adriano A. G. Siqueira, and Luiza Mesquita Sampaio do Amaral. Development of Series Elastic Actuators for Impedance Control of an Active Ankle Foot Orthosis, International Congress of Mechanical Engineering, Proceedings of COBEM 2009.

[23] Naoyuki Takesuea, Yosuke Komodaa, Hideyuki Murayamab, Kousyun Fujiwarab, and Hideo Fujimoto. Scissor lift with real-time self-adjustment ability based on variable gravity compensation mechanism. Advanced Robotics – 016.

[24] Aznizam Abdullah, Marzuki Azwani Bin Mazelan, Fathul Hazrimy Ahmad, Pranesh Krishnan, and Sazali Yaacob. Design and physical modelling series elastic actuator for ankle-foot orthosis. International Journal of Engineering and Advanced Technology 2020; 9(5). https://doi.org/10.35940/ijeat.A1432.069520

[25] Abdul Haleem Habeeb Mohamed and Muhammad Aizzat Zakaria. Torque analysis of a platform-based end effector ankle-foot orthosis for rehabilitation. Journal of Intelligent Manufacturing & Mechatronics 2019; 1(1), pp. 35–38.

[26] Chia, K. S. and Yap, X. Y. A portable PID control learning tool by means of a mobile robot. International Journal of Online and Biomedical Engineering 2016; 12(06), pp. 54–57. https://doi.org/10.3991/ijoe.v12i06.5716

[27] Azad, A. K. M., Tokhi, O., and Shaheed, H. A virtual environment for studying flexible robot manipulators. International Journal of Online and Biomedical Engineering 2009; 5(4), pp. 4–12. https://doi.org/10.3991/ijoe.v5i4.918

7 AUTHORS

Gowrishankar Govindaraj is a Research Scholar in the field of robotics at Vellore Institute of Technology, Chennai. He obtained a Master's Degree in Biomedical Engineering from Vellore Institute of Technology, Vellore, and received his Bachelor of Engineering in Electronics and Communication from Periyar University. His area of research interest is Robotics and Rehabilitation Engineering. (email: gowri.shankarg2014phd1121@vit.ac.in)

Arockia Selvakumar Arockia Doss received the Bachelor's Degree in Mechanical Engineering from Bharathiar University, Tamil Nadu, India, and the Master's Degree in Computer Aided Design (CAD) and the Ph.D. degree in Robotics (Mechanical Engineering) from Anna University, Tamil Nadu, India. He is currently

a Professor with the School of Mechanical Engineering, an Assistant Director of the Career Development Centre, and In-Charge of robotics club activities at the Vellore Institute of Technology, Chennai, India. His research interests include parallel manipulators, robotics and automation, rehabilitation devices, IoT, mechanism design, and failure analysis. He is a senior member of IEEE and a member of the Robotic Society of India (RSI). He was the Chairperson of the Indian Rover Challenge 2020 (IRC 2020). He was the Convener of the 1st, 2nd, and 3rd International Conferences on Robotics, Intelligent Automation, and Control Technologies (RIACT 2020, RIACT 2021, and RIACT 2022) (email: arockia.selvakumar@vit.ac.in).