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November 14, 2005

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
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Re: ENSC 340 Design Specification for the Auto-Conforming Ergonomic Chair

Dear Dr. Rawicz:

Attached is a document from Accomodarsi Solutions that provides a set of technical guidelines for design of the Auto-Conforming Ergonomic (ACE) Chair. The ACE Chair is an office task chair that will sense the dimensions of each user and then automatically adjust to provide optimal support and comfort.

The design specifications described in this document apply to the proof-of-concept model only. Design improvements for future iterations of the ACE Chair are discussed, but will not be implemented in this stage of development.

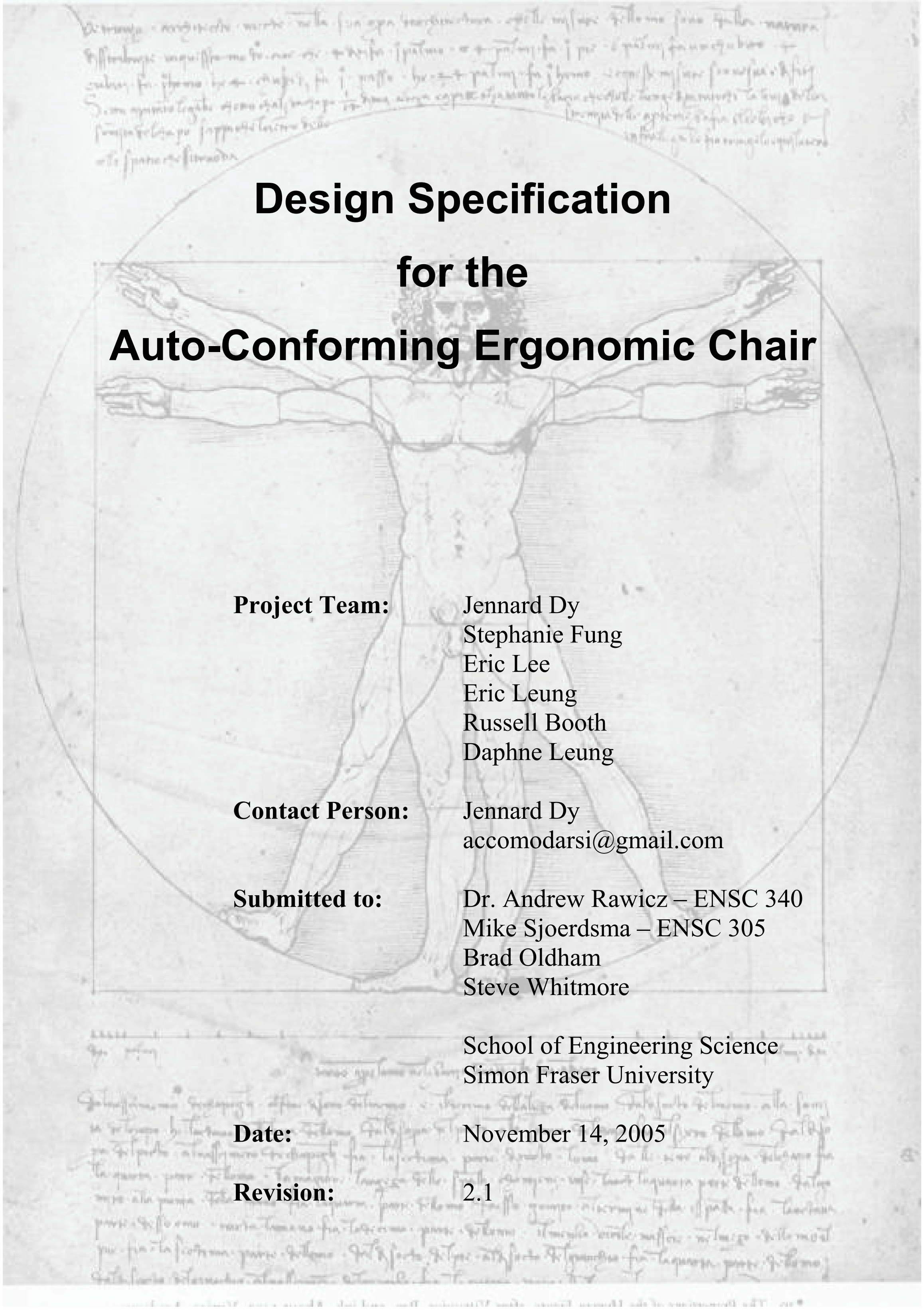
If you have any questions or comments, please feel free to contact us by email at accomodarsi@gmail.com or by phone at (778) 855-5940.

Sincerely,

Stephanie Fung

Stephanie Fung
Chief Executive Officer
Accomodarsi Solutions

Enclosure: Design Specification for an Auto-Conforming Ergonomic Chair



Design Specification
for the
Auto-Conforming Ergonomic Chair

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Date: November 14, 2005

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Executive Summary

The design specification for the Auto-Conforming Ergonomic (ACE) Chair provides a set of detailed descriptions for the design and development of our proof-of-concept model. The design specifications in this document are solely for the proof-of-concept model. Therefore, we will only discuss design considerations pertaining to the functional requirements marked I or II (minus R87-II [12]), as specified in the document *Functional Specification for the Auto-Conforming Ergonomic Chair* [1].

This document outlines the design of the ACE Chair and provides justification for our design choices. Design improvements for future iterations of the ACE Chair are also discussed. Four of the five chair adjustments will be actuated by DC motors driving power screws. These adjustments include the armrest height, armrest width, seat depth, and lumbar support height. The size of the lumbar support will be adjusted by varying the size of an expandable air pocket. Sensors located in the backrest and seat pan will detect user presence and estimate load on the chair. Distance sensors located on the armrest will determine the correct armrest width, while switches placed on the surface of the armrest will determine the appropriate armrest height. The user interface will consist of an array of buttons and a dial for manual adjustment, as well as an LCD and a group of status LEDs. A microcontroller will read inputs, apply a control algorithm, and produce commands for the actuators.

A detailed description of the resource requirements and selection criteria for a suitable microcontroller is provided. General software program process flow is also included. A description of test plans for the system and its subcomponents is provided at the end of the design specification.

During the design process we have become aware that the four-month development cycle targeted in the *Functional Specification for the Auto-Conforming Ergonomic Chair* [1] is insufficient to complete implementation of the proof-of-concept system. Therefore, the updated completion date for this phase of development is January 10, 2006.

