LIFESUIT Exoskeleton Gives the Gift of Walking so They Shall Walk

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***Abstract*— LIFESUIT Exoskeleton Gives the Gift of Walking so They Shall Walk.**

Recent studies have shown the majority of paralyzed people who participate in passive exercise therapy will regain mobility and learn to walk[i].[ii] [iii] The current medical system only pays for one session per week or month.[iv] The LIFESUIT therapy system will allow a full therapy session to be recorded[v]. By outfitting the therapist with a telemetry suit, the patient in the LIFESUIT can be moved through the entire exercise routine. The recordings are stored in a patient profile[vi] for future use. The recorded session could be "played back" allowing the paralyzed person to exercise daily and get the exercise they need to fully recover. Collaboration between the They Shall Walk.org clinic in Seattle and other physical therapy clinics in India, Nepal, Kenya and other parts of the world will facilitate faster development of exercise and therapy recordings that can then be shared. The LIFESUIT Exoskeleton prototype allows actual recovery from paralysis using the existing funded therapy and exercise sessions.

Keywords—LIFESUIT; passive therapy; exoskeleton; reciprocating gate orthosis; robothon; robogames; hardiman; arduino *(key words)*

I. Introduction (*Heading 1*)

The worlds elderly population is increasing because people are living longer in developed and developing countries. Because of this improvement in the length of life, a new need is to be sure to continue to improve the quality of life of the increasing population of elderly and disabled persons.

Recent studies have shown the majority of paralyzed people who participate in passive exercise therapy (PET) will regain mobility and learn to walk. The biggest hindrance to patients receiving passive exercise therapy is the cost. Most medical insurance will only pay for a single therapist to work with each patient and PET requires three physical therapists for it to work effectively. By using a robotic platform like the LIFESUIT therapy system only one physical therapist will be needed to supervise the care. The robotic platform will do the majority of the physical therapy. By making PET affordable, more paralyzed people will learn to walk and many will have a full recovery. This recovery will allow most of the paralyzed persons to return to full time work. This returning to work will improve the quality of life of the subjects as well as decrease cost of care. Instead of needing care takers, patients will recover and be able to care for themselves. Some will even be able to care for others.

The author experienced a spinal cord injury in 1986 and was told to accept his new fate of permanent quadriplegia. Unsatisfied with the prognosis he set out on a multi-decades long quest to give the gift of walking to the world and solve his own mobility issues along the way. Although the lifelong journey began as an entirely selfish expedition into a cure for his own aliments, the author quickly realized his mission was far greater than he could have ever imagined. Over 6 million people in the United States alone live with some form or paralysis. The world over it could be 2% of the population or 140 million people.

The author started his search for a cure by looking into better physical therapy methods as well as asking the question "What really causes nerves to heal?" After a spiritual experience with several visions and dreams about exoskeletons in 1986 the author accepted the challenge and began his research while he was an inpatient at the Silas B Hayes Army Community Hospital just outside of Monterey California.

Just thirty days after his accident the author did experience a miraculous recovery and no longer needed the new technology he was committed to develop. It was this paradigm that lead to the epiphany that this was bigger than one man's dream.

After nine and a half years of therapy the author now cycles over ten thousand miles a year and takes his health very seriously.

Twenty four prototypes developed over the last two and a half decades have led to a solid plan to begin deployment of the LIFESUIT robotic therapy system to over one thousand sites worldwide. The first of these LIFESUIT therapy gyms will be located in Seattle Washington with scheduled opening in the Fall of 2015.

The author made a point to publish ninety percent of his findings using the popular press and the internet as well as open sharing findings and results at Robotic conferences and shows. He currently holds the world record for exoskeleton high jump of eight inches and the "Land speed distance record for walking in powered exoskeletons" of five kilometers in ninety minutes. He has demonstrated the LIFESUIT Robotic Exoskeleton at the University of Washington Engineering Days event annually since 2006. He has also made a point to regularly share his work at the Robogames, Seattle Maker Faire and Robothon. The author has always been willing to share and collaborate in order to spread the technology.

The results of this type of community based research has resulted in a sort of singularity effect on the number of exoskeletons being developed and the number of teams getting involved. 2000 years ago there is evidence that the Egyptians had passive bracing, orthosis or exoskeletons that supported human ambulation. In the late 19th century there was one or two exoskeletons for human augmentation depending on what references you find. From 1950-1969 there was one reference in science fiction, Robert Heinlein's "Starship Troopers" and one real powered exoskeleton, "Hardiman" developed by GE. From 1970-1989 there were two more therapy exoskeletons, the LSURGO (Lousiana State University Reciprocating Gait Orthosis) and the "LIFESUIT". From 1990-2009 there were over a dozen. Today searching for a reference to "exoskeletons" in the EBSCO database returns over 1000 results.[vii]

II. Materials and Methods

A. *Exoskeletons developed by They Shall Walk)*

Exoskeletons were developed by building one iteration after another and testing the effectiveness by the author as a test pilot until the prototypes were safe to use. The author was the key test subject and had already walked using exoskeletons for over thirty miles and over 70 hours of exoskeleton use before enrolling in a university where human subjects board approval may have been required. Since he had already been using the exoskeletons safely prior to being aware of the need for human subject approval he has been grandfathered in for approval by the academic community. More than a half dozen Universities, hospitals, colleges and medical schools have invited the author to present and demonstrate the use of the exoskeletons repeatedly on their campuses without requiring any human subjects committee approval.

