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# Result-Oriented Engineering Capstone Designs to Aid Persons with Disabilities

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Abstract
We report on a multi-year project to use engineering capstone designs to aid elderly and persons with disabilities; and to enhance undergraduate engineering education through multidisciplinary collaboration and hands-on experience. In their capstone project, students utilize and adapt available technologies to create devices to assist persons with disabilities from the users' perspective. To this end, at the first course of the Engineering Design sequence, students are first referred to healthcare facilities and local schools that host students with learning disabilities in order to gather information regarding to real needs, available solutions, and what the latest technologies can offer. Once such preliminary information is gathered, a number of brain storming sessions are conducted to help students select and refine the most promising ideas. Teams are formed thereafter and resources are allocated to support the required hardware and software for the projects. A sample of students' design projects that resulted from this project are presented in the paper.

## I. INTRODUCTION

### A. Background

Partly due to its mild climate and partly due to its senior-friendly policies, South Florida has been an ideal retirement destiny for many Americans who want to spend their golden years near the beach in the sun. The average age of the population of South Florida is one of the highest in the world. With ever increasing population, South Florida has also a large number of persons with disabilities, including students with learning disabilities.

Technology can play a vital role in helping seniors and persons with disabilities to improve their quality of life at their place of residence. In most cases, seniors prefer to live in their homes, mainly for social and economic reasons. The benefits of adopting cutting-edge technology for healthcare has the potential of shortening the length of hospitalization, reducing the number of doctor office visits, lessening the burden of caretakers, and ultimately, improving the quality of life of the elderly and disabled. Involving engineering students in the development of technologies to assist persons with disabilities will boost the students' entrepreneurial spirit [1].

Thus, how to improve the wellbeing of the elderly and disabled population becomes one of the challenging issues that face all of us, including families, healthcare facilities and universities [2]. Being a public university located at South Florida gives us a unique opportunity to address this issue with first-hand observations and experience. During the past years, caretakers from hospitals and nursing homes as well as entrepreneurs and inventors have approached FAU for collaboration to improve the life of persons with disabilities. For example, according to our surveys, individuals with physical disabilities who are confined to a wheelchair may experience lower self-esteem and self-acceptance, and greater social isolation than those without disabilities [3-8]. To address this problem, a group of senior students from mechanical, computer and electrical engineering disciplines developed a wheelchair which has the following features: a) the seat on the wheelchair can be raised, allowing the user to bring himself to the same eye level of a standing person; b) the seat rotates about its axis allowing the user to address persons on his side without the need to move the whole chair; and c) the seat is mounted at the end of an arm which can be rotated, maintaining balance by outriggers, and bringing the seat above a bed level which facilitates transfer without help.

FAU has offered multidisciplinary engineering design courses for many years, and a significant number of projects from these courses have been healthcare related. In addition to the wheelchair project mentioned above, students developed a motor-controlled patient bed to be able to more conveniently move bed-ridden patients from one place to another. Students also developed web-controlled pill dispensers, based on microcontroller techniques, to help patients who suffer from mild Alzheimer's disease remember taking their medications. An auto-feeder was constructed by a group of students to assist disabled individuals in reaching out and taking food and drink. A device was invented by students to help kids who suffer "in toeing", in which a wireless sensing circuit was implemented to measure the foot walking direction and provide a warning signal whenever a misstep happens.

In light of all these activities, this paper reports on our efforts of developing devices and software for persons with disabilities. A number of students' design projects resulted from this practice are also presented in the paper.

## II. ENGINEERING DESIGN COURSES

Undergraduate programs in the College of Engineering and Computer Science prepare students to enter and continue the practice of engineering. Central to this task are the preparation of students to function effectively in multidisciplinary teams and the development of proficiency in design of engineering systems, components, and processes. Teamwork and design are prominent in the educational objectives and core student learning outcomes of the college.

Historically, FAU engineering curricula have featured a distributed approach to design instruction. Emphasis on teamwork and engineering design starts in the freshman year, typically with the *Fundamentals of Engineering* course, and continues throughout the curricula. It culminates in a comprehensive two semester capstone design experience in the senior year.

