Accessible Hospital Bed-

Back Angle Controller

RERC National Design Competition project

Phase I - Final Report

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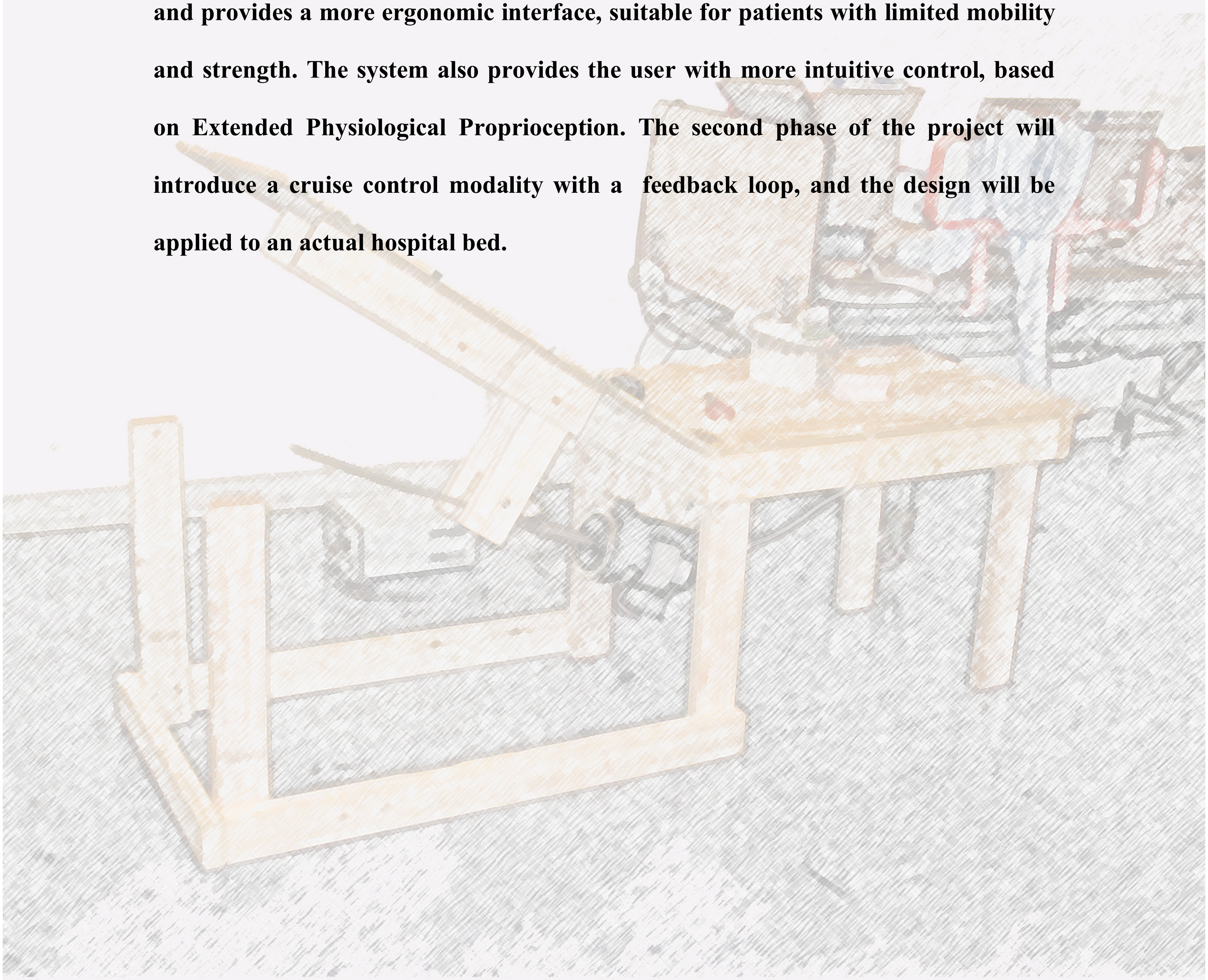
Abstract

A preliminary prototype for a hospital bed-back angle controller has been built and tested. The prototype allows the user to control the speed of the bed-back, and provides a more ergonomic interface, suitable for patients with limited mobility and strength. The system also provides the user with more intuitive control, based on Extended Physiological Proprioception. The second phase of the project will introduce a cruise control modality with a feedback loop, and the design will be applied to an actual hospital bed.