Initially there were some minor, injuries from the experimental protocols performed by the author and his team. However the author is the only human that was ever in danger. The initial risk and research was worth the trials. The result was quickly learning how to improve the LIFESUIT exoskeletons to no longer cause injury, then become less uncomfortable and finally become ergonomic, comfortable and easy to use.

III. Results

LIFESUIT exoskeleton number LS1 was the first exoskeleton to be connected to a microcontroller. We used a Basic Stamp from Paralax and the first program used to make it walk was actually a modified version of the "Hello World" program with an "LED marquee" feature that lit an eight segment display. Changing the code to power motors or actuators instead of lighting LED's was a very simple change. In the original fifteen programs that were written to control the LIFESUIT exoskeleton number LS1 through LS14 still have the LED lighting code in place, they are just commented out. On several of the programs they are used to light up a control panel so the pilot and experimenters could see when a motor or actuator was supposed to be moving.

LIFESUIT exoskeleton number LS3 was tested in the "2003 Saint Patrick's Day Dash" public foot race. There were two different knee designs being tested in that five kilometer event. One of the knees nearly completely failed in the first mile. The pit crew was able to assist the author in making repairs so the five kilometers could be completed. The successful knee was adopted for future development.

LIFESUIT exoskeletons number LS4, LS5, LS6…LS11 transitioned through testing and development using electric servos, electric actuators, hydraulic and pneumatic actuators. The result was the discovery that pneumatics, though difficult to control, were far more efficient than other power trains. The LIFESUIT exoskeletons modular design would allow interchangeable power trains as we continued to develop the system. This lead to the confirmation that a modular design would allow for faster development of individual subsystems by independent teams. This allows for the integration and separation of all moduals of the LIFESUIT exoskeleton system throughout it's development.

Because of the modular systems called "Pak's" by the author teams of engineers and students could easily work on subsystems whether they were local to the Seattle based They Shall Walk labs or not. This led to additional collaboration with people located in other states and nations. Now a team of high school students in California who want to work on an exoskeleton arm for a senior project could be mentored by the author while they contribute the overall development of the system. Private companies in India or doctors in Kenya could work on subsystems of the LIFESUIT exoskeleton.

This modular system allowed us to continue to experiment and develop the LIFESUIT exoskeletons while adding a new microcontroller from Cypress semiconductor, the PSoC. The power of the PSoC was so impressive we have changed over to it nearly completely. We have also experimented with the Arduino and other microcontrollers. With the modularity of the electronics and software it is easy to integrate different computer systems, electronics, software and hardware.

NASA, Microsoft, Boeing, Underwater Sports, Seattle Door House, Rotary, North Shore Retreat, Food Life 4 U, (*sponsors*).

LIFESUIT exoskeleton number LS12 actually caused harm and injured the author during the experimental trial walking five kilometers wearing the powered exoskeleton. This trial took place with over ten thousand witnesses during a public footrace called the "2005 Saint Patrick's Day Dash" A minor laceration on the left outer thigh where one of the struts came loose and punctured the clothing of the author near the end of the fifth kilometer of the demonstration test resulted in minor bleeding and was easily repaired with stitches by the author. The author was an EMT (emergency medical technician) while serving in the military so he usually will handle most of his medical procedures such as stitches, bandaging and splinting.

The LS12 secured and still holds today the land speed distance record for walking in robotic exoskeletons, five kilometers in 90 minutes.

LIFESUIT exoskeleton number LS13 was built to walk faster but it resulted in a problem with the air lines freezing due to the increase air flow rate. The net effect was that the demonstration at the 2006 event was unable to be completed. This prototype had more power but it could only walk for approximately 25 steps before the system would freeze. Ice actually formed on the outside of the air manifold and lines as well as inside. The result was the design of air manifold heaters and the use of clean dry air instead of moist air from SCUBA tanks. After some experimentation it was determined that the efficacy of pneumatic systems operating above 100psi really do not have much use because there is a diminishing rate of return on the increase of psi. see chart.

Chart here shows effectiveness between 30psi and 100psi

It also shows the lack of power output increase from 100-200psi.

LIFESUIT exoskeleton number LS13 did however have so much more power that when firing both the left and right legs at the same time the exoskeleton, the pilot and a payload of up to 100 pounds could be launched up to eight inches into the air above ground. Without the 100 pound payload the exoskeleton could jump up to twelve inches. We set the world record for exoskeleton high jump at eight inches. We still hold the record today. Eventually we would like to see an exoskeleton that could jump three to twelve feet in the air.

