Review of Upper Limb Exoskeleton for Rehabilitation and Assistive Application

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***Abstract*—The purpose of this research is to review upper limb exoskeleton for industrial and rehabilitation application from other researchers such as control system, mechanical design, load transmission methods, and control strategies. They mainly used the upper limb exoskeleton in the field of rehabilitation and power-assist. Electromyogram or EMG and Force sensor are used for measuring the user motion. Moreover, the load transmission methods have a lot of impact in term of speed and torque such as DC motor with gearbox, DC motor with driving wire, servo motor, and more. In this works, we study the various technique before design and develop the upper limb exoskeleton for supporting who is a disability of upper limb motion, to be more precise, low-cost, lightweight material, modern control algorithm, and capability upper limb motion.**

***Index Terms*—upper limb exoskeleton, load transmission methods, control strategies, EMG**

I. Introduction

The unremitting trends of the elderly population have contributed to the aging society in many countries. In present, one-fifth of the population will be an elderly population which is more than the working-age population. Moreover, according to Ministry of Public Health of Thailand, the statistics showing that in 2025 Thailand is going into the aged society which elderly population will increase to 25% or about 14M people from 72M people by that year but in the other way lack therapist which is about 0.01% of the population affect the rehabilitation process. Therefore, the assistive device as the exoskeletons will be playing a crucial role as rehabilitation for people [1]-[3] and power-assistant [4]-[6], who have a problem with controlling their muscle. In the field of a factory or heavy workers, elder people, and amyotrophic lateral sclerosis patients or others symptom, the power-assist exoskeleton will able the user to work more efficiently or able to do some activity in daily life such as in this research from K. Kazuo, *et al*. [7]. They develop an exoskeleton that helps to apply forces to the user's motion in order to perform some action such as eating.

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Figure 1. Power-assist exoskeleton. (https://eksobionics.com/eksoworks/)

Others than this exoskeleton that aim for daily living, the exoskeleton that strengthens workers from Ekso Bionics. According to this report, all the workers in the automobile manufacturing that tries on the exoskeleton from Ekso Bionics (Fig. 1) can lift weights up to 10 pounds.

Exoskeleton no only able to apply forces to support the user motion, exoskeleton can also help in the field of medicine. Many researchers have proposed a rehabilitation exoskeleton which can help reduce the need of a therapist and period of the rehabilitation process. Other than proposed of exoskeleton we could classifieds it into two type, the first one is the stationary exoskeleton, this type of exoskeleton are commonly used in rehabilitation because of safety and controllable. Rehabilitation exoskeleton often has a monitoring system for the therapist to analyze the result of the motion of the patient. In the other way, the second type is portable exoskeleton, portable exoskeleton has the advantage of mobility. Factory workers and other users can use this advantage to use the exoskeleton in daily activity, therefore, the exoskeleton has to be compact, lightweight, and easy to setup and use. The exoskeleton has 3 main part. The first part is input methods which are categorized several types including Electromyogram or EMG [4], [8], a Force sensor or FS [9], [10], and others input methods. K. Kazuo, *et al*. [7], proposed an input method that combined the EMG sensor as an input method between

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human and exoskeleton and Stereo Camera to identify the activity that a user perform such as eating. Secondly, actuators which can also be subdivided into smaller groups such as pneumatic, hydraulic, and types of motor. The exoskeleton is expected to be used in daily life or rehabilitation. Therefore, torque and ease of use must be considered. Hydraulic has an advantage of torque but oil leaking is not ideal for a wearable device. Pneumatic need a compressed air pump which is too big and heavy for a mobile device. However, motors such as Direct Current motor (DC motor) is a combination of torque and ease. Lastly, Controller methods covering PID controller [5], neuro-fuzzy controller [8], and a custom WOTAS controller which can assess and suppress the tremor behavior [3].

This paper represents the revision of various research on upper limb exoskeleton robots including several sub-topics such as control strategies, design, and fabrication, and different load transmission methods to develop our own upper limb exoskeleton and optimize the motion and design to fit Asia physical body especially Thai people and low cost. Our research has proposed the overview of upper limb exoskeleton in various technique in section 1, the application of a power-assist robot and rehabilitation device are described in section 2, the design of exoskeletons are described in section 3, various controllers and control strategies are discussed in 4. Conclusion and future work are presented in section 5.

