9/18/2022

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Exoskelton design progress report

MEEN 401 – 502

Group 5

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- # Introduction

People who have been diagnosed with a neurological injury like stroke, cerebral palsy and other injuries as such have been struggling with finding an effective treatment for their physical disabilities. In this project, the focus is mainly on arm amputees and patients with injuries that subject them to weakness in their upper limb movement. The aim is finding a better solution for these patients than traditional treatment that has many constraints like resources in insurance and mainly having no benefits to the user functionally like static braces. We are looking into a better, cheaper and more sophisticated solution for the patients. Exoskeletons arms can be worn and used to stabilize and guide arm movement of patients that have disabilities in that area of movement. [3]

The user transmits information signals to the controller of the exoskeleton, a wearable robotic device attached to the human arm, in order for it to produce the proper control signals for various training tactics and paradigms. This report extremity exoskeleton provides three additional adaptability degrees of freedom in addition to the four fundamental degrees of freedom for the shoulder and elbow joints to accommodate various user arm anatomy. [7]

The development and modelling of an upper extremity exoskeleton installed on a wheelchair are the topics of this essay. Our goals are to offer effective physical therapy and rehabilitation for the patient's arm as well as the ability for the therapist to employ various training techniques with varying levels of support depending on the user's condition and the severity of the injury. [8]

Additionally, this technology enables the patient to receive consistent training without the therapist's constant supervision; as a result, the therapist can treat many patients at once and the overall cost of therapy can be decreased. [10]

- ## Need statement:

Exoskeletons are external supports that can be worn to support the body, either to help a person recover from an accident or to improve their biological capabilities. As the name implies the frame provides limbs with additional movement, strength, and endurance by using a network of electric motors.

Various therapy exists are Conventional Physical Therapy, Powered Exoskeleton, and Hybrid Physical Therapy With Exoskeleton in the Treatment of Individuals With Sub-acute and Chronic Stroke. To provide a means to assist upper body mobility for people who are suffering from physical disabilities while retaining their independence as much as possible is main goal of this research report.

- ## Need Analysis:

Contexts –

The main purpose of the project is to provide a system that supports the upper body for people who are suffering from a lack of upper body mobility due to, stroke, spinal cord injury and muscle dystrophy. Stroke is a disability that constrains the movement of the patients' body as patients lose connection to their motor functions. [11]

The brain sends signals to the muscles however the motor function is lacking in responsiveness therefore the patient cannot move fore say their arms as their brain intends to move it. The upper-limb torso movements are supported by the exoskeleton to a maximum of five degrees of freedom, with the shoulder and elbow each receiving three and two degrees of freedom, respectively. [12]

Definition of Terms:

- Upper body: This means shoulders, arms and elbow of patients.
- Lower body: This means Thigh, knees, shin, calves and feet.
- Motor function: For a human to move a certain muscle, his or her brain sends neurons to the required muscle to move or function a certain way and with the required force to help with everyday life activities. This process as a whole is defined as the human motor function.
- Bodyweight: The weight of certain parts of the body like the arm, leg, etc.
- Body stability: The balance of the body weight distribution in the body.
- Portable: The exoskeleton arm can be transported from one location to another, attaching it to different furniture and changing the location where it can be used. Portable does not necessarily mean the user can walk around while wearing the exoskeleton arm, but can take it off and be able to move it to a different location where the user can wear it again.

Solutions that exist today:

There are two main solutions that are ongoing nowadays. First nurses in hospitals help in giving medicines and injections to patients that can't move or suffer from severe diseases. A stroke can be one of the factors that cause the patient to not be able to take his/her medications regularly without the help of someone, thus a nurse is there to provide the patients with their crucial needs at all times. [19]

The other solution is the existing exoskeletons that have been developed by engineers from all around the world. Some of the exoskeletons served effectively, others failed to work properly for several factors that will be discussed below. Our main aim is to design an exoskeleton that will serve as the most effective and proper exoskeleton and make the lives of the patients suffering from strokes easier. Another goal is to design an exoskeleton that will definitely improve the lives of patients. [20]