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Acronyms

A/D	analog-to-digital
ACE Chair	Auto-Conforming Ergonomic Chair
CSA	Canadian Standards Association
CU	computation unit
DIP	Dual Inline Package
EMI	electromagnetic interference
I2C or I^2C	Inter-IC (integrated circuit) bus
IC	integrated circuit
I/O	input/output
IR	infrared
LCD	liquid crystal display
LDO	low-dropout
LED	light-emitting diode
PCB	printed circuit board
PWM	pulse-width modulated
TQFP	Thin Quad Flat Pack
USART	Universal Synchronous Asynchronous Receiver-Transmitter

Glossary

ACE Chair User	An adult user with the following characteristics: • no back ailments and/or physical disabilities that affects sitting • height between 52 cm and 194 cm • weight between 45 kg and 115 kg • has body dimensions that fall between those of the 5th percentile female and the 95th percentile male [4][5].
Ergonomic	Exhibiting good design so as to maximize productivity by reducing fatigue and discomfort [3].
Flex Fatigue	The ability of foam to maintain its original properties and height [1].
Hysteresis	A laboratory test used to determine a foam's ability to retain its original firmness properties [2].
Lead	For a screw and nut mechanism, the distance that the nut moves after one turn of the screw.

1 Introduction

The Auto-Conforming Ergonomic (ACE) Chair is an office chair that will adjust itself to comfortably support anyone that sits in it with body dimensions that fall between those of the 5th percentile female and the 95th percentile male [4][5]. By sensing the position of the seated user, the ACE Chair can intelligently adjust the backrest, seat depth, and armrests to provide the user with unparalleled ergonomic support and seating comfort. Our aim is to create a chair that will not only remove the possibility that the user forgets to adjust it, but also take away the frustration that comes with the manual adjustment process. This design specification describes the technical details for the design of each component of the ACE Chair.

1.1 Scope

This document specifies the design of the ACE Chair and explains how the design meets the functional requirements as described in *Functional Specification for an Auto-Conforming Ergonomic Chair* [1]. The design specification includes all requirements for a proof-of-concept system and a partial set of requirements for a production model. As we are focusing on the proof-of-concept system, only design considerations pertaining to the functional requirements marked I or II (minus R87-II [12]) will be explicitly discussed. The appendices include mechanical schematics and process flow charts to help facilitate the implementation of the ACE Chair.

1.2 Intended Audience

The design specification is intended for use by the members of Accomodarsi Solutions. Design engineers shall refer to the specifications as overall design guidelines to ensure all requirements are met in the final product. Test engineers shall use this document to implement the test plan and to confirm the correct behaviour of the ACE Chair.

2 System Specifications

The ACE Chair will adjust the height and width of its armrests, the depth of its seat, and the height and size of its lumbar support. The ACE Chair will perform these adjustments automatically when the ACE Chair User (The User) instructs it to begin through the push of a button. The User will also have the option to fine-tune these automatic adjustments through a manual adjustment user interface.

For the automatic adjustment sequence, a correct system response would place the user in an ergonomically correct seated position with all adjustments complete within 5 minutes. In a user-controlled adjustment, the system response should correspond to the commands issued through the user interface.

3 Overall System Design

This section provides a high-level overview of the entire design. Design details that are common to all parts of the ACE Chair will be discussed in upcoming subsections, while design details specific to individual parts of the ACE Chair can be found in their respective sections.

3.1 Mechanical Design

Figure 1 provides an overview of the proposed mechanical design for the ACE Chair. Note that the armrest enclosures have been made transparent to show the underlying mechanisms. The mechanism to adjust lumbar support size and the sensors are not shown. For more views, please refer to Appendix A: Mechanical Drawings.

While designing the mechanisms to adjust lumbar support height, seat depth, and armrest height and width, we considered the following options:

- power screw and nut,
- rack and pinion, and
- pneumatic or hydraulic cylinders.

Upon further research, we found that pneumatic cylinders act too quickly for our needs. Pneumatic cylinders would also require a more complex air preparation, control, and delivery system with stringent requirements on valves and tubing. Pneumatic or hydraulic controlled adjustments would also require a more complex driving system than the motor-driven alternatives [6]. After considering the above points as well as our lack of experience with precise control of pneumatic and hydraulic systems, we eliminated this choice. Rack and pinions were removed from consideration due to cost and the need for additional locking mechanisms to prevent rollback and motor damage. Since power screws have an intrinsic locking mechanism and are widely available in different lengths and widths, they are the best mechanism for our purpose.

Other mechanical design considerations include mounting of the power screw, ensuring structural integrity of the chair, and balancing the tradeoff between speed and torque. With regard to mounting the power screws, our designs are guided by the use of supporting structures to distribute loads away from the power screw itself, while also minimizing torque and friction on the turning screw. Structural integrity design considerations in this proof-of-concept model were made under the assumption that the user will not try to break the chair by stressing it outside the intended uses of the chair. When selecting the power screw and motor combination, we considered the speed-torque tradeoff. With a constant screw rotation speed, a shallow lead will decrease the torque required to move a load, but the linear speed of the nut will also decrease. Similarly, a deeper lead screw can move a nut faster, but the torque required to turn the screw will be higher. High torque requirements result in the need for a powerful and costly motor; high speed requirements can prematurely wear out the screw.