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I. Background: Current beds and how they can be improved

Current designs for the operating systems of hospital beds are the same as those used in the mid 1970's [1]. These systems offer only one velocity for the bed back. The controls for hospital beds are also poorly designed and placed. The bed we are modifying for the project is a 25 year-old Hill-Rom bed (*Figure 1*). Because the mechanical mechanisms used in hospital beds have not changed significantly since in 1970's, the design modifications made to our bed will be applicable to those currently in use.

Having only one set speed makes the system inflexible, giving the patients and healthcare professionals little control over the bed. If a patient needs to sit up quickly, they will not be able to because the bed can not vary in speed. Alternatively if a patient is in pain and wants to move extremely slowly into or out of a sitting position, the bed will not be able to accommodate their needs.

Current hospital beds operate using pressure switches (*Figure 2*). A constant force must be applied to the switch the entire time the bed back is in motion. This is difficult, even for a healthy person, and is even harder for a person with a medical condition such as partial paralysis or carpal tunnel syndrome. Additionally the controls are flat, and the back and foot controls are next to each other. This makes it impossible for a blind or impaired-vision patient to determine which control they are activating until the bed starts moving. The location of the switches is also awkward on some beds, with the controls being located near the patient's head, forcing them to reach up to use them.

Figure 1: Hill-Rom hospital bed acquired for project. The head of the bed is slightly raised in this picture, and the location of the bed-back angle and foot position controllers on the hand rail have been circled in black.

Figure 2: The controls on the Hill-Rom bed are small, completely flat and hard to keep activated. They are located on the inside of the hand rail on both sides of the bed. Immediately below the bed back angle control (left), is the foot control. Having the two in close proximity makes it easy to activate the wrong control system.

II. RERC National Design Competition

The Rehabilitation Engineering Research Center (RERC) conducts projects on Accessible Medical Instrumentation (AMI) so that all persons can access healthcare instrumentation, services, and employment in healthcare industry irrespective of disability of any nature. The RERC-AMI funds 10 projects every year in collaboration with Marquette University and other partners throughout the United States [2]. Our client, Dr. John D. Enderle, is a Biomedical Engineering Professor at the University of Connecticut, one of the partner institutions of RERC-AMI.

Our project encompasses two semesters, and will be completed by the end of Spring semester. To apply for the competition, our team sent a proposal to Dr. Enderle. This proposal outlined our approach to accomplish the design requirements and an approximate timeline. A total budget of $2000 has been allotted to this project. At the end of Spring semester, our team will deliver a website containing detailed photos, a digital video clip of the working prototype, and a final report, in compliance with the rules of the competition [3].

III. Problem Statement

Existing bed back angle control systems do not allow the operator to control the velocity of motion. A more intuitive control system, which gives the user better control over the velocity, is desired. The user would be able to grasp a handle which operates according to a force-assist concept, and the velocity would vary with the amount of force applied. The bed back still needs to support the weight of a heavy patient, and be stable if power is lost.

IV. Requirements

The RERC project description does not provide specific requirements as to what form the finished product should take. A brief summary of the minimal performance specifications, and a list of patients who are likely to use the bed, are provided. The main expectation of the project is that the concept of Extended Physiologic Proprioception (EPP) should be utilized in order to enhance the intuitive quality of the control [4]. One specific requirement of EPP is controllable velocity, since a constant speed is often frustrating to users. The project description also required that the bed back has to support a load of at least 180 pounds, the user should not have to apply a force greater than 20 lb, and the bed should be fully functional with a force of 5 lb. Both caregiver and patient should be able to easily operate the bed, which must also comply with all safety regulations, specifically those requiring that the bed back should not move if power is lost.

The project description also provides a list of seven patients who should be able to use the finished product, along with their diseases and personal preferences. Our design needs to provide easier operation for people suffering from blindness, hardness of hearing, carpal tunnel syndrome, limited mobility and dexterity, tremors, paralysis in one side of the body, severe arthritis. The project needs to be completed within a budget of $2000.