The following table is a summarized list of advantages and disadvantages found from the literature review done on exoskeleton arms:

Advantages	**Disadvantages**
Various Exoskeleton designs provide protective covering that prevents damage to the patients.	Complex movements are limited as some design of Exoskeleton is bulky.
Exoskeleton designs help patients to immobilize muscles that are difficult for the user to move and control without using it.	Various available designs of Exoskeleton are not resizable- as a child user will grow out of the size and it not fits then.
Upper limbs exoskeleton designs are used to support the upper body of human beings.	Many of the existing designs of Exoskeleton are not portable due to its complex designs.

- ## Literature review –

According to Lane and Usiak [22], capturing the wants and needs of the end user is a typical approach in consumer product marketing and the design of medical devices, but it is not frequently used in the development of assistive technology.

Shah and Robinson [24] note that increased access to user needs, experiences, and ideas; improvements in medical device design and user interfaces; and an improvement in the functionality, usability, and quality of the devices are the main advantages of user involvement with respect to the development and evaluation of medical device technology.
Based on an anthropomorphic 5-DOF upper-limb exoskeleton for power-assisted activities, this upper-limb exoskeleton incorporates an internally rotating elbow joint. [25]

A 1-DOF internally rotated elbow joint and a 2-DOF shoulder joint are both parts of the proposed 3-DOF upper-limb exoskeleton. The 3-DOF upper-limb exoskeleton's structural characteristics were established, and the similarities and differences between the two exoskeletons were examined. Kinematics and dynamics were used to examine the workspace, joint torques, and power consumption of two exoskeletons, and an exoskeleton prototype experiment was carried out [28] In industrial situations, the suggested non-anthropomorphic 3-DOF upper-limb exoskeleton can be used as a power-assisted upper-limb exoskeleton.

Kessler and Hinds [29] say that technological advancements in assistive technology have up to now dominated the published literature, which is contrary to their claim that the fundamentals of robotic design should take psychological and social issues into account. This analysis clearly found a disproportionate quantity of material providing design specifications of exoskeleton systems, in contrast to the paucity of literature that considers the perspectives of technology users.

According to Bates and Spencer [32], there may be strong emotional reactions when wheelchairs and other assistive devices are first introduced into a person's life after the onset of an acquired handicap. Similar and strong emotional reactions can probably be anticipated when introducing someone to exoskeleton technology. The reactions can range from extremes of euphoria brought on by re-enablement to despair brought on by a fresh realization of loss.

According to McMillen and Söderberg [33] a device can only be used by the individual who perceives its benefits for their personal needs. Shah and Robinson [34] advise consumers to swiftly abandon products that fall short of their personal expectations, even if producers and healthcare providers may believe that those consumers' needs have been satisfied. The relevance and significance of user input in design processes is further justified by the potential for contradiction between technology's end users and those responsible for its creation and prescription.

Focus groups were employed by Domain and Bur ridge [35] to learn what stroke victims, their caregivers, and therapists thought about various upper limb assistive technology devices. The exoskeleton arm designed by Myomo has studies that show that it is a cheaper than other medical solutions in the long run. This all adds up to being time and money saving in the long run. [36]

The exoskeleton arm was tested and experimented with to see the effect the exoskeleton arm has on patients everyday lives capabilities. All of the tested subjects have shown improvements in everyday lives actions when they were using the exoskeleton arm. Everyday lives that were observed were eating, drinking, switching lights, and picking up a laundry basket. A detailed report of the experiment is available online. [39]

The advantages of this design are the Exoskeleton designs frequently have flexible joints that cooperate with the user's underlying muscles. This enables the user to move in a variety of ways. These suits will eventually be able to be employed to give American soldiers the ability to run faster, carry heavier weapons, and leap over obstacles on the battlefield if exoskeletons are completed. Exoskeletons are employed in vehicle production facilities today, where they improve worker performance and offer injury protection. [40]

According to the paper published by JVE journals (Journal of Vibroengineering), e-health has become a method to help the patients recover by utilizing virtual surroundings available in order from the to be able to carry out specific movements [43]. Robot assisted devices, such as the exoskeleton have been widely implemented in the field of e-health, due to its effective results it has shown in the various kinds of therapy, in which fast recovery is achieved [44].