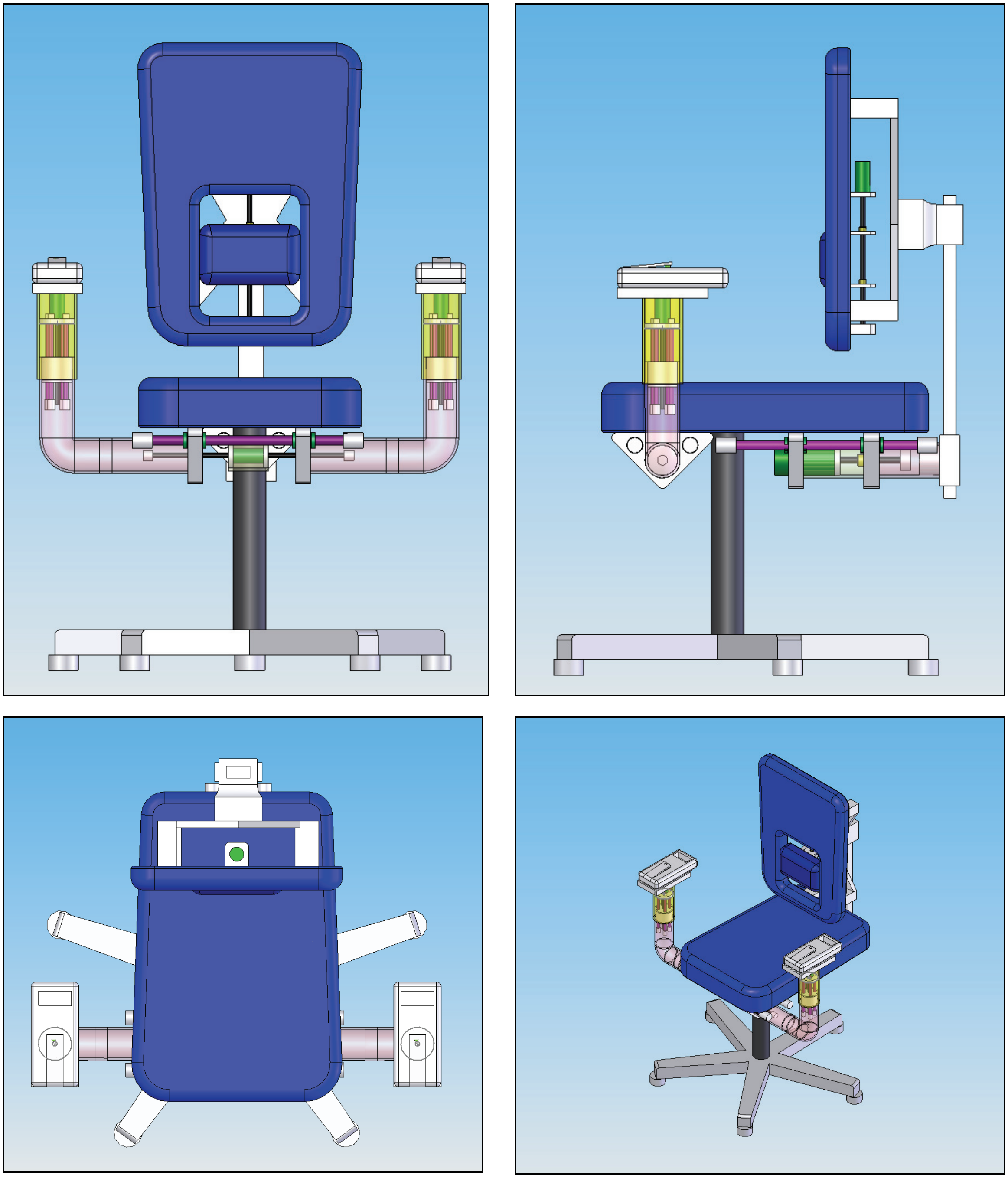

Figure 1: Mechanical Overview of the ACE Chair.
From top left to bottom right: front view, right view, top view, and isometric view.

Table 1 summarizes our calculations and estimations of maximum dynamic load, maximum adjustment time, range of adjustment, and minimum adjustment increment. These values determine the specifications for the actuators that are selected.

Table 1: Design Requirements Determining Actuator Specifications

Adjustment	Maximum Dynamic Load	Maximum Adjustment Time	Range of Adjustment	Minimum Adjustment Increment
Seat depth	356 N	60 seconds	115 mm	20 mm
Armrest height	178 N	60 seconds	100 mm	5 mm
Armrest width	178 N	60 seconds	100 mm each (max total change is 200 mm)	5 mm
Lumbar support height	45 N	60 seconds	100 mm	5 mm
Lumbar support size	N/A	60 seconds	50 mm depth	5 mm (auto) continuous (manual)

Maximum dynamic loads were determined from free-body diagram calculations that assumed the weight of the heaviest user (according to the definition of ACE Chair User) plus an arbitrary safety margin. These calculations were roughly verified by performing spring-scale measurements with test subjects. Maximum dynamic load does not apply to the lumbar support size because the applied force is dependent on the pressure in the air pocket. The safely allowable maximum air pressure will be dependent on the capabilities of the particular air pocket selected for implementation, plus a suitable safety margin.

Adjustment time was determined by functional requirement R51-II, which specifies that an entire automatic adjustment sequence be completed within 5 minutes. This time has been arbitrarily divided into equal portions for each adjustment, and includes the time required to home the chair to its initial position.

Minimum increment parameters were determined by CSA standards [7] and range requirements from anthropometric data that accommodates 90% of the population [4][5]. For automatic adjustments, the lumbar support size has a minimum increment of 5 mm. Manual adjustments made with the dial on the user interface have no minimum increment.

3.2 Cushioning

The cushioning on the armrests, seat, and backrest will be made from readily available foam material due to budget constraints. This foam material must be firm enough to support the weight of the user. Safety reasons restrict us to choices of foam that maintain their shape when cut, have low combustibility, and have a high dielectric constant.

In future development iterations, more stringent criteria will be placed on selecting appropriate cushioning. Properties such as airflow, flex fatigue, resilience, and hysteresis will be considered [2]. Physical requirements will include rounded edges and molded contours designed to enhance comfort and reduce fatigue. Fabric material covering the foam will protect it from wear and add aesthetic value.

3.3 High-level System Design

This section provides a high-level overview of the entire system and describes the placement of components on the chair.

Figure 2 depicts a block diagram showing the inputs and outputs along with the relationship between subsystems.