II. Application of Assistive Devices

A. Power-assist

Figure 2. Power-assist exoskeleton. (https://hexus.net/ce/news/general/91451-panasonic-assist-robot-exoskeletons-demoed-video/)

Recently, the power-assist upper limb exoskeletons (Fig. 2) are receiving attention [4]-[6]. This type of exoskeleton is expected to be used in the field of industry as an assistant gave the user more power to lift a certain weight and increase the performance. In the case of lifting a certain weight, the exoskeleton must have higher torque and the user can control the exoskeleton can control the exoskeleton easily with comfort. Various sensors have been proposed in order the measure the motion from the user such as EMG [4], [8], and force sensor. Along with the controller such as Dynamic Load Compensation Controller (DLCC) compensates not only with load given to the exoskeleton but gravity too [11].

B. Rehabilitation Device

The upper limb exoskeletons (Fig. 3) are used as a rehabilitation device [1]-[3]. Rehabilitation has a high impact in the field of medicine due to the aging society and stroke and another disease. The exoskeleton not only assist the power of the user, but it can also rehabilitate the patient. Robot-aided rehabilitation has a lot of advantage over the tradition of one-on-one rehabilitation such as the duration and number of courses can be increased without increasing the therapist. The exoskeletons for various research have a different control strategies such as fuzzy controller [7], [12] due to the nature of non-linear exoskeleton joint, Sliding Mode Controller (SMC) helps to track desired trajectories and helps reduced the chatter [2], [13], and fixed motion controller which is a preprogrammed controller that allow only certain motion for rehabilitation [14]. Wearable Exoskeleton for Tremor Assessment and Suppression from E. Rocon and his team, presented an exoskeleton for tremor patient rehabilitation which is using WOTAS (Wearable Orthosis for Tremor Assessment and Suppression) [3]. WOTAS can operate basically in three control methods. The first mode is Monitoring mode, the function of this mode is to monitor the patient which no force is applied. The second mode is Passive control mode, the exoskeleton will not apply any force on to the patient, but the exoskeleton is able to suppress the tremor behavior. The third mode is Active control mode, the exoskeleton will apply forces in order to actively compensate and effective suppression of tremor.

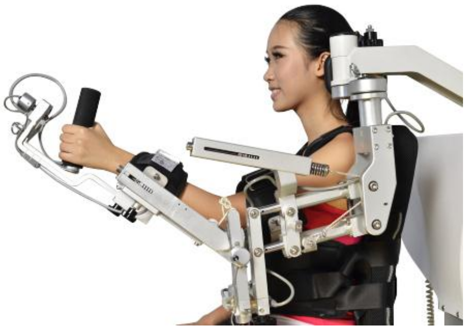

Figure 3. Commercial rehabilitation upper limb exoskeleton. (https://exoskeletonreport.com/product/nx-a2/)

C. Exo-spine

Human Spine can be classified as one of the upper limbs. Back pain, spine deformity, and Kyphosis or also known as round back or hunchback which the spine has an excessive curvature. These symptoms can affect the patient's daily activity or long-term living. Therefore, exo-spine have been developed not only to support and strengthen the user's spine, but the exo-spine can also be one of the rehabilitation devices too. In [15], they presented a passive exo-spine in the purpose of reducing the risk of developing low-back pain (LBP). Not only that they presented a mechanical design of the exo-spine. Joints of the spine are spherical joints (Figure 4) which allow the user to have a large range of motion while the exo-spine produce the support toque.

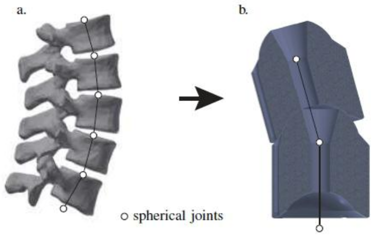

Figure 4. Design of the Exo-spine [15].

P. Joon-Hyuk, *et al*. [16], they presented an active exo-spine call RoSE (Fig. 5) for the treatment and rehabilitation of spine deformity. The exo-spine consist of many actuators that will support the spine. Since this exo-spine is powered by 40 Watts Lithium polymer battery, it can be easily portable and used in daily life.

Figure 5. Design of RoSE [16].