Engineering Design is a sequence of two design project courses that must be taken in two consecutive semesters. During the course of Engineering Design I and II, students work on various joint engineering multidisciplinary projects. The goal of these projects is to foster creative thinking, diversified background exposure, teamwork, communication, and collaboration skills. Therefore, students are normally required to form teams of three to four members from various disciplines to foster inter-disciplinary interaction. Students are encouraged to form their own teams, or consult with the coordinators to join other forming teams. Students may mutually develop their own project, adopt one from a list suggested by Engineering faculty, or participate in projects sponsored by local industry. Once teams are formed, students are mandated to continue the teamwork to complete the project over a two-semester sequence.

## III. DESIGN PROJECTS OVERVIEW

Some student design projects are aimed at adapting available technology to create tools to assist elderly and persons with disabilities from the perspective of the people with disabilities and their support persons [9]. To this end, it is important to consult with the users before entering the design stage in order to gain a full understanding of the needs, and to determine what the technology can offer.

Disabilities can be divided into the following categories: vision, hearing and speech disabilities; mobility disabilities; and other cognitive disabilities such as mental and learning disability [9-12]. Our projects will aim at helping both people with cognitive and mobility disabilities.

At the first course of the Engineering Design sequence, students are referred to local healthcare facilities such as MorseLife and Center for Aging Seniors [13] and local schools to interact with healthcare professionals and users in order to gather information regarding to current needs, available solutions, and what the latest technology can offer. Once information is gathered, a number of brainstorming sessions are conducted to help the students select the most promising ideas. Thereafter, teams are formed and resources are allocated to support the required hardware for the projects. During the entire design process, the following 8 questions are asked in order to improve the quality of student projects and the students' learning experience [14-16]:

1. Is the design the result of consultation with the healthcare practitioners and persons with disabilities?
2. Is the design suited to the users' diverse social and physical environments?
3. Does the design reflect the technology innovations in the field?
4. Is the analytical component of the design sound?
5. Is the design inexpensive to produce, purchase and maintain?
6. Is the design easy to use?
7. Is the design effective?
8. Will the eventual product be affordable?

Sample projects are given in the next section.

## IV. Detailed Description of Sample Projects

### A. Mobility Assist Device for Traversing Steps

The device allows for the transport of a person in a wheelchair up and down steps or steep inclines. The device is intended as an aide to an assistant who would provide for stability and a human awareness of possible tipping danger, which maximizes overall occupant's safety. The device would provide the 'muscle' to traverse the obstacle, allowing the assistant to focus on the comfort and safety of the rider. Once the obstacle is overcome, the device then reconfigures, becoming a normal manually operated wheelchair. This solution is advantageous when attending a private function or ceremony.

The overall device was built to be half scale in size. This made the overall project more affordable and allowed for safer testing and evaluation. The wheelchair traction apparatus (Fig 1) is mounted in an aluminum frame to keep the overall weight as low as possible. The frame also employs an anti back-tip device that does not allow the wheelchair to exceed a tilt back of 23º. The drive tracks are primarily a low durometer rubber, similar to tennis shoes. This allows the friction obtained to be sufficient to travel up or down most surfaces. The tracks are reinforced with Kevlar for strength. Attached to the frame are all the drive axles, motors, batteries and a deployment mechanism with electronics bay.

The deployment mechanism is of a scissor-screw jack hybrid design similar to that found in a car seat. The motive force is derived from separate electric motors that allow the deployment mechanism to take the weight of the wheelchair as well as shift of the center of gravity relative to the traction frame. This ability to change the center of gravity increases the overall stability and safety of the device.

Once the system is deployed it is driven by a pair of motors via a drive chain and sprocket. The entire operation is controlled via a wireless controller which can either be used by the assistant, or the person in the wheelchair, which allows this person to participate and not provide a sense of control. The wireless controller is operated using a single command button, like that of a wrist watch. The commands are displayed on a large screen and provide information on the wheelchair performance such as relative tilt angle, battery capacity, deployment mode and throttle position.  The wireless controller also provides alarm indication in the event of dangerous tilt angles or traction device overload. The prototype device has been successfully tested with a 40 lb payload going up 11º steps with a maximum device angle of 22º.