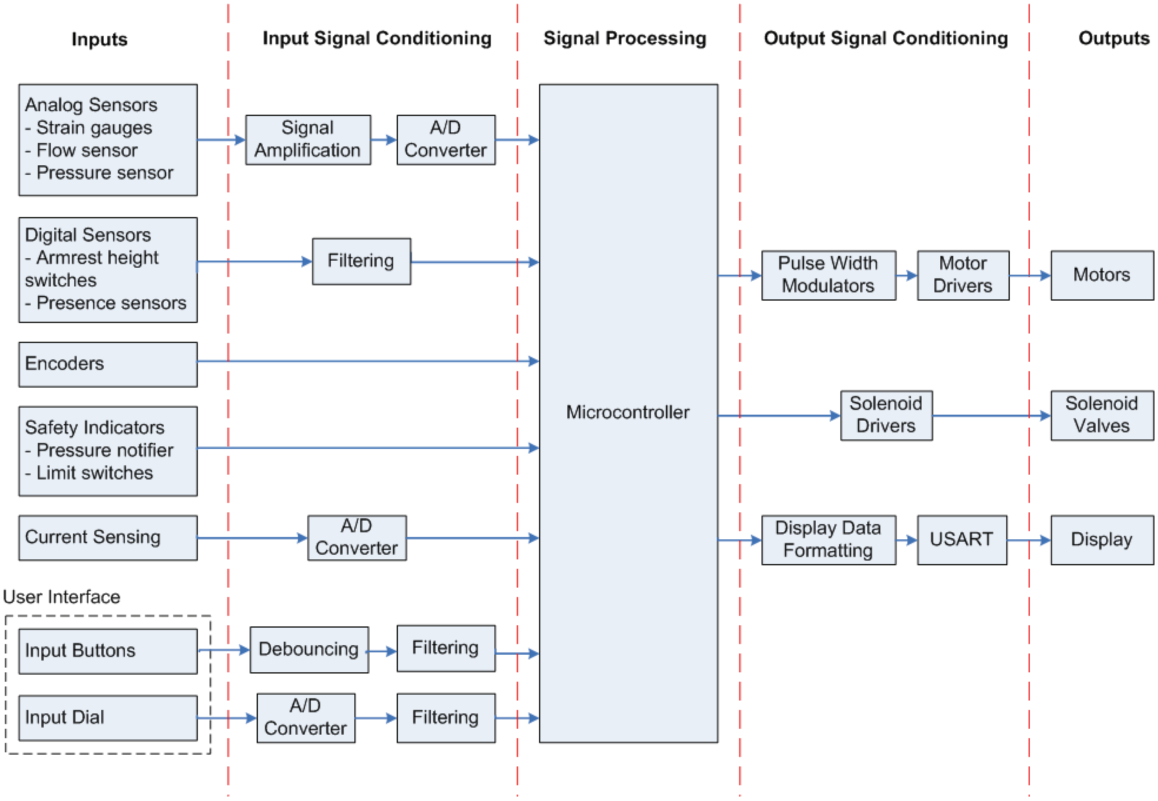

Figure 2: System Block Diagram

System inputs include user input buttons, analog and digital sensors, motor encoders, safety indicators, and current measurements. These inputs are conditioned for use by the processor through signal amplification, filtering, and A/D conversion stages.

The signal processing stage consists of the microcontroller, which contains control software that provides the logic used to synchronize, monitor, and activate all other system components.

The output signal conditioning stage provides the necessary hardware to create the appropriate power-amplified, pulse-width modulated signals that drive the motors. Solenoid drivers drive the solenoid valves in the lumbar support size adjustment system. LCD data is first formatted and then transmitted through an USART port, while the LED data is driven directly by the microcontroller.

3.4 Sensor Placement

The following types of sensors will be used in the ACE Chair:

- Load sensors (strain gages)
- Distance sensors (IR sensors)
- Presence sensors (strain gages and switches)
- Pressure sensor
- Flow sensor

Figure 3 illustrates the placement of these sensors on the chair. The pressure and flow sensors, which are part of the lumbar support size adjustment system, are not shown in the figure. They will be described in Section 6.1.1.

Figure 3: Sensors on the ACE Chair. Sensors are highlighted in yellow.

To measure load and presence, strain gages have been selected for their cost effectiveness. Other options considered were force-sensing resistors and load cells. Load cells are geared more towards industrial applications and their bulky metal construction would be difficult to accommodate in the ACE Chair. Although force-sensing resistors are small and thin, they are better suited to applications where one desires to measure a small force normal to the surface of an object.

IR sensors will be used to measure the distance between the top of the armrest and the underside of the user's forearm. These sensors provide the rough accuracy needed to adjust to the correct armrest width. Other factors in deciding to use IR sensors were our familiarity with their operation and their low-cost availability (free from previous projects).

The sensors placed on the seat pan and on the backrest will detect user presence and the load applied by the user. This placement configuration allows for some detection of improper seating positions, such as slouching and forward-lean, in addition to presence.

Distance sensors placed on the top surface of the armrest are recessed in order to maintain a level surface for supporting the forearms. In addition to distance sensors, switches are also placed in the armrest for the purpose of threshold detection of a force applied normal to the top surface. This configuration facilitates the determination of correct armrest width with the distance sensors, and the correct armrest height using the switches.

Figure 4 illustrates the placement of the sensors on the armrest.

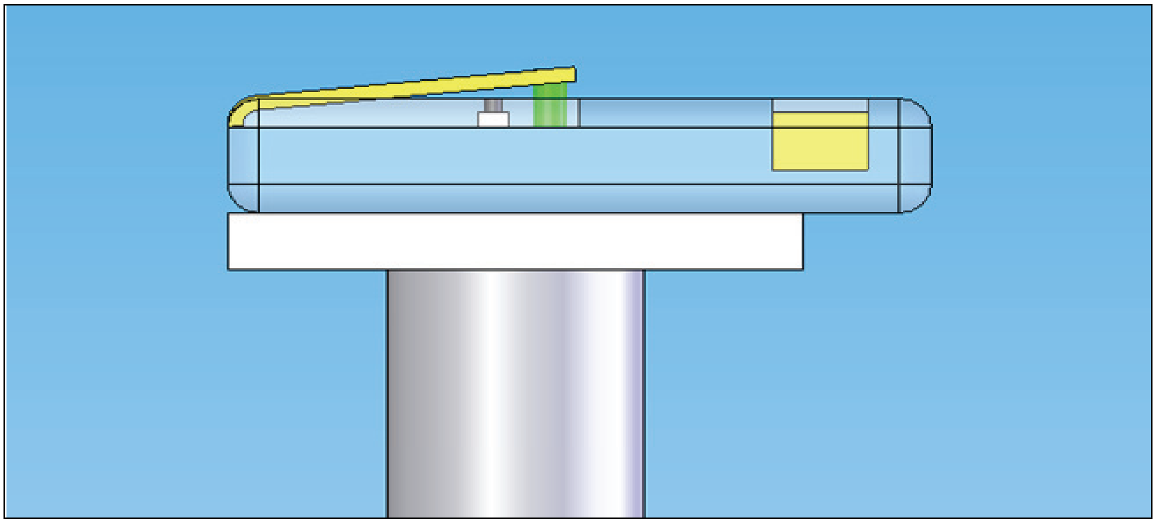

Figure 4: Sensor Placement on the Armrest. (Cross-sectional side view)

Armrest sensors are highlighted in yellow. The green cylinder represents a spring next to the white and black switch.

The element on the right represents the distance sensor. A yellow covering over the switch represents the active area where an applied force will depress the switch. A spring, shown in green, supports the cover and provides a resistive force to be overcome before activating the switch.

3.5 Actuator Placement

Five DC motors and one air source serve as the actuators in the ACE Chair. For the proof-of-concept system, the air source will be placed on the ground due to time and budget constraints. The choice of air source will be justified in Section 6.1.1.

Figure 5 shows the placement of the actuators in the proof-of-concept model.