The main three types of modalities are: Active, passive, and assistive. In the active mode, the patient basically does all the work, yet in the passive mode it's the opposite, where the exoskeleton carries out the task. The assistive mode combines both the patient's ability and the exoskeleton to carry out the task together. The assistive mode is what helps the patient to recover, since it helps the patient get better in carrying out the everyday tasks, he/she needs to accomplish [45].

Major Functions:

A function that the exoskeleton must have is to maintain the stability of the patients' body. This is crucial as an imbalance of weight due to the exoskeleton being worn can cause imbalance in the patients' body weight and could lead to muscle strains, which need to be avoided. [22]

The bodyweight of the patient must be supported by the exoskeleton in the area required to help the patient carry his or her own bodyweight. This is crucial as patients might lack control of certain muscles to uphold certain body parts. The exoskeleton must have a feature that allows muscle flexibility in order to move muscles in all directions needed and not for say limiting the patient's arm in a certain one dimensional axis. [28]

Functions:

- To Aid the motor function in a human body to overcome a specific injury as Exoskeletons frequently combine small brushless DC motors with gearboxes to achieve high torque and encoders to provide positional input.
- To Support the upper body parts of patients by using various designs.
- To assist the patient to lift their arm by using various types of exoskeleton and thus providing instant relief to them.

Requirements:

- The size of the exoskeleton implemented on the arm. What this means is that people can grow out of the size of their exoskeletons, like children whose arms are growing as they age.

- The load applied on the arm. Trying to make the exoskeleton lightweight for the user can be difficult as exoskeleton arms can weigh up to 17kg. [7]
- Increased load on the back (especially the lower part) if it were to be a portable exoskeleton, which could lead to serious injuries.
- The exoskeleton might not fit some patients perfectly, causing the joints to change in shape after damaging the cartilage.

Function Structure -

To provide a means to assist upper body mobility for people who are suffering from physical disabilities

1. Strengthen upper limbs movement
    1. Provide sufficient lifting force
    2. Train muscle movement
2. Control movement
    1. Controllable speed of movement
    2. Provide ability of rotation of shoulder and wrist
    3. Leverage the elbow
3. Support the bodyweight of the patient
    1. Provide means to reduce weight of wearing the device on the arm
    2. Decrease the strain on the back
    3. Have a zero position (starting position that removes the actual weight of the design on the arm at that position).
4. Maintain patient's stability
    1. Balance the overall bodyweight
    2. Provide means to increase comfort of user

Function requirements –

Function	Requirement	Source
Strengthen upper limbs movement	Show progress in improvement in upper limbs muscle strength and movement after a while of using the exoskeleton. This is a form of medical treatment by using the exoskeleton arm. Flexible design size having 20 cm to 50 cm of limbs size.	https://www.rtcnews.com/mach/science/new-exoskeleton-does-
Support bodyweight of the patient	Have a total structure weight of less than 17 kg of exoskeleton so that it not becomes bulky. On the other hand it exhibits an almost iso-elastic behavior whereby the lifting force of the mechanism is constant for a wide working range	X-Arm - Exoskeleton Reporthttps://exoskeletonreport.com › product › x-arm

Maintain patient’s stability	Taking the weight on the user's arm from his/her necks and shoulders and applying it to their stronger core.	https://www.levitatetech.com/2018/01/28/how-do-exoskeletons-work/
Provide sufficient Lifting force	Lifting force of a 66N (15 lbs)	https://www.nbcnews.com/mach/science/new-exoskeleton-does-
Train muscle moveme nt		https://www.levitatetech.com/2018/01/28/how-do-exoskeletons-work
Controlla ble speed of moveme nt	-	https://www.frontiersin.org/files/Articles/261051 /fnins-11-00352-HTML/image_m/fnins-11-00352-g0 01.jpg
Provide ability of rotation of shoulder and limb	Flexion/extension 0-90/0-45 (deg) movement range	https://aip.scitation.org/doi/10.1063/5.0051484
	Abduction/adduction 0-90/0-45 (deg) movement range	
	Internal/External rotation 0-80/0-30 (deg) movement range	