Fig. 1: The mobility assist device

**B. Advanced Hospital Bed**

The advanced hospital bed is designed to facilitate the transport of mobility impaired patients. This , in turn, reduces the strain on both the patient and the caregiver. The advanced hospital bed is different from any other hospital bed by its capability to bring the patient to a standing position. Thus, there is no need for a nurse to carry and raise the patient to this position. Moreover, patients that use walkers, can approach them with no help.

The advanced hospital bed operates through the combination of hydraulics and electric actuators. The bed is positioned vertically through the use of two hydraulic cylinders operated via foot controls located at the base of the bed. The upper portion of the bed is allowed to rotate 90 degrees in either direction through the use of a bearing assembly. The upper surface of the bed has three different user controlled movements: The tilting of the head and thigh sections, as well as the tilting of the entire bed surface relative to the ground (See figures which numbers?). The target market of this bed would be for hospitals or rehab centers where the patient has a condition where the act of sitting up is painful or not feasible. This would allow the patient to get in and out of the hospital bed without the need to bend over. Since there is no current design that allows this ability, it seems as though the marketing potential for this product is strong.

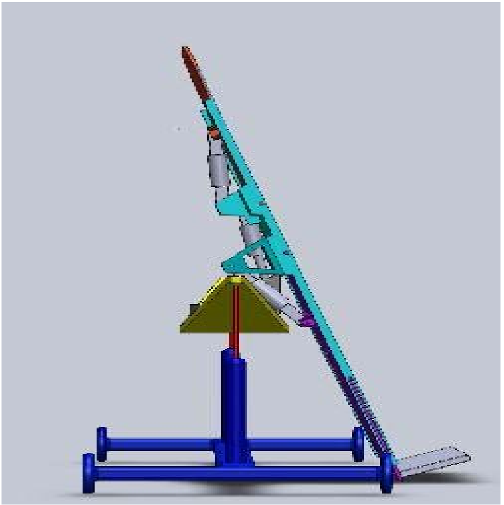

Fig. 2: Horizontal rendering of the device

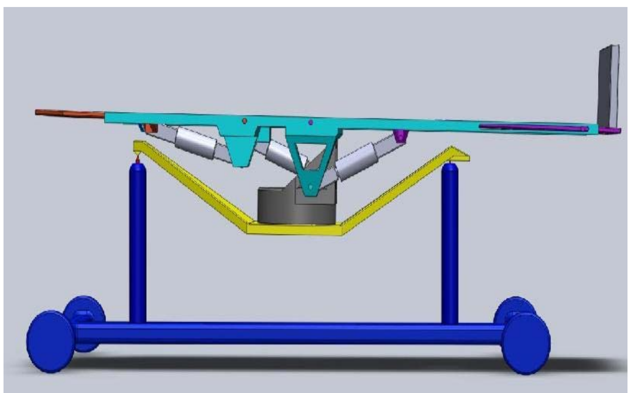

Fig. 3: Another rendering position of the device

### C. Stair-climbing Walker

Elderly persons are more susceptible to injuring themselves than anybody else,. Due to their gradual losses in bone density, muscle tissues, vision , and hearing capability, the elderly persons are challenged in carrying out their daily life routines. To overcome or to facilitate the challenges, they need supportive aids . Conventional walkers assist elderly persons in walking on a flat surface. However, these walkers are inadequate in ascending or descending a flight of stairs due to the stair's geometry. Therefore, a safer walker that can be utilized in ascending or descending a flight of stairs has been designed for elderly persons.

Not only that a stair-climbing walker enables elderly persons in ascending or descending a flight of stairs, but it can also be utilized in walking on a flat surface. The walker has a brake mechanism that assists in preventing elderly persons from falling while operating the mechanism. It is designed to be optimally used on any staircase.