V. Our priorities in this project

In order to produce a competitive and useful finished product, we have set ourselves specific priorities in this project

1) Originality: We believe that, in the context of the National Design Competition, our prototype can set itself apart through its originality. In particular, we believe our cruise control modality will offer the users a unique and highly efficient control mechanism.
2) Simplicity: In our search for originality, we must not forget that the hospital bed needs to be easily operated by the uninitiated user. It must not, therefore, require any learning, and should be self-explanatory. The control needs to be intuitive,

and will provide some feedback to the patient in order to inform them of the state of movement of the bed. The controller will be ambidextrous and be moveable to allow for maximum caregiver and patient ease of use.

VI. Design description

Our design can be subdivided into three discreet parts: the user interface, with which the user directly interacts; the variable frequency drive and AC motor, which drive the bed in response to commands given from the user interface; and the feedback loop, which ensures stability and compliance of the bed back with the commands originating at the user interface (*figure 3*). The following description of the design follows these three subdivisions.

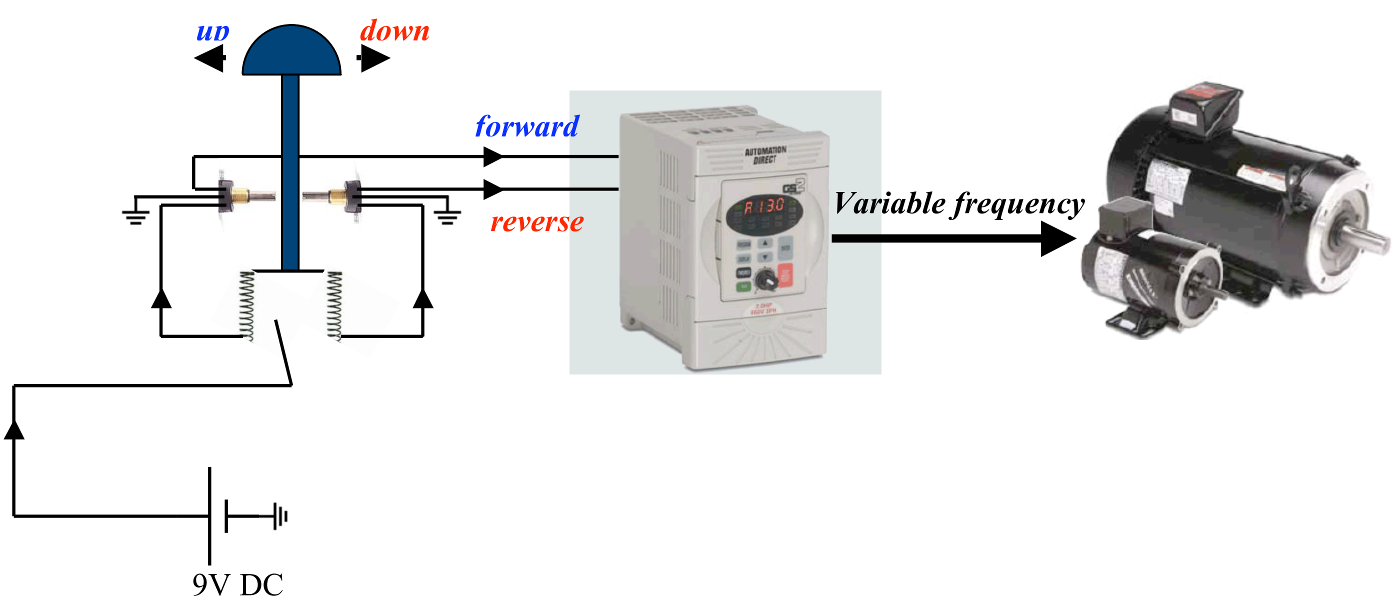

Figure 0: General diagram of the design

a. User interface

The user interface consists of two control modalities, which correspond to two options between which the user can choose. The first and simplest of those two modalities is a joystick-like controller, to which the user can apply force directly, causing the bed back to move up or down. The speed of movement is dependent on the amount of force and displacement applied to the controller. In addition, the controller is designed with ergonomic features for maximum usability by patients with impaired force and movement. The second control modality, which will be completed in the second phase of the project, is a control panel similar to the cruise control of an automobile. Further description of this feature is provided in the *Future Work* section below. We now turn to a technical description of the joystick-like controller. In particular, we describe its electronic and ergonomic aspects.

i. Controller electronics

Several requirements need to be addressed in the circuitry of the controller. The controller needs to be stable in the absence of external force. It must have the ability to move the bed back in either direction. It should also provide the user with some basic feedback. Most importantly, it must be able to provide an increasing output voltage with increasing force applied to it.