LIFESUIT exoskeleton LS14A was used to demonstrate the ability to continue to function if the computer system or the electrics failed. The control system was redesigned using logic gate valves in the pneumatics that would allow the exoskeleton to be operated even if the computer failed and there were no electrics for sensors. This back up failsafe system is so effective that the pilot is able to completely operate the LIFESUIT exoskeleton without the use of a computer or any electrics. It is a bit like riding a bicycle in that the pilot feels like they are dancing with the robot.

LIFESUIT exoskeletons LS13 and LS14 were entered into the Robogames (Robot Olympics) competitions to compete for weight lifting and walking were they were awarded the Gold and Silver medals for both events since they were the only exoskeletons that competed in the event. It was a bit surprising that there were no other exoskeletons present at the Robogames since, at the time DARPA had already awarded multi millions of dollars to develop exoskeletons that were a lot closer than the They Shall Walk lab in Seattle. In fact one lab that received $5 million was just across the water and they did not even show up.

LIFESUIT exoskeleton LS14B was developed to test out a landing gear system that would eliminate the need for a launching chair. The landing gear would allow a test pilot wearing the LIFESUIT to transform it from the walking exoskeleton to a rolling wheelchair. The LS14B was a real life Transformer robot that could be worn or piloted.

LIFESUIT exoskeleton LS15A was the first of the exoskeletons that was able to stand unmanned. We demonstrated it at several venues and now you can see many exoskeletons around the globe that have adopted features of it. We are excited to have been able to inspire others to develop exoskeletons. We are committed to delivering exoskeletons to the millions of people who deserve a chance to walk.

LIFESUIT exoskeleton LS15A was the first of the rescue suit exoskeletons that could be used by first responders to dig survivors out of ruble after a disaster. The LIFESUIT exoskeleton LS15A allows the pilot to lift up to one thousand pounds, concrete slabs, I-beams and more.

LIFESUIT exoskeleton LS16 is the therapy model being developed for deployment into the medical community. CAD models have been developed to perfect the design. We are now raising funds to manufacture the first run of these prototypes. A company that build wing sections for Boeing aircraft will build the chassis, a Seattle based electronics firm will build the electronic control assemblies and a local software firm will clean up and finalize our software prototypes. The final assembly will be done in Seattle and testing will begin right away with our local test pilots.

The Test Pilot program allows for paralyzed persons who want to walk again to take proactive part in raising the money needed to build a LIFESUIT exoskeleton that will allow them to stand, walk and exercise. They will work with our staff to raise the money for the LIFESUIT we will custom build the suit for their needs and local physical therapists, nurses, doctors and students will work together to implement a therapy plan based on a similar lifestyle exercise therapy routine used at the Seattle Veterans Hospital Spinal Cord Injury Unit and the University of Washington[viii]

IV. Discussion

Further development of the LIFESUIT robotic exoskeleton is needed to advance the therapy model to where it can be used in over one thousand sites worldwide. They Shall Walk's ten thousand square foot research facility will continue to work using community based research where students and professionals work together to solve real world problems. It will expand to include another building where the LIFESUIT therapy clinic will open within a block of the existing facility.

A physicist in the United States, James Shakarji, has developed a simple and amazing brain computer interface that could be used to control the exoskeleton. There is a demonstration scheduled for the soccer world cup kick off to be performed by a brain computer interface controlled exoskeleton being piloted by a paralyzed person in June of 2014. We are all very excited to see how that goes.

Only $150,000 is needed to advance the research to a point where the prototypes are ready to be deployed. $2 million will allow the new LIFESUIT therapy clinic. $42 million will allow the infrastructure to get the LIFESUIT deployed to over one hundred sites worldwide and set the foundation so that we can install the system at over one thousand sites.

As the publication and collaboration of exoskeleton research continues the technology will continue to improve and the cost will continue to decrease.

In addition to the therapy prototype that is ready for deployment They Shall Walk has been developing a Rescue Suit for use in disaster relief efforts. We expect to see some amazing results from the testing we will begin with the local fire department in the Seattle area this next year. Results will be presented online and at upcoming conferences.

The next phase of prototype development we expect to present on in the next few years is a “At home and at work” model of the LIFESUIT. This model will completely replace wheelchair because they will convert from a rolling chair to a walking suit with the simple push of a button and will be able to recharge at home and at work.

The singularity of exoskeleton development is here. We will be hosting a new competition at the high school level that challenges the FIRST robotics challenge teams to develop exoskeletons and demonstrate them during the off season from FIRST competitions. The exoskeleton challenge will go on during the summer encouraging those students who want to keep their robotics skills up.

A. *Abbreviations and Acronyms*

PT=physical therapy, PET=passive exercise therapy, psi=pounds per square inch, LS=lifesuit (robotic exoskeleton), DARPA=Defense Advanced Research Projects Agency

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