Leverage the elbow	Flexion to be in the range 0 to 30 degrees in the elbow. As well as 50 degrees for both pronation and supination.	https://pubmed.ncbi.nlm.nih.gov/32501919/
Have a zero position	A starting point where no torque or force is required or applied by the exoskeleton arm or the user.	http://www.columbia.edu/~njr2121/JP_13.pdf
Balance the overall bodyweight	Ensure the symmetrical body weight distribution in the human body is retained as much as possible when wearing and using the exoskeleton arm. (Fully balanced body weight is not yet achieved)	https://www.researchgate.net/publication/2582550 23_Design_of_a_perfect_balance_system_fo_active _upper-extremity_exoskeletons

Provide means to increase comfort of user	Should be more comfortable than general commercially available exoskeleton arms.	https://www.researchgate.net/publication/235730055_Comfort_of_two_shoulder_actuation_mechanisms_for_arm_therapy_exoskeletons_A_comparative_study_in_healthy_subjects

- **CONCEPTS –**

CLEVERarm:

An innovative upper-limb exoskeleton for stroke sufferers is called CLEVERarm. The shoulder girdle, elbow, wrist, and glenohumeral (GH) joint may all move with the use of CLEVER ARM's six active and two passive degrees of freedom (DoF).

A new and better kind of physical treatment called CLEVERarm encases the upper limb of a patient with disabilities and neurological problems, such as stroke. Prior methods and equipment might be time-consuming and demanding when employed with this form of physical treatment. [30]

In contrast to currently available devices, newly created full-arm robotic device is small and light enough to be easily transported and used in a variety of locations, including homes, hospitals, clinics, and rehabilitation facilities. [31]

Pros:

Compact, lightweight, ergonomic, enhanced rehabilitation arm for virtual and augmented reality. [32]

Cons:

High cost, limitations on the performance of the available systems and uses of plastic materials has low durability, 4 DOF [34]

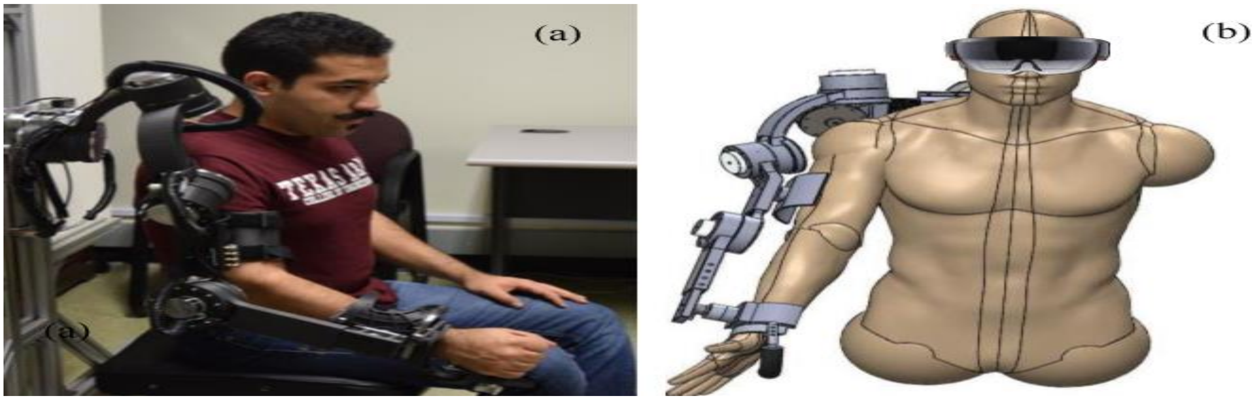

*Figure 1 (a) Schematics of **CLEVERaRM** Design and (b) CAD model of CLEVERaRM*

Parallel Actuated Shoulder Exoskeleton Robot:

A recently created exoskeleton robot built to study the shoulder's neuromuscular characteristics during both static posture and dynamic movement in three dimensions, including intrinsic and reflexive systems.