Two options were considered: a rotating controller (*figure 4*), and a sliding controller (*figure 5*). The displacement-dependent output voltage can be obtained by including a potentiometer which resistance is varied by the motion of the controller. In the case of the rotating controller, a turning potentiometer can be used, while a sliding potentiometer can be used for the sliding controller.

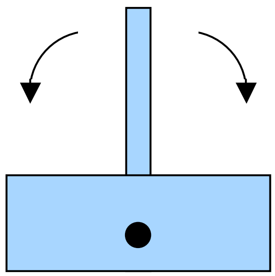

Figure 0: Diagram of a rotating controller

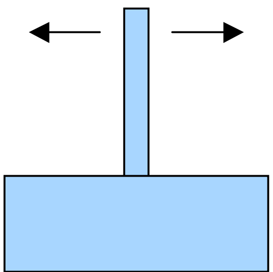

Figure 0: Diagram of a sliding controller

In order to implement reversibility of the bed back, two separate circuits are needed in the controller: an "up-circuit" which is closed when the controller is pushed forward, and a "down-circuit" which is closed when the controller is pushed backward. One circuit, at the most, can be closed at any one time. A circuit is closed by pushing down a momentary switch. Thus, when the user pushes the controller forward, a momentary switch is pushed, and this switch closes the "up-circuit". Furthermore, the more the user pushed, the higher the resistance in the potentiometer, and the more voltage is output. The "down-circuit" works according to the same mechanism (*figure 6*).

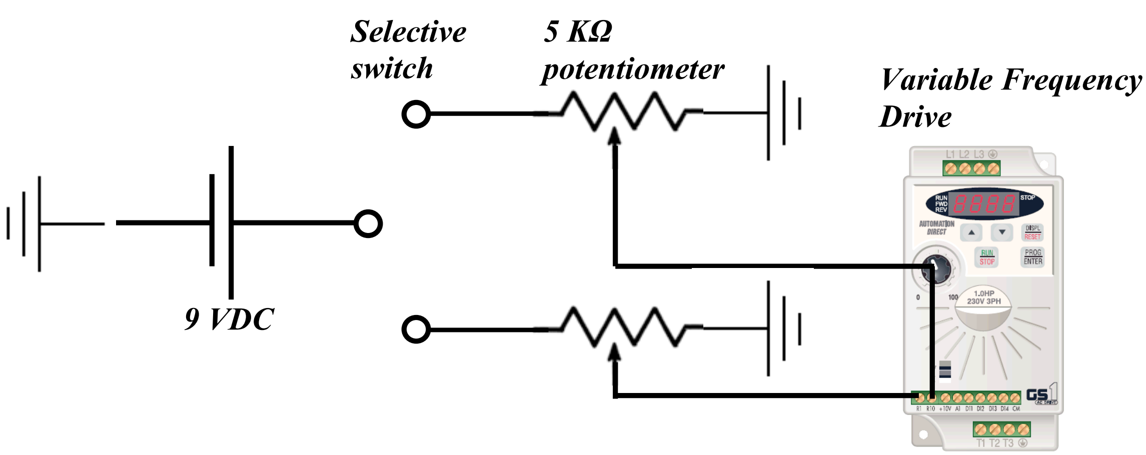

Figure 0: Circuitry of the controller. The selective switch is a simulation of the two momentary switches, each of which closes a circuit ("up-circuit" or "down-circuit")

ii. Controller ergonomics

The head of the controller was designed based on the patient requirements of the competition. The ergonomic head is 4” wide, 2” deep, and 2” high (*figure 7*), and has an ellipsoidal shape, similar to a bar of soap. It is made of wood, and is covered with a rubber coating which features “forward” and “backward” red arrows in relief. These dimensions and shape were chosen so that it would be easy for most patients to grip. For those patients who have trouble performing the grasping motion, such as patients with carpal tunnel syndrome, the sides of the controller are perpendicular to the base so they have a place to push the controller with the side of their hand. The rubber coating makes it easy to move the controller without having to apply a large grip force. It also provides the blind and impaired-vision users with a tactile contrast with the raised smooth arrows that indicate the direction of motion. Since the red arrows have a strong color contrast with the rubber coating, they will also be highly visible to most other users.

