

*“Accessible Power-Assist Hospital
Bed Back Angle Controller”*

Team:

**BED BACK &
BEYOND**

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Team Bed Back & Beyond

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Executive Summary

Bed Back & Beyond is a team organized to produce an accessible power-assist hospital bed back angle controller. Bed Back & Beyond's emphasis is designing a reliable, easy-to-use, *extended physiologic proprioception* (EPP)-based power-assist back angle controller for a prototype platform (i.e., a hospital bed).

Powered hospital beds often use open-loop controls to set the back angle and typically move at a constant slow velocity while an operator presses a momentary contact switch. The concept of *extended physiologic proprioception* (EPP) suggests that users might benefit from a more intuitive approach of manually grasping a handle on the side of the bed and using force-assist concepts to set the back angle in which motion speed increases with the amount of force applied to the handle.

The Bed, Back & Beyond system uses a unique joystick controller equipped with motors to apply direct mechanical feedback to the user. The angle of deflection determines the speed with which the bed back is raised or lowered and the amount of feedback force. This control system is designed to communicate with the bed back motor through a pulse-width modulator and also a clinometer which detects the bed back angle. Currently, the motor and clinometer are not integrated with the joystick. The control system, bed back motor, and clinometer are successful in independent tests of functionality.

Background

Adjustable beds are widely used in hospitals, medical facilities, and, increasingly, in the home. These beds provide a patient increased comfort and allow the patient to sleep with the upper portion of the body at an incline, thereby relieving stress on the lower back by minimizing joint compression. Most beds also adjust to let the patient sit upright allowing patients more mobility to perform everyday actions such as eating, exercising the upper body and working from their bed. The adjustment mechanism on these beds may either be manual or electronically controlled. Manual beds use a lever or set of cranks to raise and lower the bed back which can be difficult for patients and caregivers lacking in upper body strength, hand strength, dexterity or physical ailment. Electronically controlled beds generally have a set of buttons that when pushed adjust the bed to the desired positions at a single speed.

Design Criteria

The bed back platform must be capable of supporting the upper-body portion (45%) of a 400 lb. patient, or 180 lbs. The platform must be stable at all times even under loss of power. The platform's range of incline must be from 0° to at least 75°. The controlling mechanism must be mounted on the side of the bed within comfortable reach for patients and caregivers while not hindering movement onto and off of the bed. The controller must also function by one-dimensional input and be easy and intuitive to use. The input device must be able to withstand normal operator force up to 20 lbs and be fully operable with a minimum input force of only 5 lbs. The input device must be usable for people

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with limited dexterity. The bed back platform must adjust with a variable speed relative to the force applied to the input device. The input device must be capable of exerting force feedback on the user relative to the applied force. The platform must decelerate to the adjustment mechanism's lowest speed as it reaches the upper and lower limits of its range. The controller must be able to detect the platform's angle of inclination. The system must draw power from a standard AC power socket. The entire angle-adjustment mechanism must be suitable for use in both medical facilities and the home.

Ethical Analysis

Analysis of design solutions for this project was in accord with ethical engineering principles. The safety of the patient and healthcare provider was the primary concern when analyzing possible design solutions. We targeted our proposed design to allow the greatest accessibility for our selected patient pool regardless of socio-economic backgrounds. In turn, a greater usability can be ensured. In evaluating which design approach was the most feasible for our project, our team considered engineering ethics to be just as important to a good design solution as the mathematics, biomechanics, and electrical engineering behind the project.

Social Analysis

The analysis of design solutions was not targeted at a particular patient pool and thus a non-biased approach with equal treatment for all patients was standard. This prototype was designed to be accessible to a wide range of patients including those with conditions that which may limit dexterity such as carpal tunnel syndrome and Parkinson's disease. Bed Back & Beyond developed this design to meet the needs of the greatest amount of patients. Investigations on handedness and anthropological studies regarding the use of the human hand were considered in order to understand the role of ergonomics in the design. This prototype is may be mounted for use with either hand and is comfortable for use by patients and caregivers. [1].

Even though the design was not targeted at a particular patient pool there are several clients from the client list that would benefit from a power-assisted back angle controller. The home health nurse Jorge, who has back pain from lifting patients and carpal tunnel syndrome, would benefit from a bed that made it easier to help patients sit up in bed and a joystick that provides feedback. Lakisha is a patient with Parkinson's disease, her limited dexterity and tremors make her an ideal patient for a joystick with feedback. Sani is partially paralyzed, having a joystick that is operational with as little five pounds of force is ideal for her. Also having a bed that moves at variable speeds will help her sit up more quickly. She will be able to avoid looking "sick" to others. Dolores is a patient with arthritis. Arthritic patients who may have trouble controlling the button controls of current hospital beds would benefit from a handle to palm or grasp. Her grandson Tyler helps her in and out of the bed. Tyler will benefit from a handle that is easy to reach from the side of the bed and requires little strength to operate.