III. Design of Exoskeletons

A. Degree of Freedom (DoF)

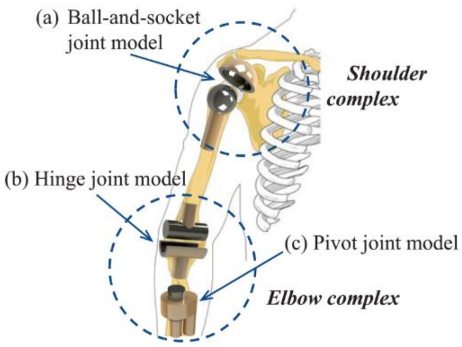

Figure 6. DoF of human upper limb. (http://dynamicsystems.asmedigitalcollection.asme.org/article.aspx?articleid=2528544)

Amount of Degrees of Freedom or DoF depends on the implementation of the upper limb exoskeleton. Human has 3 DoF on the shoulder and a hinge joint between the upper arm and lower arm (Fig. 6). Normally the upper limb exoskeletons have 3 DoF [2], [3]. DoF is related to the kinematic model coordinates required to ascertain the position of the upper limb exoskeleton, in which the concept of DoF in the kinematics of machines is used in three application, the first application is DoF of a body relative to a reference frame, DoF of a kinematic joint, and DoF of mechanism.

B. Load Transmission Methods

There are many types of load transmission methods such as pneumatic, hydraulic, and types of motor. The exoskeleton is expected to be used in daily life or rehabilitation. Therefore, torque and ease of use have to be considered. Hydraulic has an advantage of torque but oil leakage is not ideal for a wearable device. Pneumatic need a compressed air pump which is too big and heavy for a mobile device. However, motors such as Direct Current motor (DC motor) has a combination of torque and ease of use. Therefore, many other researchers pick this type of load transmission method for their exoskeleton [8], [14]. There are 3 ways of using this method as the actuator, the first method is attaching motors directly to each joint [12], the second method is the pulley system [8], [17], the third method is gear transmission [2], [18]. In each method has their own advantage such as attaching motors directly give you easy setup, the pulley system is lightweight, low impact, and low friction, and the gear transmission works smoothly, strong, drive ratio is constant, and high transmission efficiency. Servo motors have been proposed in the research from Mohammad Mahdavian, *et al*. [19]. Servo motor has been considered as the drive system for the rehabilitation exoskeleton because of this application will not be any great amount of load applied and this type of motor which has a lot of precision and ease of use. Therefore, this motor is also considered in future research. Our future research is based on a compact and portable device. Therefore, the load transmission method has to be small, lightweight, portable, and easy to set up and use in daily life.

C. Input Methods

Several input methods have been presented in other researches such as surface Electromyogram or sEMG, and Force sensor. There are other sensors that track the position, speed, or angle of each joint of an exoskeleton such as an accelerometer, gyroscope, and potentiometer.

1) Surface electromyogram or sEMG

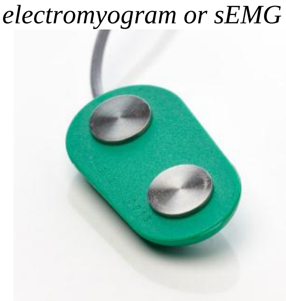

Figure 7. sEMG. (http://www.biometricsltd.com/img/products/emg-sensor.jpg)

There are two types of EMG sensor, one is intramuscular EMG which measure by using a needle probe puncturing through the skin and the second type is sEMG which the electrodes attach to the skin (Fig. 7). It measures muscle response and can be used in various ways such as help detect neuromuscular abnormalities but, in this case, it is used to detect user's muscle response in order to control the motion of exoskeleton. sEMG sensor attaches directly to the skins where the user's muscle is. Since it is difficult to use raw data as an input value, K. Kazuo, *et al*. presented the equation called Mean Absolute Value or MAV [8] that able to extract the raw data considering its effectiveness for real-time control.

$$MAV = \frac{1}{N}\sum_{k=1}^{N}|x_k| \quad (1)$$

The equation (1) of MAV, where x_k is the voltage value at k^{th} sampling, N is the number of samples in the segment. The number of samples is set to be 100 and the sampling time is set to be 1ms in their research.

In the other way, some other researchers use an amplifier and filter in order to use the signal from the EMG sensor. Since the EMG sensor gives a lot of noise therefore filter is necessary. This research on EMG signal amplification and filtering from W. Jingpeng, et.al. show a method of amplifying and filtering (Fig. 8). According to the figure raw signal which is amplitude from the EMG sensor goes into the first stage amplification or pre-amplifier since the amplitude is weak. Then, it goes into the high-pass filter and low-pass filter. The outcome of that will then go into the second stage amplification in order to invert the amplification so that it can easily be adjusted. After that, the signal will then go into the low-pass amplification in order to suppress the high-frequency noise. The output signal for these processes is fed into an analog-digital converter or ADV in order to convert the analog signal into a digital number.