The stair-climbing walker (Fig. 4) is mainly composed of two 4-wheel assemblies, one brake mechanism, and one main frame. To construct a 4-wheel assembly, the team needed four aluminum bars in dimensions of 20”x1.00”x0.25”, four lightweight wheels in diameter of 3 in, one guiding block in dimensions of 5.56”x5.56”x0.5”, eight slotted sliders in dimensions 1.00”x5.00”x0.188”, two spacer in a diameter of 0.56” and height of 0.75” and another two space in a diameter of 0.56”and height of 1.00”. To get started constructing the walker, most of the required components were fabricated from raw materials and obtained by dissembling a commercially available product that has the required components.

The main frame is made of a 1/2”diameter stainless steel pipe. It is bent resembled to a reverse U. The main frame is reinforced by welding diagonally crossing structural rods. Each end of the main frame is bent in such a way that it can slide freely in a groove of a guiding block. Moving the main frame ends along the grooves rotates the 4-wheel assembly. For the brake mechanism, a gear and pawl are installed in between the two 4-wheel assemblies. The gear and pawl are held by crossing-rods. Brake handle is installed near top end of the main frame. Brake cable connects the brake handle and the pawl. Thus, when the brake handle is grabbed, pawl pivots around its rotating axis to lock in the braking gear.

Whenever the stair climbing walker is utilized on a flat surface, the user would just have to push and grab onto the structural handle using it as a conventional walker. When the stair-climbing walker is utilized for ascending or descending a flight of stair, the first two front wheels of the stair climbing walker has to be in contact with the rise of the stair. Once it is in contact with rise of the stair, the main frame can be maneuvered along the guiding groove to rotate the wheel assemblies forward. Each time the main frame is utilized to rotate the wheel assemblies; the slider and brake wedge prevent the stair walker from pushed backwards and reducing the risk for any elderly person from falling down the flight of stairs.

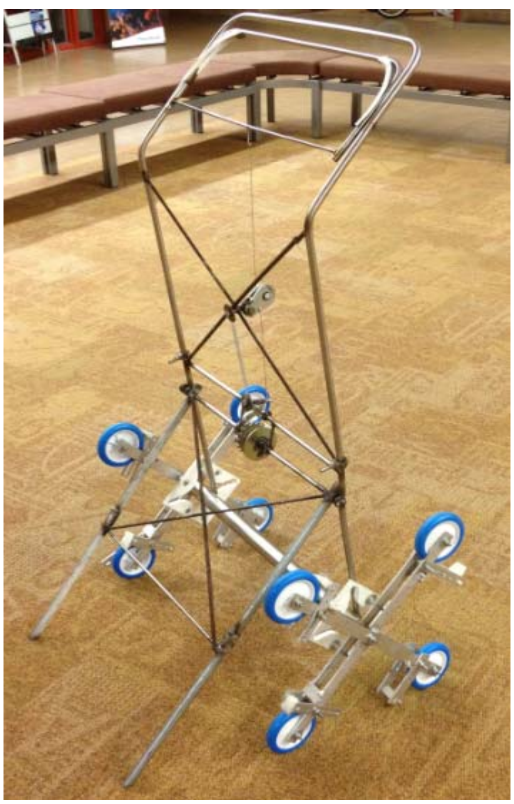

**Fig. 4:** Stair-climbing walker

**D. Teleoperated Robotic Arm with a Kinect Camera**

The design project provides an interface that is capable of wireless control of a robotic arm using 3D-positional data output from the Microsoft Kinect [is that a commercial name?], as well as using supplementary data from a "Sense" glove that houses various sensors. The Sense glove enhances fine-point control of the end effector of the robotic arm, which in this case, is a claw. While the project programming is based on a specific robotic arm, the real value of the programming is in its portability. The longer term goal is that, with a few modifications, the new control interface can be applied to any sort of robotic arm design.

Fig. 5: Teleoperated robotic arm

The design provides intuitive control for robotic platforms; this can be quite beneficial for individuals who have poor motor functions, due to advancing age. The ability to allow a robotic device to perform functions that the individual cannot perform while retaining the same motions is quite useful. It allows ease of use for complex machines that usually require complex control methods that take time to learn.