Figure 0: The controller is lightweight with visual and tactile cues to indicate the direction of bed motion.

The entire control apparatus will be contained in a box that can be easily attached or detached from either hand rail so the user can have it on their side of choice.

b. VFD and AC Motor

i. Variable Frequency Drive

A variable frequency Drive (VFD) is a system which is used to control the rotational speed of an AC induction motor by altering the frequency of the power supplied to the motor.

Figure 8: GS2-10P5 model from Automation Direct

A 0.5 horsepower VFD (*figure 8*) was purchased from Automation Direct. The chosen model (GS2-10P5) is capable of receiving a single-phase input voltage of 115VAC from any wall outlet, and provide a three-phase, controllable-frequency output voltage of 230 VAV, which can be fed into the motor to control its speed [5]. The VFD can be controller using an external DC voltage between 0 and 10 V. The VFD functions according to a fixed Voltage/Frequency ratio, which means that the frequency of the output voltage is directly proportional to the input voltage [6]. This analog control voltage is provided by the controller described above. The output frequency of the VFD can be altered anywhere between 0.1 Hz to 400 Hz by varying the analog input voltage. A digital input is also needed to instruct the VFD whether to provide forward or backward motion.

In the first phase of the project, only analog voltage from the controller was available, and no digital signal was available. For this reason, the controller does not yet have the ability to instruct the VFD to reverse the rotation of the motor. The keypad on the VFD had to be used to operate the motor. However, in the completed project, a microcontroller with digital output will be added to control the forward/reverse motion of the motor. More details on this feature are provided in the *Future Work* section below.

ii. AC motor

A three-phase, 0.5 horsepower AC induction motor (*figure 9*) was purchased from Automation Direct. The chosen model (Y360) takes an input voltage of 230 VAC [7]. This model was chosen because it is able to provide rotational speeds (1.8 - 1800 RPM) similar to that of the motor on the existing bed (90 RPM). The speed of an AC motor is known to be directly proportional to the frequency of the input power, following the relationship:

Figure 9: MicroMAX Y360 motor model from Automation Direct

$$N_S = \frac{120F}{p}$$

where F is the frequency of the input power,

p the number of poles per phase winding,

N_S the number of revolutions per minute.

The input voltage is obtained from the VFD, and the frequency of this input can be varied to control the speed of the motor.

c. *Cruise Control and Feedback Loop*

A feedback loop is needed for two reasons: to provide the user with information on what the bed is doing, and to implement the cruise control modality. The feedback loop will also allow for the smooth operation of the bed back at the beginning and end of operation, during velocity changes. Thus, two feedback loops will be implemented: one that feeds into the VFD, and another one that feeds into the user interface.

A sensor will be attached to the bed back in order to detect its angle with the horizontal at all times. The cruise control modality allows the user to set what angle they would like their bad back to be at. By comparing these two values (reference angle set by the user and actual angle at that moment), the feedback loop can operate to minimize the difference between them.

Two distinct feedback options have been considered. The first is a proportional-derivative (PD) loop. To use this loop, a numerical reference angle needs to be specified by the user. An error measurement can be found by taking the difference between the actual angle and the reference angle. The time rate of change of the errors can also be found by adding a differentiator circuit. The feedback loop with then output a signal into the VFD in order to smoothly minimize that error.

$$\text{Output} = K1\ \xi + K2\ d\xi/dt$$

where ξ is the error measurement

$d\xi/dt$ is the time rate of change in the error

K1 and K2 are constants.

By manipulating the circuitry in the controller, K1 can be changed to determine how quickly error is reduced, thus controlling the speed of the bed. K2 can also be changed to determine how smoothly the bed back velocity changes, allowing for smoother starts and stops.