Fast perturbation (>100 / s) is needed to quantitatively characterize these qualities in order to distinguish their contribution from that of the voluntary process. Understanding these shoulder control characteristics may help with upper limb performance augmentation or rehabilitation during actual human-robot physical contact. [36]

Pros:

The parallel actuated exoskeleton has a advantages of producing high acceleration due to its parallel construction, which is quick enough to meet the speed required for the assessment of unique neuromuscular features of the shoulder. [37]

Cons:

Complex mechanisms and having bulky design. In one implementation, the stroke length of the **top two actuators 108 and 110 may be 152.42 mm** and the bottom actuator 112 may be 101.62 mm.

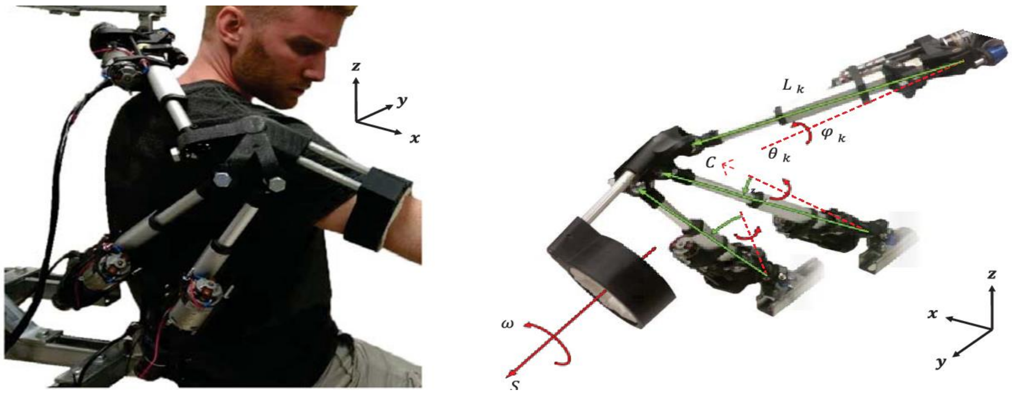

*Figure 2 Schematics of **Parallel Actuated Shoulder Exoskeleton Robot** Design*

CRUX: A Compliant Robotic Upper-extremity eXosuit for lightweight, portable, multi-DoF muscular augmentation :

Wearable robots may be able to give their users more stability and power. These additions are perfectly engineered to activate in unison with the user's actions and supply additional force as required. However, given to the intricacy of the underlying human anatomy, building such robots is exceedingly difficult. In this study, we introduce CRUX, a flexible robotic exosuit for the upper extremities.

This exosuit has a lightweight (1.3 kg), flexible form for transportation and was designed with inspiration from tensegrity models of the human arm. We also demonstrate how CRUX keeps the upper extremities fully flexible for its users while supplying multi-DoF augmentative strength to the main arm muscles, which is demonstrated by monitoring the person exercising the arm's heart rate then Exosuits like CRUX could be helpful.

Pros:

Lightweight, portable, multi-DoF muscular augmentation

Cons:

Limited Power Range, Not portable and limited range

Figure 3 Schematics of CRUX Design

6-REXOS:

6-REXOS, a 6-DOF upper-limb exoskeleton, supports users with mild neuromuscular disability. Three motion generating units are included in 6-REXOS to add four active rotational DOFs and two passive translational motions to the forearm and wrist movements. The elbow and wrist joints each include two flexible connections to facilitate translational motions that improve kinematic redundancy and maintain the alignment of the axes in both joints.

It has been determined how important the kinematic redundancy is based on a variety of factors, including the manipulability index, singularity analysis, and condition number. Additionally, a kinematic model of a human arm was created to examine how well these systems worked together and also the incorporation of kinematic redundancy has been found to enhance the maximum and minimum manipulability index.