After establishing a basic description of the design, the team addresses the finer details. The components that are incorporated into the “Sense” glove include: flex sensors (resistance changes based on bend), an accelerometer, an Xbee wireless module, and Arduino Nano microcontroller and a vibrational motor. These sensors provide the data on the user’s hand and wrist motions, this data is then sent via the Xbee RF module to the computer. The vibrational motor is used to give the user tactile feedback; when the robotic arm grips an object a small vibration is felt that is proportional to the gripping force.

The other sensor used to read the user’s motions is the Microsoft Kinect$^{TM}$. The Kinect is a sensor array that includes a color camera, infrared projector, and an infrared camera. The infrared components are used to calculate depth; this combined with the color camera allows the Kinect to track a user in 3D space. This data is used to map the location of the user’s arm and control the robotic arm to follow its movements.

All of the sensory data is processed through a programmed Windows application. The program allows the user to see the view from the Kinect camera, adjust the camera position, see the data points being read, as well as the angle data being output to the arm. The program calibrates a starting position of the user's hand as a reference and controls the robotic arm to follow the user's hand from this origin.

## E. Wheelchair Lift for Paraplegic Drivers

The purpose of this project is to provide paraplegic people with full independence when entering or exiting a vehicle, with the possibility of storing the wheelchair on the vehicle. The vehicle chosen for this project is a van. For this purpose two mechanisms were designed, the first one is responsible of lifting the paraplegic person from his wheelchair to the driver's seat. This mechanism is attached to the roll bars inside the van. The second mechanism, called the wheelchair holder, is responsible of storing the wheelchair on top of the van's roof. This mechanism is attached to the roof rails of the van. These two mechanisms allow the paraplegic drivers to easily access the vehicle's driver seat, no matter how high the vehicle is.

The wheelchair lift for paraplegic driver mechanisms enables the users to use their vehicles freely without the need for anybody else to help. This impacts directly users' independence and takes paraplegic people many steps closer to having a normal life.

The wheelchair holder mechanism shown in Fig. 6 was made of a box, big enough to hold the wheelchair, which rotates around a rod that is attached to two bearings, in addition to an actuator and a winch. Initially the box is at the horizontal position. The actuator is used to move the box from this position to a vertical position and back, this actuator provides 400 lbs. of force with a maximum extension of 24". The winch is responsible of lifting the wheelchair to the inside of the box for storage, and lowering it back to the ground. It provides a pull force of 2000 lbs.

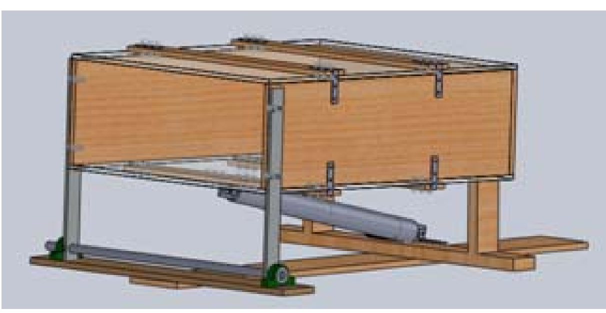

Fig. 6: Wheelchair holder mechanism

For the rail mechanism shown in Fig. 7, the principal components making this mechanism are a rail, a sliding bar, a support, an actuator and a winch. The support simulates the roll bars of an actual van, to which the rail is to be attached. The sliding bar is connected to the rail using two rollers. The actuator is responsible for moving the sliding bar in and out of the van's cabinet. The winch allows moving the paraplegic person vertically, while the actuator moves the user horizontally. The winch used for this mechanism is similar to the one on the wheelchair holder mechanism, however this actuator provides 250 lbs. and has a maximum extension of 30". The winches were bought with the controls included. For the actuators, a 4 channels control device was used to allow the control of both actuators using only one remote. All the electrical components on this project require a 12V input, which can be provided by the van's battery.