The second feedback mechanism considered is a fuzzy logic system. This system simplifies the mathematical requirements, as all inputs and outputs are reduced to discrete sets, such as “low”, “medium”, and “high”. Thus, the system will accomplish the same features described in the PD loop, without requiring the user to enter a numerical value for their desired angle. We believe this system is the more desirable one and we will implement this feedback loop into our prototype in the second phase of our project.

VII. Progress

Several parts of the project were completed during Phase 1. This section reports on what has been accomplished. The Future Work section below details what still needs to be done during Phase 2 of the project.

a. Simulation platform and controller

In order to test the motor and circuitry, and to ensure the designed mechanisms worked successfully, a platform was constructed. The platform contained most of the important features that will be implemented onto the existing hospital bed. The platform was build out of wood to minimize cost, while providing adequate strength and durability.

Our existing hospital bed operates by a screw mechanism. The motor on the bed turns a screw that moves the bed back closer or farther from the motor depending on the direction of rotation. Because the bed back has only one degree of freedom, which is rotation about the bed attachment to the middle of the bed, the bed back is forced to rotate up or down, thus rising or descending. The same mechanism was implemented on the simulation platform (*figure 10*).

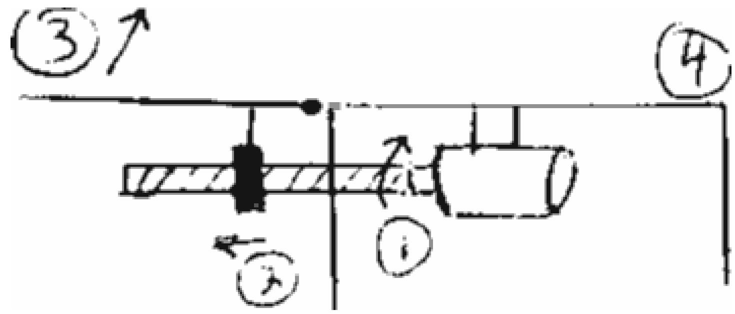

Figure 10: Schematic showing the mechanical principle behind the simulation platform.

1) The motor turns and the screw attached to the motor rotates.

2) The threaded block connected to the bed back moves away from the motor.

3) Because the block only has one degree of freedom, the threaded block forces the bed back to move upward.

4) The bed back angle is changed according to how fast the motor rotates.

The motor and VFD were loosely mounted to the bed to allow quick assembly and disassembly when we mounted the components on the actual bed. The controller is also being assembled and will include several key components. The ergonomic handle that was described earlier has been built and the controller's circuitry is under construction.

b. Cost

This project is being supported by a $2,000 grant from RERC. During phase 1 of the project, $671.42 has been spent, leaving $1,328.58 in the budget. The majority of the funds spent went into the hospital bed, motor and VFD, all of which will be reused in the second half of the project. The remaining costs went toward the simulation platform and the controller prototype, as well as the poster for the end-of-semester presentation. The items purchased for the prototypes include: lumber, wood screws, sand paper, component box, potentiometers, balsa wood, wood glue, springs, switches and a threaded drive shaft. The stiff collecting collar and setscrews were donated.

Item	*Cost*
Hospital Bed	$200.00
AC Motor	$144.00
VFD	$159.00
Platform/Controller Prototype	$114.91
Poster	$53.51
Total Spent	$671.42

VIII. Future work

a. Improve the controller

An improved circuitry for the controller is proposed for phase 2 of the project. The current controller prototype is of the rotating type, which performs very well ergonomically, but is quite hard to build, since it requires a tight connection to two rotating potentiometers. It is difficult to maintain the rotating potentiometers in place.

The improved controller would use sliding potentiometers instead, and these would be attached to the bottom of the control box. This design would require no tight connections, and would thus perform much better mechanically.

b. Cruise control and feedback loop

As described in the *Design Description* section above, a feedback loop will be implemented as a cruise control modality. This loop will be programmed on a microcontroller (Analog Devices, ADUC7026) [8]. The programming can be done in C, using the Keil µVision compiler (Keil ARM Embedded Development Tools) [9].

IX. Acknowledgements

We wish to thank the RERC for their generous grant. We also thank Dr. Tompkins, Mr. Ray Marion (WEMPEC), and Mr. Bern Jordan (TRACE) for their valuable help and advice.

X. References

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