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Market Analysis

Current hospital bed back angle controllers do not incorporate EPP concepts, and therefore an accessible power-assisted back angle controller is needed for the medical device market. Today's respected hospital bed manufactures include Hill-Rom, Stryker, and Narang Medical Limited. These manufactures have beds that operate a single speed without feedback. There are a large number of individuals who would benefit from a power-assisted back angle controller. 1.5 million people in the United States currently have Parkinson's disease [2]. The muscle tremors and stiffness associated with this disease make the use of current hospital bed with momentary contact switches difficult to use. Approximately 800,000 individuals in the United States have Cerebral Palsy, which degenerates muscle coordination and causes random involuntary movements making precise motions almost impossible [3]. In addition, arthritis and other rheumatic diseases affect approximately 40 million Americans which cause swelling and stiffness in joints [4]. The diseases described above show the types of individuals that would benefit most from an EPP controller. The symptoms of their diseases make it difficult to use the current hospital bed controllers. Patients who do not have diseases affecting the control of their motor system would still benefit from the variable speed and the feedback control. Currently there are approximately 7,600 hospitals, 18,000 nursing homes, 106,000 hospice care facilities, and 1.4 million home health patients in the United States [5]. Thus we feel there is an ample market for a power-assisted hospital bed back angle controller.

Materials and Design

The goal of the controller design was to create a prototype input device that is compact, sturdy, and reliable enough to withstand day-to-day home and clinical use. The materials and components were chosen with these standards in mind. The control box itself was fashioned from medium-density fiberboard (MDF) and acrylic glass or polymethyl methacrylate (PMMA). The MDF was chosen for its workability and the acrylic was used to allow visibility of the working components while providing additional stability. Four sides of the control box were securely glued together while the top and one side panel of the assembly had temporary fittings to allow access for troubleshooting as seen in Figure (1). The J3L from ETI systems is a single-axis industrial strength joystick with a low profile and rated for 2 million operations. The J3L contains a spring centering device and has a 10 k Ω precision potentiometer. A longer lever arm was needed on the underside of the joystick so a stainless steel rod was permanently affixed to the lower portion as illustrated in Figures (1 & 2). The joystick handle was encased in rubberized foam to make it easier to grip. The joystick was mounted through the top acrylic panel and positioned with the extended lever arm between two motor and transmission systems. The two DC servo motors and gear trains were recycled from a Microsoft Sidewinder Force Feedback Pro, a feedback-enabled 2-axis PC game controller. The transmissions were positioned along the same axis so one motor only resists the joystick's forward motion and the other motor resists the backward motion. The original gimbles, the components connected to the gear trains which come in contact with the joystick extension, were replaced with machine screws as seen in Figure (2). The controller was

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mounted to the side rail of a Hill-Rom Model 820 adjustable hospital bed as in Figure (3). The hospital bed was donated by Saint Louis University Hospital. A section of the side rail was cut away so the controller's position was convenient for both patient and caregiver use while still allowing the rail to be raised and lowered.

An Accustar electronic clinometer was mounted to the side of the bed back platform. This device contains a dielectric fluid which, upon a change in orientation angle, creates a shift in capacitance proportional to the angle.

A 12V DC electric gear motor was coupled to the existing screw jack operated by the original AC bed back motor to bypass the original controls and to enable variable speed. The gear train was reconfigured to use the DC motor as shown in Figure (4).

The C8051F120 microcontroller from Silicon Laboratories was used to interface all other components of the entire system. This microcontroller was selected because of its wide range of ports including two ADCs, two DACs, and two UARTs through which to interface all of the devices. The C8051F120 also has a serial port on board which was very useful when troubleshooting software functionality. The microcontroller was programmed using the SiLabs F120 development kit. The SiLabs kit comes with compiling software as well as a debugger in order to ease the programming process. The microcontroller interfaces with the computer via USB to make downloading the written code to the board extremely easy.

A block diagram of the system is illustrated in Figure (5). The projected and actual budgets are listed in Appedix I.