Fig. 7: Rail-lift mechanism

## V. Student Project Evaluation

The procedure for evaluation of student design projects has been under a number of revisions to in order to improve students' grasp in techniques and skills for engineering design. A key component is that frequent feedbacks from the instructor, the classmates and the end-users should be obtained in a regular basis.

Feedbacks from the class instructor are obtained mainly through weekly project review sessions, in which members of each individual group talks directly with the instructor. In these sessions, the project progress of each project is evaluated against the schedule proposed by the group. Attention is given to the weakest link of the project chain; for instance, parts are not available, difficulties in establishing connections between communication devices, or a driver does not have enough power to drive the motor. To avoid a prolonged delay, students are encouraged to devise alternative solutions for some critical problems. For instance, the wheelchair mobility assist device shown earlier involved a remote controller that was capable of control the wheelchair in a number of ways. The controller was mainly implemented by a computer engineering student. Without his controller ready, one might not be able to test many functions of the wheelchair mobility assist device. The group made a manual control box, which simulated the entire functions of the remote controller and tested the device completely before the remote controller was finally ready. This practice ensured that the entire project could complete on schedule.

Feedbacks from classmates are solicited through weekly discussions and a number of 5-week project status reports. The practice is partly based on the concept of active and cooperative learning techniques. It has been shown that active and cooperative learning techniques are a more engaging and effective way to learn than the prevalent lecture format [16-20]. Weekly-discussions involving all the students in the class facilitate this paradigm. The class usually starts with an overview by the instructor on the status of the entire class and what are expected in the coming week. Thereafter, members of each group take the podium, overviewing the progress of their project, with emphasis on issues that bother them the most. Often students from other groups are able to give valuable comments and suggestions; for instance, whether the group should choose Bluetooth or Zigbee communication protocol for their autonomous vehicle, or how to overcome the signal fading problem in a fall-detection device. Students are generally much more active in these sessions, in comparison to lecture sessions.

Feedbacks from end-users are obtained through three stages, pre-proposal visits, middle project communications and end-project presentations. Among these three interactions, students have done a good job in the first stage visits. One reason for that a specific assignment was given to those students who chose to do a project to help elder persons or people with disabilities. In the assignment, students are required to contact these end-users or their care-takers. To facilitate the process, a set of instructions are given to the students. Students are required to submit reports on the activities for grading. Because a grade is given for the assignment, students tend to take the assignment seriously and results from the interactions are in general fruitful. On the other hand, although we encourage students to have periodic interactions with the end-users and show their project to them, we don't give grades for these activities; therefore some students do not actually take these earnestly. We plan to design a more rigorous mechanism in the near future to encourage students having more interactions with end-users.

At the end of the semester, each student design project is demonstrated in public, and is evaluated based on the following three categories: creativities, difficult levels, and completeness. Evaluations are done by classmates, observers and instructors. The observers may involve university staff members, end-users, and industrial representatives. Results of the evaluations will be used for two distinguished purposes: 1. Assign a grade for the project, and 2. Rank the projects for Capstone Project Awards. Only instructors' evaluations are considered for grading these projects. On the other hand, evaluation results from everyone are used for choosing award winning projects. Since all the students are involved in the process, and since they know that their final products may benefit people with disabilities, and since there is a competition, students in the design class tend to be more enthusiastic about their endeavor.

## VI. CONCLUDING REMARKS

In this paper we reported on our multi-year multidisciplinary engineering capstone designs to aid elderly and persons with disabilities. A number of students' design projects resulted from this project were presented. Measures taken for prompt and effective student project evaluation were discussed. In the next phase of the research, direct measures of student learning are to be formulated. Survey forms are being carefully designed so that statistical data can be extracted from the surveys obtained from various classes. Pre-course questionnaires focus on the goals and expectations of the students, and their background. End of course surveys give the students an opportunity to express their views of the course materials and of the instructional activities that is based on the Active and Cooperative Learning methodology. So far not enough data has been gathered for a statistically significant report. The results from such assessment and surveys will be reported in the future. Furthermore, we will closely monitor the progress of the students over at least a five-year period to see if the proposed activities improve the technical skills and community spirit of students.

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