Pros:

Solid design , Highly redundant , less cost

Cons:

Misalignment occurs and rigid and complex structure

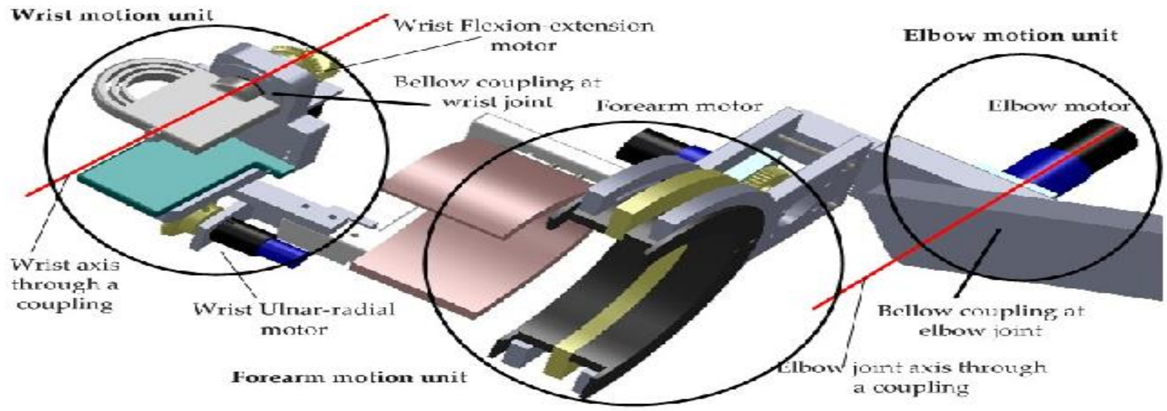

Figure 4: Schematics of 6 REXOS Design

EksoVest :

The EksoVest is a passive upper-body exoskeleton that was developed by Ekso-BIONICS and EkosVest uses two distinct mechanisms—moment generation and hinge mechanisms to lessen the load and amount of fatigue experienced by the operator on the shop floor. Particularly for overhead tasks, the exoskeleton helps the wearer carry some of the strain.

The vest has been found to enhance the centre of pressure velocity in the anteroposterior direction by 12% while decreasing the shoulder abduction range of motion by 10%. Additionally, it has considerably decreased the spine stress, particularly during overhead drilling activity.

The most robust, naturally tracking, and assisting exoskeleton vest available is called EVO, the following iteration of EksoVest. Based on feedback from the market, EVO includes more exoskeleton technologies that we have been developing.

Pros:

Increase productivity and reduce fatigue , increase strength and stamina and protection from injuries.

Cons:

The EksoVest only fits patients ranging from 5 feet 2 inches tall to 6 feet 4 inches tall so it has size barrier, High cost.

Figure 5 : Schematics of EKSOVEST Design

- **Concept Evaluation -**

We were able to select the idea that best suited our needs and criteria by using an assessment process to quantify the concepts and identify the best possible design solution.

Two assessment processes were used to determine which concept was the best:

(i) Absolute evaluation, in which all requirements had to be met, and

(ii) Relative evaluation, in which concepts were contrasted with one another in light of a set of evaluation criteria.

- Material:

(To be put into a different document for future sections of the report)

- Make it less expensive than models currently available which cost upwards of 65,000 U.S dollars
- Be able to Withstand Qatar Weather (High temperatures humidity)
- More economical than current market
  Lightweight (less than 10kg on the arm)

After studying various designs we design an upper limb exoskeleton design which has above mentioned features in the given price by considering all absolute parameters evaluations.

- ## Absolute Evaluation –

The table below displays the best criteria to evaluate concepts of the exoskeleton arm. This is done to determine the best conceptual design for the device that satisfies our design requirements. **A** concept that fails any absolute criterion is rejected.