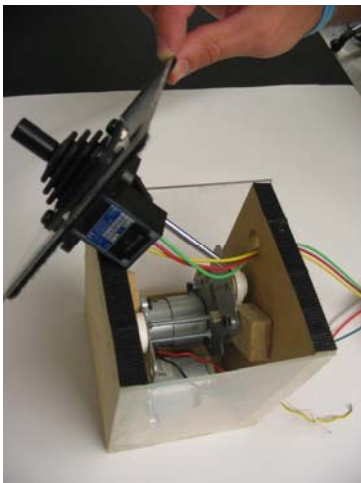


Figure (1) Controller with Top Panel Removed

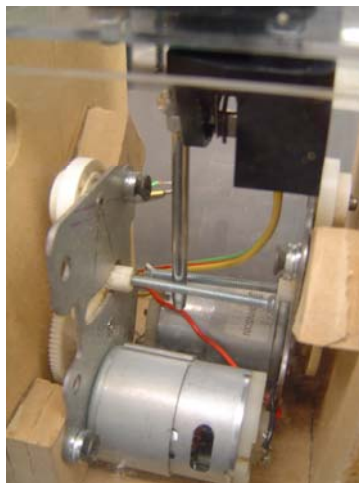


Figure (2) Modified Transmission Systems



Figure (3) Controller Mounted on Bed

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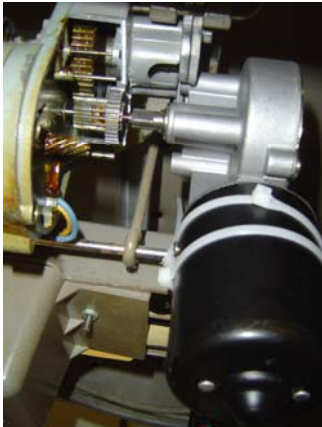


Figure (4) DC Motor Coupled to Existing Motor

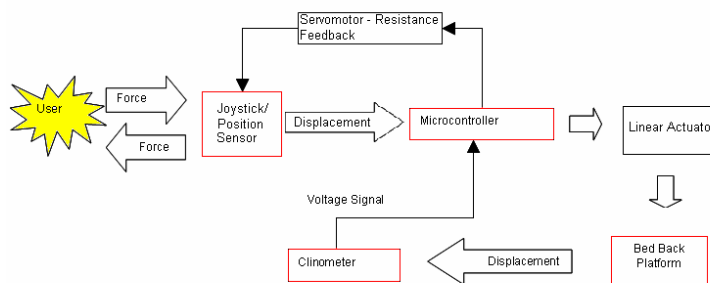


Figure (5) Block Diagram of System Components

Hardware Operation

The joystick functions as a 0 – 10kΩ potentiometer. When a voltage is run across the variable resistance, the output is a voltage proportional to the displacement of the joystick. Once an initial displacement force is applied to the joystick, a small force will be applied back to the user through servo motors in contact with the joystick extension. This feedback should be similar to that of a gaming joystick used with many computers.

The servo motors are mounted with the joystick in a custom casing. The servo motors apply the feedback to the joystick through the gear train and extended lever arm.

In order to attain variable speeds on the servo motors, it would be desirable to implement an electronic voltage selector circuit. This circuit would choose between three different voltages, dependent upon the force applied to the joystick, the corresponding voltage would be sent to the servo motor for the respective feedback.

The angle of the bed back is positioned by an actuator operable at variable speeds. The angle of the bed is measured using the Accustar electronic clinometer.

The five main devices will interface with the microcontroller. The joystick, two servo motors, clinometer, and actuator should all be controlled by the micro.

Velocity of the bed will be dependant upon three main criteria, direction of movement, bed angle, and force applied to the joystick. If moving from horizontal to upright at full force applied, the bed will move fastest at lower angles, move slowest when approaching upright, and at a moderate speed at angles in between. The opposite is true for movement from upright to horizontal. This will allow patients to move at a desired speed while not being difficult to attain a comfortable bed angle.

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Software Operation

The software is the key to whole system integration. The completed program will use 2 ADCs to interpret the signals coming in from the joystick and the clinometer. The software uses both DACs to turn on the individual servo motors for force feedback. Ideally, the system would use one DAC to select the proper voltage for the feedback on the joystick, the other DAC would be utilized to send a signal to an electronic PWM motor controller in order to vary the speed of the actuator. The code is attached in Appendix II.

Results

The major objectives of this prototype design and their completion status are outlined in Table (1).

Results of input force tests are shown in Tables (2) and (3).

Results of the weight test are in Table (4).