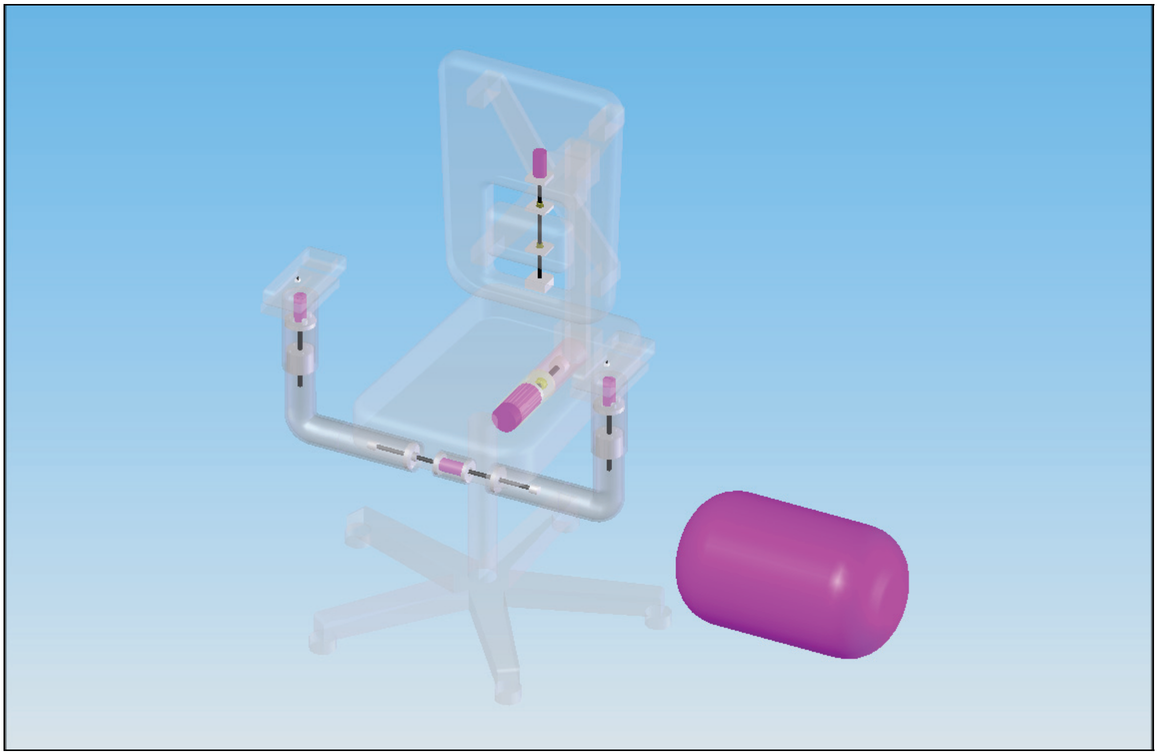

Figure 5: Actuator Placement on the ACE Chair.
Actuators are purple and power screws are black.

Actuators are placed with consideration to being minimally intrusive to the user. Ease of mounting and wiring considerations are other contributing factors in the choice of placement.

3.6 Electrical System

The ACE Chair will have two power supply voltages, 5V and 12V. Everything runs on 5V except for the motors and the solenoid valves. Because of the more stringent requirements for a consistent voltage, in addition to the voltage regulation provided by the power supply, we are using a low-dropout (LDO) linear voltage regulator. From summing the current requirements for the 5V line (along with some extra capacity), the linear voltage regulator must be capable of supplying 2A. For safety, we place a fast-acting 3A fuse in series with the 5V line coming from the power supply. An additional fast-acting 1A fuse is placed in series with the supply line to the computational unit (CU). Note that the power supply used in the proof-of-concept system is capable of continuously supplying more than 20A for the 5V line.

The DC motors and solenoid valves are powered by 12V. With a feedback loop, encoders, and PWM to control the motors, it is not critical that the motors receive exactly 12V. Similarly, the solenoid valves will only be used in fully on or off positions, relaxing the need for an accurate supply voltage. Therefore, we can rely entirely on the voltage regulation of the power supply and save cost by not placing an additional voltage regulator on the 12V line. A slow-acting 20A fuse is placed in series with the 12V supply line coming from the power supply. Even though we are using a 20A fuse, we do not anticipate using anything close to 20A during normal operations. To reduce current spikes, we are gradually ramping commands to the motors in all situations except for limit switches. In the worst case, if each motor is stalled, the 5 motors will use much more than 20A combined. We plan to avoid this situation by disabling the motors if the sensed current level rises too much.

As shown in Figure 6 and Figure 7, to reduce noise and improve signal integrity, we plan to create four ground planes. By grouping similar functions together, we intend to have a separate ground plane for each of the analog, digital, driver, and driver logic circuits.