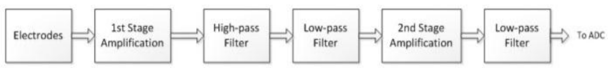

Figure 8. Diagram of the amplification and filtering circuitry [20].

sEMG sensor provides a safe, and invasive method that allows an objective quantification of the energy of the muscle. Each of the electrodes is placed in the specific placement for each muscle (Fig. 9).

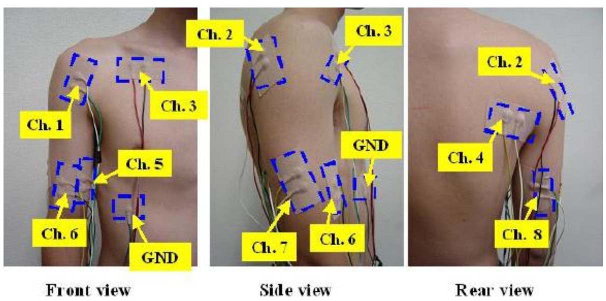

Figure 9. Placement of electrodes (sEMG sensors) [1].

2) *Force sensor (FS) or force-sensing resistor*

Figure 10. Force sensor or Force-sensing resistor. (https://www.sparkfun.com/products/9375)

A force sensor (Fig. 10) is one type of resistor which can refer to the other name called Force-sensing resistor or FSR. Force sensor has been used in many researches such as H. Jian, *et al*. They presented an exoskeleton that uses force sensors as the input method [14]. In order to measure the motion more accurately, they design a special double-shell wearable ring consist of an Inner shell, an external shell, and some force-sensing resistors. This design will improve the accuracy and comfort for the user (Fig. 11).

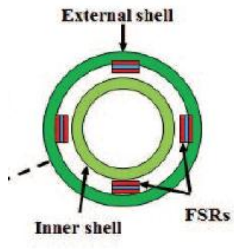

Figure 11. Special double-shell wearable ring [14].

Most of the research use sEMG as their input method, but in the other way the force sensor's data is easier to handle, and the sensor is more affordable.

IV. Controller and Control Strategies

Many Control strategies have been proposed in many research such as PID controller, Neuro-fuzzy controller, Sliding Mode Controller, and fixed motion controller. Each control strategy has its own advantage and purpose. The motion of exoskeleton can be separated into 3 topics including speed, direction, and torque.

A. *PID Controller*

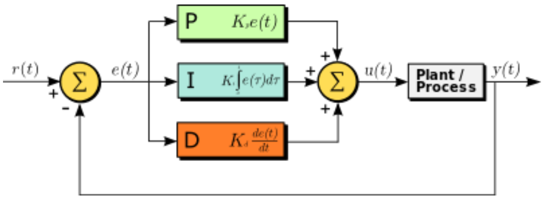

Figure 12. Block diagram of the PID control strategy. (https://en.wikipedia.org/wiki/PID_controller)

PID controller or a proportional–integral–derivative controller is used a lot in linear industrial control systems. PID controller will optimize the current speed without slow respond or overshoot. Since PID controller is generally made for linear system and exoskeleton is a nonlinear system. Although you might be able to use a PID controller with an exoskeleton and assume that it is a linear system, it might just not control the exoskeleton that well. In the other way, PID is easy to program, tune, and set up as shown in Fig. 12.

In [5], they presented a PID control system which is a combination of a master controller and a slave controller. The master controller will receive the reference angle from each joint. The signal will be calculated and sent to the slave controller which is an Arduino controller. In this case, the slave controller will respond to the signal and sending the motor control signal to the exoskeleton (Fig. 13).

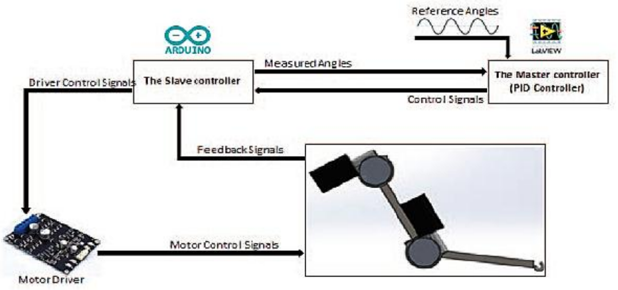

Figure 13. PID control system [5].