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Table (1): Prototype objectives and current status

Objective	Status
Joystick	
Detection of input angle	Success
Withstand 15 lbs. resistive force	Success
Force Feedback	
Applies resistive force in both directions	Success
Resistive force increases with input angle	Failure
Withstand 15 lbs. resistive force	Success
Allows minimal input force	Success
Clinometer	
Detection of bed back angle	Success
Bed Motor	
Raises and lowers unloaded bed back	Success
Raises and lowers bed back loaded with 180 lbs.	Failure
Adjustable speed in both directions under manual PWM control	Success
Maintains position with loss of power	Success
Bed Back	
Supports 180 lbs	Success
Control Box Mount	
Patient ease of operation (On a scale of 1-5, 1-Unusable, 5-Intuitive)	4 (n=6)
Caregiver ease of operation (On a scale of 1-5, 1-Unusable, 5-Intuitive)	4 (n=6)
Integration	
Joystick + Force Feedback	Success
Joystick + Force Feedback + Clinometer	Failure
Joystick + Force Feedback + Bed Motor	Not Completed
Clinometer + Bed Motor	Not Completed
Total System Integration	Not Completed
Single AC power source	Not Completed

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Table 2. Minimum input force required for operation

Trial	Force Required for Operation (lbf)
1	1.7
2	2.1
3	1.6
4	1.8
5	1.7
6	1.7
7	1.8
8	1.7

Table 3. Input force to failure

Trial	Force to Failure (lbf)
1	14.8
2	17.6
3	16.4
4	15.3
5	16.3
6	14.5
7	14.8
8	14.6

Table 4. Weight Test

Weight	Lift Success
45 lbs	Success
90 lbs	Success
180 lbs	Failure

Discussion

As illustrated in Table 1, total system integration was not completed. Continued prototype development could complete the integration of the clinometer, complete programming for variable speed of the servos, and develop a means of digital control of the bed actuator.

The joystick interfaces with the system seamlessly. It has three speeds for forwards, three speeds for reverse and a neutral position. The microcontroller can send an output voltage on DAC1 or DAC2 in order to turn on either the forward or reverse feedback motor. These motors only run on one speed however, which does not fully meet our outcome description.

The servo motors need to run at three different speeds correlating to the three deflection positions the joystick is programmed to detect. A simple voltage selector circuit could be completed by a EE student to obtain an electronic voltage selector circuit by use of the onboard DAC. The circuit can be seen in Appendix III. Once this circuit is implemented one can select between three different source voltages by varying the output voltage on one of the DACs. All outputs should be tied to both servo motors so these motors can run on any of the three source voltages. By way of just a voltmeter one can test the voltages being output by the DAC and they should be calibrated accordingly to the specific MOSfets used to build this circuit.

The programming was written so that the clinometer interfaced with the system just fine. However, while troubleshooting the system, the micro only pulled the correct values while stepping through the program using the debugger. When the microcontroller was

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allowed to run freely, it did not pull the correct values from the clinometer. A screenshot showing the correct values of the clinometer being pulled while stepping through the program can be seen in Appendix IV.

The clinometer and joystick need to function together while the micro is allowed to run freely. The failure of this integration is believed to be due to a sampling issue and this should be the first area inspected when troubleshooting this problem. The program uses the parallel port on the microcontroller to communicate with the PC via HyperTerminal. In order to error test, one must just run HyperTerminal while running a parallel cable between the PC and the micro, the current angle range as well as the joystick position is displayed on screen via a send0_char routine written in the program specifically for error testing.

The current PWM system is manually operated and does not meet the project outcomes outlined earlier. An electronic PWM could replace the manual version currently in place. This would involve little extra hardware except for replacing the manual PWM for an electronic one, however would involve quite a bit of programming.

Also, the problem of how to power all the components from a traditional AC source must be solved. Currently, the bed motor and PWM are powered by a 12V battery, the servo motors by a 3V battery pack, and the microcontroller draws power from the PC via USB.

Tables 2 and 3 show results from the input force tests outlined in Appendix V. The controller was operable at approximately 2 lbs of force, less than the 5 lbs specified in the design criteria. The force to failure was 15 lbs, less than the 20 lbs specified in the design criteria. This is largely due to a loosening of the machine screw from the transmission. With a better adhesive, the system can likely withstand 20 lbs of force.

Table 4 contains the results from the weight test of the motor outlined in Appendix V. The failure is due to a loosening of the coupling mechanism between the DC motor and the gear system. The 12V DC motor is rated to have 102 lb-in of torque, more than enough to support the bed back and 180 lbs.