Table 11: Absolute concept evaluation

Evaluation criteria	Description
Safety	The safety factor of using the device. Is there a possibility that the parts or incorrect usage of the device can cause injuries? This criterion evaluates whether the device needs further configuration to ensure the safety of the user.
Portability	How much the device weighs can determine how easy it is to transport it to different locations for use. How big the dimensions and size of the device can also determine its portability.
Cost	How does the device cost compare to other options available in the market? Is it cheaper and within the range of the users budget?
Quality	The quality of the material used for the device.
Maintenance	Does the device need maintenance? If yes, then how often? How much are the maintenance cost and time? A device that requires less maintenance time and cost is better in this criterion.
Operation	Does the device require an external power source (like a chargeable battery, fuel, etc.)? How will that affect the longevity of its operation? How long can the device operate until it needs to stop to recharge, cool, get a resupply of power source, etc.?

Effectiveness	The evaluation of the required functions. How well does the device accomplish the required functions for the user?

Table 22: Relative concept evaluation

Evaluation Criteria	**Concepts**					
	1. (CLEVERarm)	**2. (Parallel Actuated Shoulder Exoskeleton Robot)**	**3. (CRUX)**	**4. (6REXOS)**	**5. (EksoVest)**	
Safety	**3**	**3**	4	5	4	
Ease of transportation	**5**	**4**	3	3	4	
Cost	**6**	**3**	1	0	3	
Load of exoskeleton used	**2**	**4**	2	1	3	
Operation Capacity Range	**5**	**3**	5	4	3	
Precision	**2**	**3**	5	4	3	
Quality	**3**	**2**	3	4	2	
Maintenance	**6**	**2**	4	3	2	
Net score (total x weight)	**3.98**	**3.17**	**3.2**	**3.1**	**3.44**	
Rank	**1**	**4**	**3**	**5**	**2**	

- ## **Concept Selection –**

After completing the evaluation process of all concepts, the **CLEVERARM** has the highest score among the other concepts. The evaluation criteria considered many different requirements: power requirement, load of exoskeleton device used , Degree of Freedom , cost, safety, schedule feasibility, and reliability.

The **CLEVERARM** was considered as the reference in the said evaluation. The first criterion was power requirement by exoskeleton to operate is reduced the energy expenditure required to walk. The average energy used while walking with the weighted vest and no exoskeleton was 6.98 Watts/kg while Walking with the weighted suit and exoskeleton required 6.56 Watts/kg.

CRUX Exoskeleton design are lighter in weight as compared to other design and also has robust design but it was too costly.

6 REXOS is still in the phase of its design improvement, where an adaptive orthosis is required for improved pHRI, which helps to reduce the relative motion between the human arm and exoskeleton. It has been noted that the introduction of the kinematic redundancy improves the maximum and minimum manipulability index by 21.13% and 22.25% respectively. Furthermore, it is concluded that adding kinematic redundancy to the 6-REXOS through a flexible coupling improves the manipulation, which guarantees comfort motion assistance.

Moreover, a mechanical and a gas spring mechanism, mounted on the back of the user, help to bypass the applied forces on the human elbow and shoulder joints. The Stuttgart jacket also has a passive lower-extremity module, which helps to ground the applied forces on the upper-limb module. The technical features of Stuttgart Exo-Jacket was selected based on the ergonomically analysis of the task and environment which are low cost and also easily available and reduces the chances of future injuries.

Exo jacket has 3 active and 9 passsive DOf while 6 REXOS has 4 active and 2 passive DOF While The shoulder girdle, elbow, wrist, and glenohumeral (GH) joint may all move with the use of CLEVER ARM's six active and two passive degrees of freedom (DoF).