B. *Neuro-fuzzy Controller*

A neuro-fuzzy controller is a combination of neural network and fuzzy logic. The neural network is an artificial network is a simulation of a human brain. The human brain consists of many small processors and connected with many networks that help human learn and think quickly. But the controller doesn't have the same complex network as a human brain. It can only run the program that has been programmed on to it. Therefore, in order to simulate a human brain, the neuro-network controller is needed. Fuzzy logic is based on a degree of truth rather than true or false, therefore fuzzy logic has been used in many machines that can't be expressed as true or false. Neuro-fuzzy enables the controller to adjust the exoskeleton position to suit the position of each user based on IF-THEN rules.

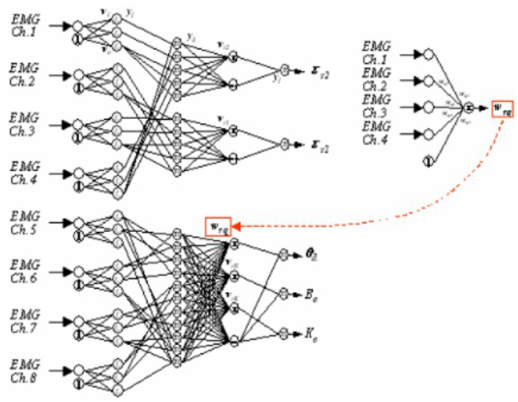

Figure 14. Neuro-fuzzy controller [8].

The sEMG based 3 DoF exoskeleton from Kazuo Kiguchi, *et al*. [8], they used sEMG sensors with the neuro-fuzzy controller. The outputs of the neuro-fuzzy controller are the torque for shoulder joint motion and the desired impedance parameters and desired angle for elbow motion of the exoskeleton. One neuro-fuzzy controller is prepared for each posture region (Fig. 14).

C. *Sliding Mode Control*

Sliding mode control or SMC is a nonlinear controller, this strategy could introduce undesirable chattering problem to the exoskeleton. Therefore, in order to reduce the chattering problem, SMC has to be used with other control strategies such as PID, and fuzzy logic. 5 DoF exoskeleton robot from E. Amir, *et al*. [12]. They presented the combination of SMC, PID, and fuzzy controller. The purpose of using a PID controller and SMC controller is the robustness against the model uncertainty and external disturbances and quick response. Along with T-S fuzzy control reduced the control input mathematical calculation volume so that it can allow the user to control the exoskeleton without any chatter during the process of rehabilitation. Another controller in [13], SMC is used with a PID controller to enforce the tracking error to approach to the sliding surface and ensure expected control performance and specifications. In which, the SMC control strategy introduces the chattering problem. Therefore, a fuzzy controller is used for adjusting the SMC parameter.

D. *Fixed Motion Control*

Fixed motion control has been proposed in the research from H. Jian, *et al*. [14]. They presented this control strategy that mainly focuses on the fundamental motion methods that are often used in daily life. Therefore, four motion modes have been presented as shown in Table I.

TABLE I. MOTION MODE OF DAILY ACTIVITY [14]

Mode	Motion
I	Stop
II	Bending and stretching around single joint
III	Moving straight
IV	Moving along a smooth curve

V. CONCLUSION AND FUTURE WORK

TABLE II. SUMMARY CHART

Paper	Propose	Actuator type	Controller method	Main Input	DoF
[1]	Rehabilitation	DC motor	-	EMG	1
[2]	Rehabilitation	DC motor	PID + SMC	-	3
[3]	Rehabilitation	DC motor	WOTAS	Force sensor	3
[4]	Assist	-	ANFIS	EMG	2
[5]	Low cost+Assist	DC motor	PID	-	2
[6]	Low cost+Assist	-	Only Simulation	EMG	6
[7]	perception assis	DC motor	Neuro-Fuzzy	EMG+camera	4
[8]	Power-assist	DC motor	Neuro-Fuzzy	EMG	3
[9]	Assist	DC motor	Nested PID	Force sensor	3
[10]	Assist	DC motor	Nested PID	Force sensor	3
[11]	Faster	-	Dynamic load compensation	EMG + Force sensor	2
[12]	Chattering free	DC motor	Fuzzy+PID+S MC	-	5
[13]	Rehabilitation Power-Assist	Servo Motor	SMC + PID + fuzzy	Force sensor	9
[14]	Power-assist	motor	Fixed motion	Force sensor	3
[15]	Exo-spine	Passive	-	-	-
[16]	Exo-spine	Linear actuator	-	-	-
[17]	Compact design	DC motor	-	Force sensor	3
[18]	Rehabilitation	DC motor	-	EMG	3
[19]	Rehabilitation	Servo motor	Data acquisition LABview	Force sensor	3