Conclusion

Team Bed Back & Beyond began this project with the goal of creating a refined and fully-functional prototype. The team's inexperience with both the mechanical systems and the programming involved resulted in delays and incompleteness of a finished product. Appropriate steps were not taken for the team to familiarize itself with the components, understand the underlying principles, and come up with well-planned implementation strategies in a timely manner. While total system integration was not completed, the individual success of the components is encouraging. With continued effort, a fully-functional prototype could likely be achieved. The simplicity of this design as well as the low cost make the prototype appealing for continued development.

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Once a working prototype is achieved, further work should be performed to decrease the overall size of the controller. This can be achieved by selecting smaller servo motors and replacing the recycled transmissions with systems specifically designed and manufactured for this project. Durable plastic or metal should be considered as housing materials and tested for stability, sterilizability, and shielding properties. Finally, greater consideration should be given to the mounting location on the bed as well as the joystick handle to achieve the maximum level of convenience and ergonomic support for users.

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Appendix I Budget

Component	Budgeted Cost	Actual Cost
Joystick	\$200.00	\$130.00
Servos	\$37.80	\$0.00
12V DC Motor	\$300.00	\$60.00
12V PWM	Not Budgeted	\$45.00
Microcontroller	\$200.00	\$114.00
Clinometer	\$250.00	\$160.00
Bed Materials	\$100.00	\$0.00
12V Battery	Not Budgeted	\$29.00
Miscellaneous Hardware	Not Budgeted	\$20.00
Total	\$1,087.80	\$558.00

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Appendix II Code

```
#include <c8051f120.h>
#define TX_BUFFER 100
#define ADC0_BUFFER 100

extern void Init_Device(void);

void jumpstart_uart0();

//take out all SEND_CHAR() calls
//Modify angle degree digits after mounting clinometer
char tx0_buf[TX_BUFFER];
int tx0_head;
int tx0_tail;
int tx0_running;
int ADC0_buf[ADC0_BUFFER];
int ADC0_head;
int ADC0_tail;

void init_ser()
{
    tx0_head = 0;
    tx0_tail = 0;
    tx0_running = 0;
}
void init_ADC0()
{
    ADC0_head = 0;
    ADC0_tail = 0;
}

void send0_char(char this_one)
{
    tx0_buf[tx0_head] = this_one;
    tx0_head += 1;
    if(tx0_head == TX_BUFFER)
        tx0_head = 0;
    jumpstart_uart0();
}

void jumpstart_uart0()
{
    if(tx0_running != 1)
    {
        SFRPAGE = 0;
        TI0 = 1;
    }
}

void adc0int (void) interrupt 15
{
    SFRPAGE = 0;
    if(AMX0SL == 0x07) //dr mitchell code
    {
        ADC0CN &= 0xCF; // clear ADC0 int flag
        ADC0_buf[ADC0_head] = ADC0H*256;
        ADC0_buf[ADC0_head] = ADC0_buf[ADC0_head]+ADC0L;
        ADC0_head = ADC0_head+1;
    }
}
```

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```
        if (ADC0_head >= ADC0_BUFFER)
        {
            ADC0_head = 0;
        }

    }
    else //my modified code
    {
        ADC0CN &= 0xCF; // clear ADC0 int flag
        ADC0_buf[ADC0_head] = ADC0H*256;
        ADC0_buf[ADC0_head] = ADC0_buf[ADC0_head]+ADC0L;
        ADC0_head = ADC0_head+1;
        if (ADC0_head >= ADC0_BUFFER)
        {
            ADC0_head = 0;
        }
    }
}

void serint (void) interrupt 4
{
    SFRPAGE = 0;
    if (TI0)
    {
        TI0 = 0;
        if(tx0_tail != tx0_head)
        {
            SBUF0 = tx0_buf[tx0_tail];
            tx0_tail += 1;
            if(tx0_tail == TX_BUFFER)
                tx0_tail = 0;
            tx0_running = 1;
        }
        else
            tx0_running = 0;
    }
}

void main(void)
{
    int i;
    int counter;
    int angle;
    int position; //Joystick Position
    int new_position; //Joystick Position

    Init_Device();
    init_ser();
    init_ADC0();