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Appendix –

Figure 1

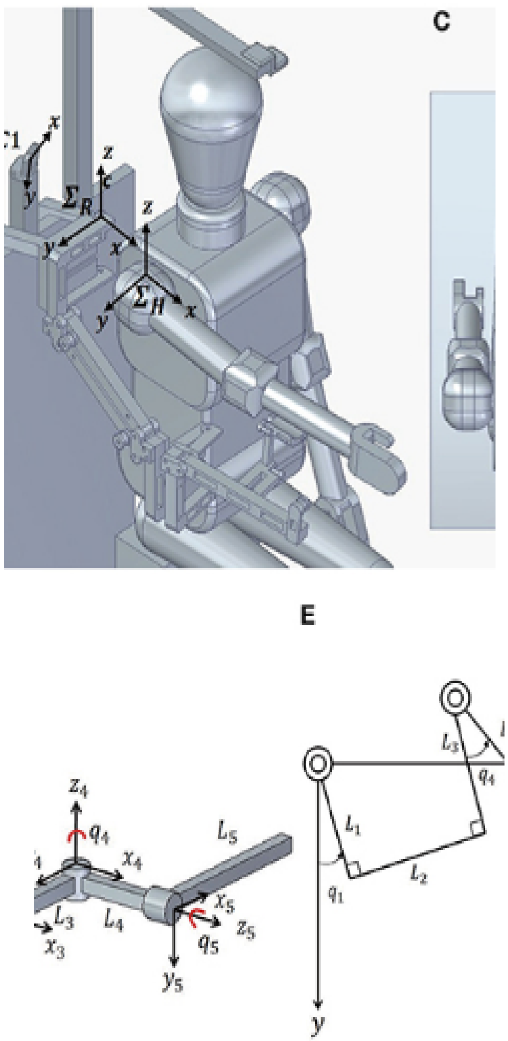

FIGURE 1. Kinematic structure of Exoskeleton Actuated by Soft Modules (EASoftM) (A) Overall structure of the proposed EASoftM with a participant. (B) Close-up picture of upper body. $\sum_R$ represents the base coordinate of the robot, $\sum_{C1}$ the camera coordinate used in the vision-based control law, and $\sum_{C2}$ the camera coordinate to record the trajectories of the end-effector. The exoskeleton has two parallel links and four degrees of motion that approximates normal human anatomy of upper limb. (C) Overall structure of the proposed EASoftM (view from top). The attachment to the upper limb was set up at the end of exoskeleton to support the wrist of a participant. (D) Denavit-Hartenberg parameters of exoskeleton structure. The soft modules are attached to the joints (q_1 and q_4) to rotate the joints, and the rubber bands are attached to the parallel structure of link L_2 and L_5 to fix the joint angles of q_2 and q_5 within a certain range, resulting in compensation of the gravity. (E) Kinematic structure of exoskeleton in 2D work plane. As the passive joints (q_2 and q_5) lift up the upper limb,the active joints rotates shoulder and elbow (q_1 and q_4) to make a reaching motion possible within this 2D plane.

Table 1

i	a_{i-1}	α_{i-1}	d_i	θ_i
1	0	0	0	q_1
2	0	$-\frac{\pi}{2}$	L_1	q_2
3	L_2	0	0	q_3
4	0	$\frac{\pi}{2}$	$-L_3$	q_4
5	0	$-\frac{\pi}{2}$	L_4	q_5
E	L_5	0	0	0

TABLE 1. DH parameters for the kinematic structure.

Table 2

L_1 [mm]	L_2 [mm]	L_3 [mm]	L_4 [mm]	L_5 [mm]
100	210	100	100	210

TABLE 2. Length of links of exoskeleton.

Figure 2

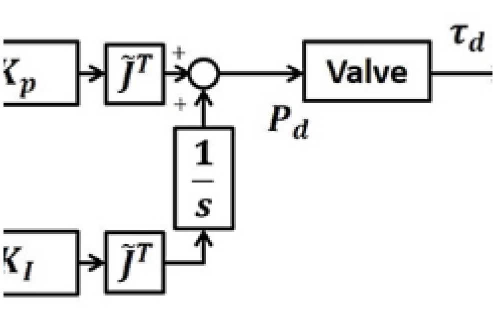

FIGURE 2. Block Diagram of the control law. Based on the direct transformations from visual space to actuator space, the proposed control scheme will allow a robot to execute visually directed reaching motion with its end-effector without reference to its precise kinematics and necessity to calculate the inverse kinematics.