This paper covers various topics including the application, design, and control strategies of upper limb exoskeleton as summarized in Table II. Since many countries about to get into an aged society such as Thailand, the exoskeleton will play a huge roll in both terms of power-assist and rehabilitation. Power-assist exoskeleton can be used in a factory for workers and in daily living for elderly people or some patient. Rehabilitation exoskeleton will be used as equipment for the rehabilitating process in order to compensate for the lack of therapist. Not only that, we reviewed the mechanical design of the upper limb exoskeleton including degrees of freedom, load transmission methods. and input methods. In the same way, we reviewed control strategies including PID controller, Neuro-fuzzy controller, sliding mode controller, and fixed motion controller.

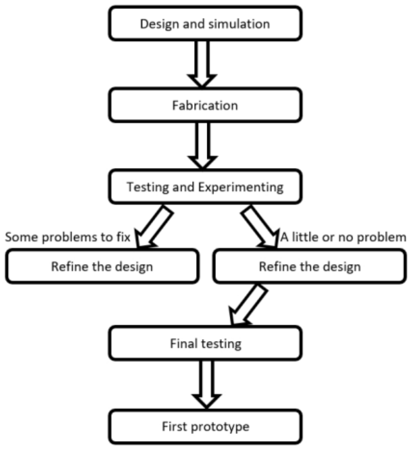

Figure 15. Future plan.

In the future work, this revision of upper limb exoskeleton will be implemented in our future work in order to develop an exoskeleton that is a low cost, portable, suitable for elderly people physical body, and can perform in both applications including rehabilitation and power-assist. Therefore, the design of the exoskeleton has to be considered wisely. For some examples, BLDC motor with gear reduction is chosen since it has an acceptable torque to weight ratio and it can be controlled and set up easily. The degree of freedom is also one of the most important topics that must be considered. According to the summary table, most of the upper limb exoskeleton has 3 DoF since the human upper limb including hand and wrist has 6 DoF [21]. We focus only on the arm and shoulder, therefore 5 DoF on each side has been selected for our upper limb exoskeleton platform. Our future plan is shown in Fig. 15.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

S. Sirawattanakul and W. Sanngoen conducted the research; S. Sirawattanakul reviewed and analyzed the cited paper; S. Sirawattanakul wrote the paper; W. Sanngoen gave advices to S. Sirawattanakul on how to write the paper; S, Sirawattanakul presented the paper at the conference; all authors had approved the final version.

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References

[1] B. Borhan, I. Mahdi, and N. Soharb, “Design and development of one degree of freedom upper limb exoskeleton,” *IEEE International Conference on Robotics and Mechatronics (RSI)*, Oct. 7-9, 2015, pp.223-228.

[2] B. Mahdieh, N. Saeede, H. Mojtaba, and M. Vahid, “Sliding mode control of an exoskeleton robot for use in upper-limb rehabilitation,” *International Conference on Robotics and Mechatronics (ICROM)*, Oct. 7-9, 2015, pp. 694-700.

[3] E. Rocon, A. F. Ruiz, J. L. Pons, J. M. Belda-Lois, and J. J. Sanchez-Lacuesta, “Rehabilitation robotics: A wearable exo-skeleton for tremor assessment and suppression,” *IEEE International Conference on Robotics and Automation*, Apr. 18-22, 2005, pp.2271-2276.

[4] J. Shao-Fu, Y. Kuu-Young, and K. Chun-Hsu, “Real-time control for an upper-limb exoskeleton robot using ANFIS,” *IEEE International Conference on Advanced Robotics and Intelligent Systems (ARIS)*, 2017, Sep. 6-8, pp. 25.

[5] G. Mohamed, M. Bishoy, S. Omar, and I. Khalil, “Design and analysis of low-cost upper limb exoskeleton,” *IEEE International Conference on Computer Engineering and Systems (ICCES)*, 2017, Dec. 19-20, pp.80-84.