    SFRPAGE = 0x00;
    REF0CN = 0x03;
    AMX0SL = 0x07; //measure position first
    new_position = 0;

    send0_char('S');
    send0_char('t');
    send0_char('a');
    send0_char('r');
```

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```
send0_char('t');
send0_char('i');
send0_char('n');
send0_char('g');
send0_char('r');
send0_char('\n');

for(i=0;i<6500;i++); //wait for a bit

while (1 == 1)
{
    if (ADC0_head != ADC0_tail)
    {
        counter ++;
        if (AMX0SL == 0x07)
        {
            position = ADC0_buf[ADC0_tail]; //joystick position
            ADC0_tail += 1;
            AMX0SL = 0x06;
        }
        else if (AMX0SL == 0x06)
        {
            angle = ADC0_buf[ADC0_tail]; //clinometer angle
            ADC0_tail += 1;
            AMX0SL = 0x07;
        }
    }

    if (ADC0_tail >= ADC0_BUFFER)
    {
        ADC0_tail = 0;
    }
}

if(counter >= 30) //waiting for a bit
{
    counter = 0;
    new_position = 1;
}

if(new_position == 1)
{
    if (0x490 <= angle && angle < 0x544) //0 degrees to 30 degrees (45 to 15 on
clinometer)
    {
        send0_char('0');
        send0_char('t');
        send0_char('o');
        send0_char('3');
        send0_char('0');
        if (0x000 <= position && position < 0x15C)
        {
            send0_char('F');
            send0_char('R');
            send0_char('\t');
            SFRPAGE = 0x00;
            DAC0CN = 0x80;
            DAC0L = 0xff;
            DAC0H = 0x0f;
        }
    }
}
}
```

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```
//                                     //FASTEST REVERSE SPEED
//                                     //Actuator in reverse
//                                     //fastest servo feedback
//                                     //servo in reverse
//                                     }
if (0x15C <= position && position < 0x2B8)
{
    send0_char('M');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DAC0CN = 0x80;
    DAC0L = 0xaa;
    DAC0H = 0x0a;

//                                     //Medium Reverse Speed
//                                     //actuator in reverse
//                                     //medium feedback
//                                     //servo in reverse
//                                     }
if (0x2B8 <= position && position < 0x3EB)
{
    send0_char('S');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DAC0CN = 0x80;
    DAC0L = 0x55;
    DAC0H = 0x05;

//                                     //Slowet Reverse Speed
//                                     //actuator in reverse
//                                     //slow feedback
//                                     //servo in reverse
//                                     }

if (0x3EB <= position && position < 0x414)
{
    send0_char('D');
    send0_char('M');
    send0_char('\t');
    DAC0L = 0x00;
    DAC0H = 0x00;
    DAC1L = 0x00;
    DAC1H = 0x00;

//                                     //DON'T MOVE BED
//                                     //no feedback
//                                     }
if (0x414 <= position && position < 0x570)
{
    send0_char('S');
    send0_char('F');
    send0_char('\t');
    SFRPAGE = 0x01;
    DAC1CN = 0x80;
    DAC1L = 0x55;
    DAC1H = 0x05;
```

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```
// //LOWEST Forward SPEED
// //actuator in forward
// //low feedback
// //servo in forward
}
if (0x570 <= position && position < 0x6CC)
{
    send0_char('M');
    send0_char('F');
    send0_char('\t');
    SFRPAGE = 0x01;
    DAC1CN = 0x80;
    DAC1L = 0xaa;
    DAC1H = 0x0a;

// //Medium Forward Speed
// //actuator in forward
// //medium feedback
// //servo in forward
}
if (position >= 0x6CC)
{
    send0_char('F');
    send0_char('F');
    send0_char('\t');
    SFRPAGE = 0x01;
    DAC1CN = 0x80;
    DAC1L = 0xff;
    DAC1H = 0x0f;

// //Highest Forward Speed
// //actuator in forward
// //high feedback
// //servo in forward
}
}
new_position = 0; //remeasure position
}

if(new_position == 1)
{
    if (0x3c6 <= angle && angle < 0x490) //30 degrees to 60 degrees (45 to -15 on
clinometer)
    {
        send0_char('3');
        send0_char('0');
        send0_char('\t');
        send0_char('o');
        send0_char('6');
        send0_char('0');
        if (0x000 <= position && position < 0x133)
        {
            send0_char('F');
            send0_char('R');
            send0_char('\t');
            SFRPAGE = 0x00;
            DAC0CN = 0x80;
            DAC0L = 0xff;
            DAC0H = 0x0f;

// //FASTEST REVERSE SPEED
```

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```
//                                     //Actuator in reverse
//                                     //fastest servo feedback
//                                     //servo in reverse
}
if (0x133 <= position && position < 0x266)
{
    send0_char('M');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DAC0CN = 0x80;
    DAC0L = 0xaa;
    DAC0H = 0x0a;

//                                     //Medium Reverse Speed
//                                     //actuator in reverse
//                                     //medium feedback
//                                     //servo in reverse
}
if (0x266 <= position && position < 0x3EB)
{
    send0_char('S');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DAC0CN = 0x80;
    DAC0L = 0x55;
    DAC0H = 0x05;