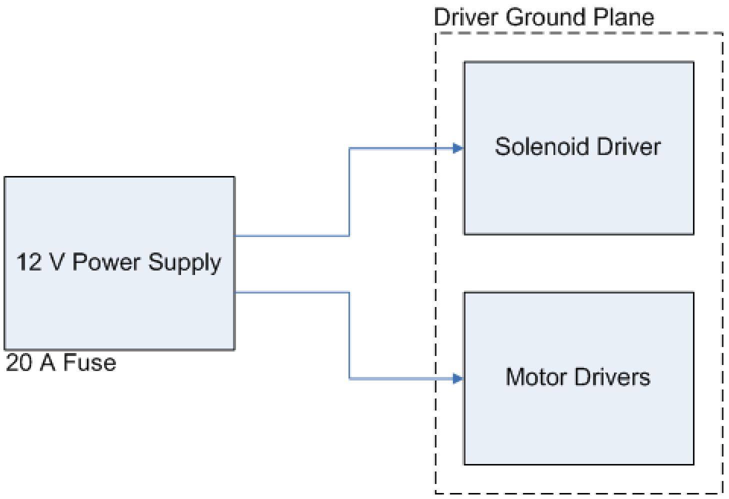

Figure 6: 12V Ground Plane

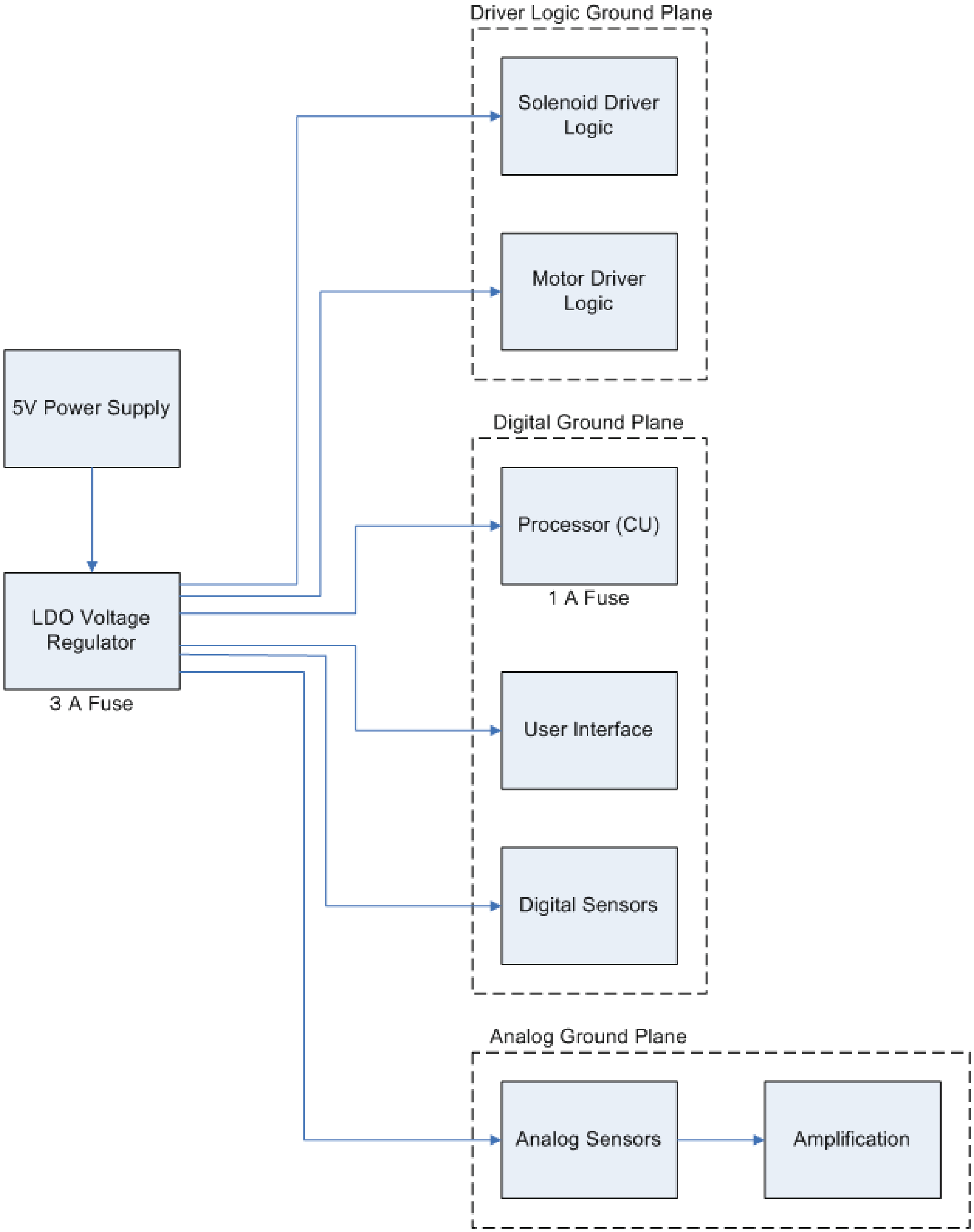

Figure 7: 5V Ground Planes

3.6.1 Noise Considerations

Because we will require long wires to route signals to a large number of motors, sensors, and solenoids, electromagnetic interference (EMI) is of particular concern in our design. The following steps will be taken to reduce the detrimental effects of noise in the electrical system:

- Utilizing sufficient signal strength
- Maintaining a high signal-to-noise ratio
- Routing wires carefully to minimize unnecessarily long wire lengths
- Carefully laying out the PCB
- Shielding of EMI noise from the motors and solenoids

3.6.2 Safety Considerations

To protect electronic components from damage and prevent harm to developers and users, electrical safety in the ACE Chair will be enforced by taking the following precautions:

- Use of fuses in high current areas
- Magnetic isolation of solenoids from other electromagnetic devices
- Proper insulation of wires
- Use of current sensing circuitry
- Use of heatsinks to dissipate heat from voltage regulator and drivers

Heatsinks were chosen for heat dissipation because fan cooling comes with an increase in noise level, and a powered cooling system would add complexity to the system.

3.7 Power Supply

The following power requirements of the ACE Chair must be met:

- Maximum Current: 20A
- Voltage: 12VDC, 5VDC
- Number of connectors: Minimum 4
- Can be run from a wall electrical outlet, R10-II
- AC to DC conversion
- Regulated

The maximum current is determined by summing the current requirements for all electronic components. The motor and solenoid drivers require supply voltages of 12V, while the logic and sensors require 5V. The four connections to the power supply include: one for the analog sensors, one for the digital circuits, one for the motors, and one for the other actuators.

A computer power supply will be used for the proof-of-concept ACE Chair because we have one readily available at no cost. In the final product, the ACE Chair will be furnished with a custom-designed power supply, battery charger, and a more appropriate sealed lead acid battery supply.

4 Armrests

The armrests provide support to the seated user's arms. Armrests also provide support to the user when he/she is getting in and out of the chair. In the ACE chair, the armrests' height and width are adjusted automatically, and in tandem – both armrests should be at the same height and width.

4.1 Physical and Mechanical Design

The armrest height and width adjustment mechanisms are linked together so one of them needs to support the other. In our design, the armrest width mechanism supports the armrest height mechanism.

4.1.1 Armrest Height Adjustment Mechanism

The armrest height adjustment mechanism is shown in Figure 8. Parts have been coloured for easy identification. The motor is coloured green, the power screw is black, and the support rods are shown in purple. The outer and inner PVC pipes are the tinted yellow and pink shells, respectively.

The upper part of the mechanism attaches to the inside of the yellow PVC pipe. The lower part of the mechanism is fixed to the inside of the pink PVC pipe, which fits inside the outer pipe. The mounting for the motor and the nut-controlled cylinder will be made with aluminum. We chose aluminum because it provides adequate structural support and is easy to cut and shape. The cushions for the armrests are placed on top of the outer PVC pipe. The outer pipe is open on the bottom so when the nut moves upwards with respect to the screw, the outer pipe fits over the inner pipe.

The motor is attached to a 3/8" screw that turns a nut. We chose this screw because it provides enough support and can turn quick enough to meet our adjustment time requirements. The nut is fixed inside a cylinder so that the cylinder effectively increases the size of the nut. Depending on the direction of the rotating motor, the non-rotating cylinder will move up or down relative to the rotating screw.

The cylinder has holes allowing 4 support rods to pass through. As the cylinder travels up and down the screw, the 4 support rods help the screw maintain the upright position of the armrest. Without the support rods, the armrest is only supported by the screw, thereby exposing the screw to much torque and radial loading when the armrest is fully extended. The support rods essentially prevent the outer pipe from sagging forward and backward or left and right when the user puts his arms on the armrests. They also inhibit any horizontal twisting of the armrests. The shoes on the ends of the rods limit the range of motion of the armrest height to 10 cm.