[6] C. Guo, Z. Fo, G. Chuang, and S. Mei, “Design of joint Structure for Upper Limb Exoskeleton Robot System,” *IEEE 2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL)*, Nov. 19-22, 2017, pp. 1092-1095.

[7] K. Kazuo, K. Yasunori, and H. Yoshiaki, “Task-oriented perception-assist for an upper-limb power-assist exoskeleton robot,” *IEEE 2010 World Automation Congress*, Sep. 19-23, 2010.

[8] K. Kazuo, H. Mohammad, and Y. Takefumi, “Adaptation strategy for the 3DOF exoskeleton for upper-limb motion assist,” *IEEE International Conference on Robotics and Automation*, Apr. 18-22, 2005, pp.2296-2301.

[9] K. Manoj and O. Raul, “Design and Fabrication of an Intention-Based Upper-Limb Exoskeleton”, *IEEE International Symposium on Intelligent Control (ISIC)*, Sep. 19-22, 2016, pp.179-184.

[10] K. Manoj and O. Raul, “Modeling of an Intention-Based Upper-Limb Exoskeleton”, *IEEE National Aerospace and Electronics Conference (NAECON) and Ohio Innovation Summit (OIS)*, July 25-29, 2016, pp.201-206.

[11] Z. Shitong, S. Qiuzhi, and W. Xin, “Design and Simulation of Load Dynamic Compensation Controller Based on Dynamic Model for Upper Limb Exoskeleton Robot*”, IEEE International Conference on Unmanned Systems (ICUS)*, Aug. 9, 2017, pp.110-115

[12] R. Amir and K. Reihaneh, “Fuzzy sliding mode control of 5 DoF upper-limb exoskeleton robot,” *International Congress on Technology, Communication and Knowledge (ICTCK 2015)*, Nov. 11-12, 2015, pp. 25-32.

[13] W. Qingcong, W. Xingsong, D. Fengpo, and Z. Qing, “Fuzzy sliding mode control of an upper limb exoskeleton for robot-assisted rehabilitation,” *IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, May 7-9, 2015.

[14] H. Jian, H. Weiguang, X. Wenxia, M. Samer, and A. Yacine, “Control of upper-limb power-assist exoskeleton using a human-robot interface based on motion intention recognition,” *IEEE Transaction on Automation Science and Engineering*, vol. 12, no.4, pp. 1257-1270, Oct. 2015.

[15] B. Matthias, D. Laura, R. Carlos, M. Matthew, V. Bram, and L. Dirk, “Toward low back support with a passive biomimetic exo-spine,” *IEEE International Conference on Rehabilitation Robotics (ICORR)*, July 17-20, 2017, pp.1165-1170.
[16] P. Joon-Hyuk, S. R. Paul, R. P. David, A. K. Sunil, “Robotic Spine Exoskeleton (RoSE): Characterizing the 3-D stiffness of the human torso in the treatment of spine deformity,” *IEEE Transaction on Neural System and Rehabilitation Engineering*, vol.26, no.5, pp.1026-1035, May 2018.
[17] S. Hwiwon and L. Sangyoon, “Design and experiment of an upper-limb exoskeleton robot,” *IEEE International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, Jun. 28 - Jul. 1, 2017, pp.807-808.
[18] G. Shuxiang, G. Jiange, G. Jian, Z. Weijie, and H. Yuye, “Design of the structural optimization for the upper limb rehabilitation robot,” *IEEE International Conference on Mechatronics and Automation*, Aug. 7-10, 2016, pp.1185-1190.
[19] M. Mohammad, G. Amirmasoud, and Y. Aghil, “Design and fabrication of a 3DoF upper limb exoskeleton,” *IEEE RSI International Conference on Robotics and Mechatronics*, Oct. 7-9, 2015, pp.342-346.
[20] W. Jingpeng, T. Liqiong, and E. John, “Surface EMG signal amplification and filtering,” *International Journal of Computer Applications*, vol. 82, no.1, pp.15-22, Nov 2013.
[21] F. Fei, W. Haoping, and T. Yang, “Robust time delay estimation based intelligent PID control of 6dof exoskeleton robot,” *IEEE International Conference on Intelligent Human-Machine Systems and Cybernetics*, 2017, pp. 386-389.

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