//                                     //Slowet Reverse Speed
//                                     //actuator in reverse
//                                     //slow feedback
//                                     //servo in reverse
}
if (0x3EB <= position && position < 0x414)
{
    send0_char('D');
    send0_char('M');
    send0_char('\t');
    DAC0L = 0x00;
    DAC0H = 0x00;
    DAC1L = 0x00;
    DAC1H = 0x00;

//                                     //DON'T MOVE BED
//                                     //no feedback
}
if (0x414 <= position && position < 0x599)
{
    send0_char('S');
    send0_char('F');
    send0_char('\t');
    SFRPAGE = 0x01;
    DAC1CN = 0x80;
    DAC1L = 0x55;
    DAC1H = 0x05;

//                                     //LOWEST Forward SPEED
//                                     //actuator in forward
//                                     //low feedback
//                                     //servo in forward
```

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```
    }
    if (0x599 <= position && position < 0x6CC)
    {
        send0_char('M');
        send0_char('F');
        send0_char('\t');
        SFRPAGE = 0x01;
        DAC1CN = 0x80;
        DAC1L = 0xaa;
        DAC1H = 0x0a;

//          //Medium Forward Speed
//          //actuator in forward
//          //medium feedback
//          //servo in forward
    }
    if (position >= 0x6CC)
    {
        send0_char('F');
        send0_char('F');
        send0_char('\t');
        SFRPAGE = 0x01;
        DAC1CN = 0x80;
        DAC1L = 0xff;
        DAC1H = 0x0f;

//          //Highest Forward Speed
//          //actuator in forward
//          //high feedback
//          //servo in forward
    }

    new_position = 0; //remeasure position
}

if(new_position == 1)
{
    if (0x2fd <= angle && angle < 0x3c6) //60 degrees to 90 degrees (-15 to -45 on
clinometer)
    {
        send0_char('6');
        send0_char('0');
        send0_char('\t');
        send0_char('o');
        send0_char('9');
        send0_char('0');

        if (0x000 <= position && position < 0x200)
        {
            send0_char('M');
            send0_char('R');
            send0_char('\t');
            SFRPAGE = 0x00;
            DAC0CN = 0x80;
            DAC0L = 0xaa;
            DAC0H = 0x0a;

//          //Medium Reverse Speed
//          //actuator in reverse
```

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```
//                                     //medium feedback
//                                     //servo in reverse
                                     }
if (0x200 <= position && position < 0x3EB)
{
    send0_char('S');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DAC0CN = 0x80;
    DAC0L = 0x55;
    DAC0H = 0x05;

//                                     //Slowet Reverse Speed
//                                     //actuator in reverse
//                                     //slow feedback
//                                     //servo in reverse
                                     }
if (0x3EB <= position && position < 0x414)
{
    send0_char('D');
    send0_char('M');
    send0_char('\t');
    DAC0L = 0x00;
    DAC0H = 0x00;
    DAC1L = 0x00;
    DAC1H = 0x00;

//                                     //DON'T MOVE BED

//                                     //no feedback
                                     }
if (0x414 <= position && position < 0x600)
{
    send0_char('S');
    send0_char('F');
    send0_char('\t');
    SFRPAGE = 0x01;
    DAC1CN = 0x80;
    DAC1L = 0x55;
    DAC1H = 0x05;

//                                     //LOWEST Forward SPEED
//                                     //actuator in forward
//                                     //low feedback
//                                     //servo in forward
                                     }
if (position >= 0x600)
{
    send0_char('M');
    send0_char('F');
    send0_char('\t');
    SFRPAGE = 0x01;
    DAC1CN = 0x80;
    DAC1L = 0xaa;
    DAC1H = 0x0a;

//                                     //Medium Forward Speed
//                                     //actuator in forward
//                                     //medium feedback
//                                     //servo in forward
                                     }
}
```

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```
        new_position = 0; //remeasure position
    }
}

} //close while
} //close main
```