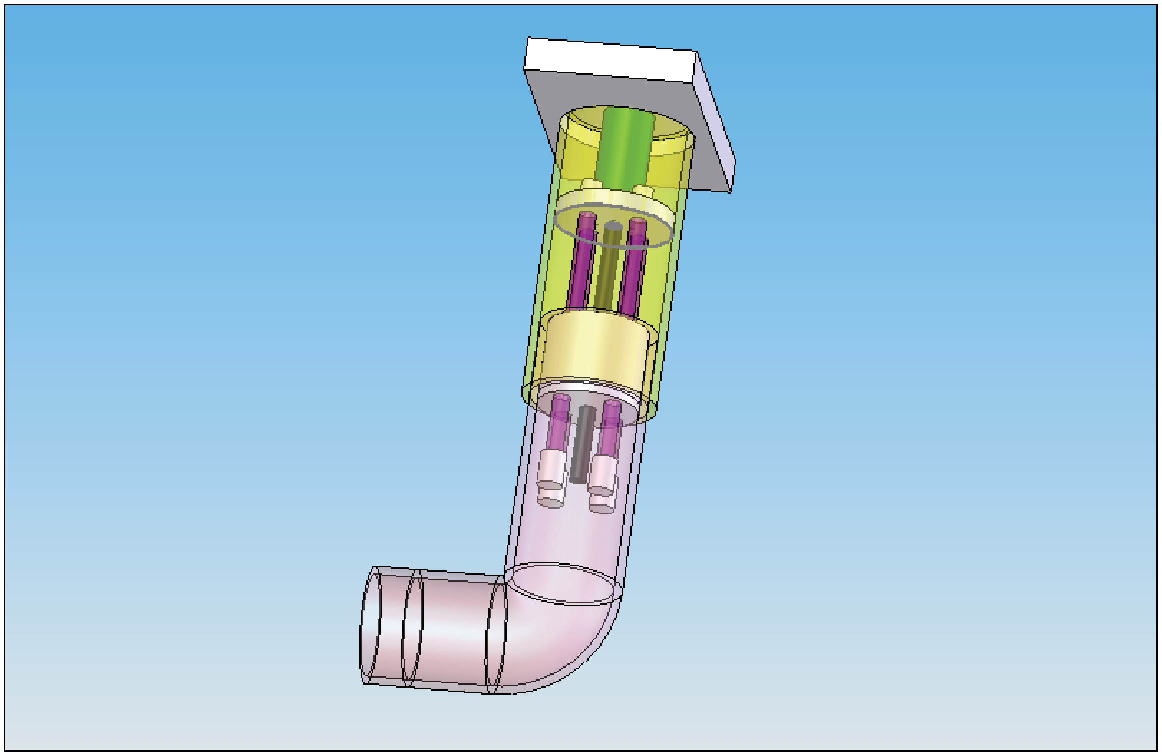

Figure 8: Armrest Height Adjustment Mechanism

4.1.2 Armrest Width Adjustment Mechanism

The armrest width adjustment mechanism connects the two armrest height adjustment mechanisms. The entire armrest assembly is shown in Figure 9. Parts are shaded again as follows: the motor is in green, the power screw is black, and the support rods are purple. The outer and inner PVC pipes are the tinted yellow and pink shells, respectively.

The mechanism is similar to the armrest height adjustment mechanism except mounted perpendicular. Through a pair of PVC pipes, the armrest width adjustment mechanism moves the entire armrest height adjustment mechanism horizontally.

The nut is attached to a disc that is fastened to an outer pipe such that when the nut moves left or right, the outer pipe overlaps a smaller, inner pipe. To compensate for the huge radial torque from the armrest height adjustment mechanism, the outer pipe is supported by a system of two thick rails. A ring surrounds the outer pipe and connects to bearings that travel along the rails, distributing the load evenly and reducing the torque on the screw.

We are only using one motor for the armrest width, coupling the output such that it turns two screws simultaneously. These screws will either move outwards or inwards by a maximum of 10 cm each. As a result, the armrest width adjustment mechanism is symmetric along the center of the motor and the inner pipe.

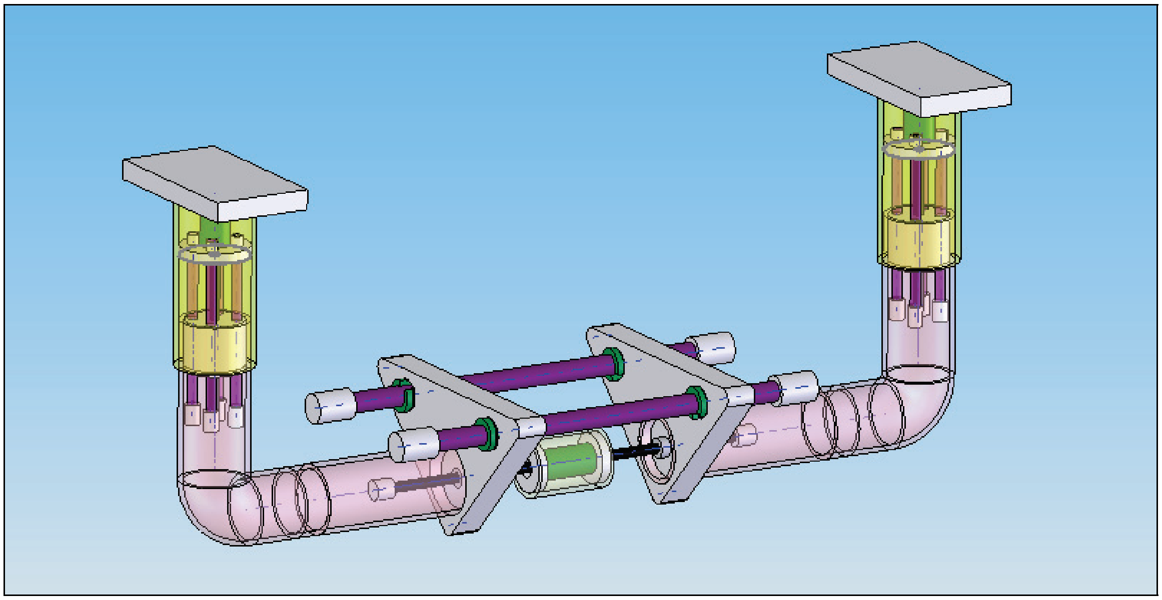

Figure 9: Armrest Width Adjustment Mechanism

The mechanism in Figure 9 attaches to the underside of the seat at the ends of the support rods. These attachments are not shown.