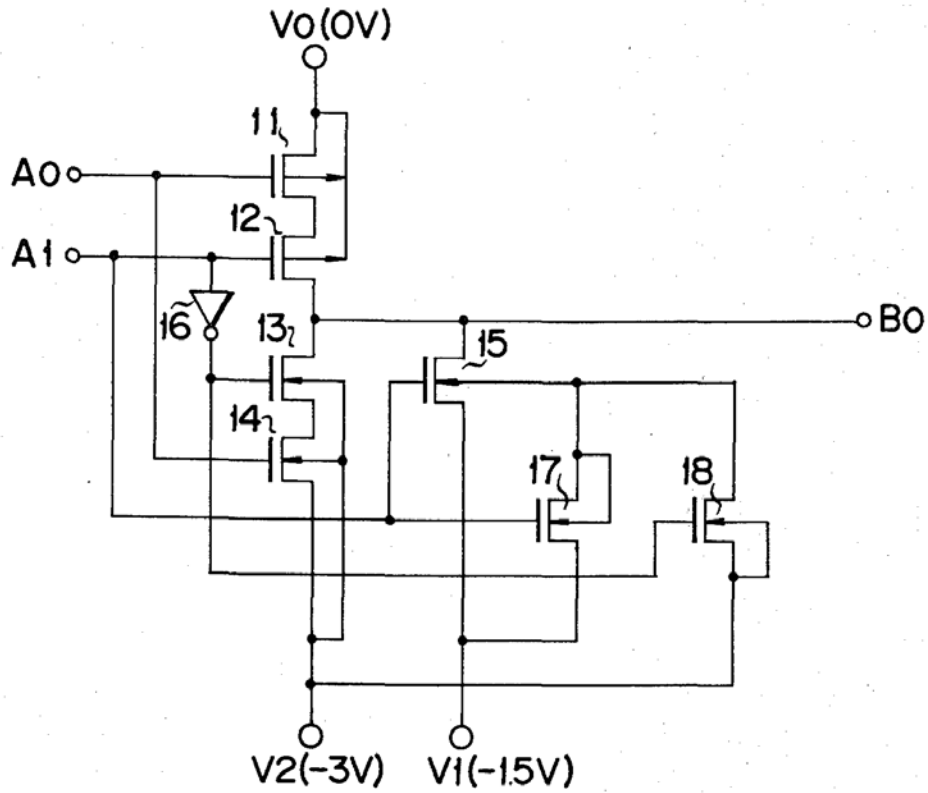
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Appendix III

Example voltage selector circuit:

United States Patent 4,324,991 4/1982 Tamaki



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Appendix IV

```
if (0x000 <= position && position < 0x15C)
{
    send0_char('H');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DACOCN = 0x80;
    DACOL = 0xff;
    DACOH = 0x0f;

    //FASTEST REVERSE SPEED
    //Actuator in reverse
    //fastest servo feedback
    //servo in reverse
}

if (0x15C <= position && position < 0x2B8)
{
    send0_char('M');
    send0_char('R');
    send0_char('\t');
    SFRPAGE = 0x00;
    DACOCN = 0x80;
    DACOL = 0xff;
    DACOH = 0x0f;

    //Medium Reverse Speed
    //actuator in reverse
    //medium feedback
    //servo in reverse
}
```

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Appendix V

Testing Protocols

Operational Force Test

Force required for operation was measured using a fish scale hooked on the joystick handle and secured in place. Pulling force was then gradually applied until joystick deflection and a visible readout from the microcontroller. This force was recorded and the trial repeated.

Force to Failure Test

Force to failure was measured using a fish scale hooked on the joystick handle and secured in place. Pulling force was then gradually applied until failure. Ideally, failure would be considered a crack or other malfunction of the joystick, the joystick extension, or the transmission. Due to a limited supply of components, failure in this test was considered an observable bed or deformation in the joystick, joystick extension, or transmission.

Weight Test

The weight test was performed by attaching increments of disk weights to the bed beck platform and testing the ability of the bed motor to successfully raise and lower the bed back at variable speeds. Failure was defined as inability to raise or lower the bed back at low or high speeds or any other malfunction of the motor. Upon success, the weight on the bed back was increased and the test repeated.

Hyperterminal Testing

In order to fully test the system sending signals into the micro should be tested and verified using HyperTerminal. By using the send0_char routine, various characters will be displayed in HyperTerminal depending on the desired output. As can be seen in the figure above, the send0_char routine will send a HR to HyperTerminal if the joystick is in the furthest reverse range or an MR if in the medium reverse range. Different ranges are specified with the send0_char routine for all joystick ranges as well as ranges for angles with the clinometer input.

When implementing systems that need a voltage out, the DACs should be implemented to their fullest capabilities. The DACs only have a 2.4 V max output so their best use should be with switches or turn on voltages on transistors. The DAC functionality can be tested by using a multimeter and verifying the desired voltage output.

Sampling times and timer overflows can all be altered using the provided SiLabs software. This may be necessary depending on the desired times of specific hardware.

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