4.1.3 Other Designs

We also examined other design possibilities, such as having one movable vertical column to move the entire armrest system. Upon further investigation, we found that the motor required for this system would be more expensive than the combined cost of 2 smaller motors. We also explored a scissors mechanism for armrest height and width adjustment, but its motion is nonlinear and the mechanism has a high possibility of pinching the user. In the end, besides cost and complexity, we chose the current mechanisms because both motions are linear and the possibility of pinching is small.

4.2 Electronic Design

Considering the movement of the armrest adjustment, we chose sensors that will take advantage of that movement. The armrest adjustment sequence will begin with the armrests at the lowest and widest possible position. The armrests move in towards the seat until the width is correct, then the armrests move up until the height is correct. For the armrest width we decided to use distance sensors, while for the armrest height we will use switches. We assume that the user holds his arms by his sides with a 90° angle at the elbows.

4.2.1 Distance Sensors

The distance sensors will be mounted on the top surface of the armrests, one on each armrest. The sensors emit infrared light and evaluate the received reflected light to determine the distance to the object reflecting the light. As the armrests move in, the distance should be large, since nothing is above the armrests. Once the armrests are under the user's forearms, a shorter distance will be detected, ending the armrest width adjustment sequence. By setting a range of distances corresponding to the range of sitting elbow heights, we can check the distance sensed to see if it falls within this range. The sitting elbow height will range from 176 mm to 274 mm [1].

4.2.2 Switches

Once the armrests are at the correct width, the height adjustment will begin. Again, switches are mounted on top of the armrests, one on each armrest. When the armrest reaches the correct height, contact with the user's forearms will compress the spring, as shown in Figure 4. Upon reaching a certain threshold force, the switches will be depressed, completing the armrest height adjustment. A switching threshold of 10 N is used to stop the armrests.

4.2.3 DC Motors

For the entire armrest mechanism, three motors are needed: two for the armrest height and one for the armrest width. The DC motors turning the screws need to overcome the forces for the armrest width and armrest height adjustments as indicated in Table 1. To meet the adjustment time requirements in Table 1, the motors need to have a rotational speed of 200 RPM in turning the 3/8" screws.

5 Seat

The seat depth must be adjusted correctly to allow the user's legs to be positioned so that there is no compression behind the knees. The seat depth of the ACE Chair will be adjusted by moving the backrest forward and backward.

5.1 Physical and Mechanical Design

Based on the anthropometric data of 5th percentile females and 95th percentile males, the range of the seat depth adjustment is 115 mm [4].

5.1.1 Seat Depth Adjustment Mechanism

The backrest will move forward and backward using the mechanism in Figure 10. Parts are shaded as follows: the motor is in green, the power screw is black, and the support rods are purple (one is selected making it a dark blue-green). The nut is shown in gold and the PVC pipe is tinted pink.

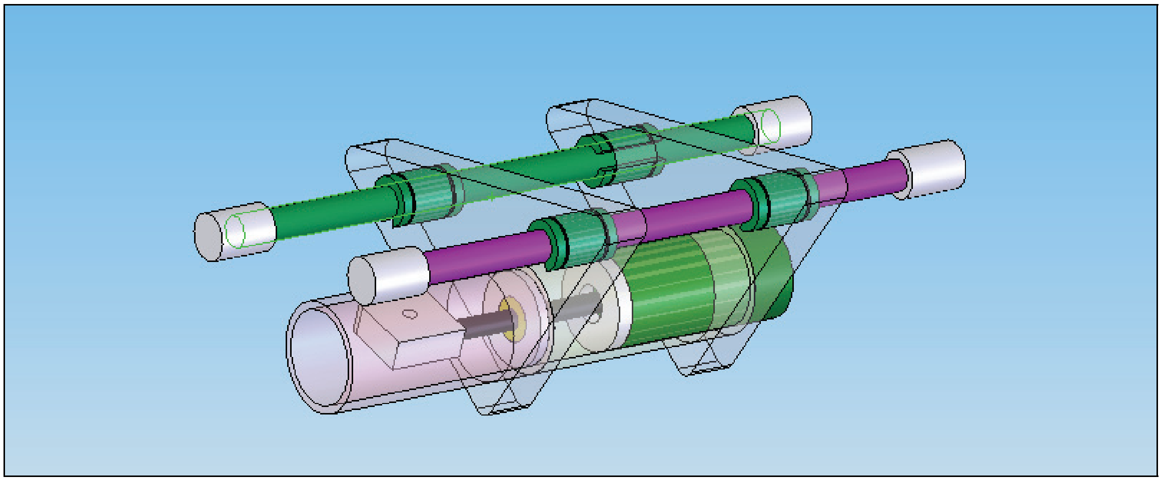

Figure 10: Seat Depth Adjustment Mechanism

The movement of the seat depth mechanism is exactly like one side of the armrest width mechanism. They are also structurally identical except that two triangular supports are attached to the underside of the seat at the top faces, instead of one for the armrest width, since the backrest is heavier than one armrest.

5.1.2 Other Designs

Two choices were available in adjusting the seat depth. One is to adjust the seat itself, and the other is to adjust the backrest forward and backward. We chose to adjust the backrest because, with this approach, we only need to overcome the force of the user's back. On the other hand, in adjusting the seat itself, the entire weight of the user must be overcome. Additionally, moving the seat forward and backward will cause instability as the center of gravity shifts away from the chair base. By keeping the seat centered on the base and only moving the backrest, we do not need to worry about instability. The disadvantage to moving the backrest is a more complex seat tilt adjustment mechanism. However, as seat tilt adjustment is not a requirement for the proof-of-concept model, this disadvantage is moot. Additional considerations will need to be made when designing the production model.

5.2 Electronic Design

Similar to the armrests, we have a screw being moved by a DC motor. The sensors consist of strain gages.

5.2.1 Strain Gages

Strain gages measure mechanical strain by exhibiting a change in electrical resistance proportional to the change in strain [8]. Since strain gages are essentially variable resistors, they can be easily incorporated into an electric circuit. One useful configuration for strain gages is the Wheatstone bridge, shown in Figure 11.

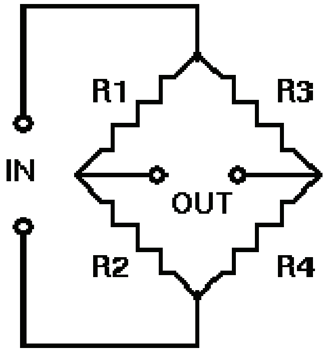

Figure 11: The Wheatstone Bridge (Image Courtesy of Ken Bigelow) [9]

The four resistors in Figure 11 do not have to be all strain gages. Each load-sensing component will be made from a Wheatstone bridge with active strain gages as R1 and R2, and fixed-value resistors as R3 and R4. This configuration does not suffer from non-linearity errors compared to other configurations [10]. Given a constant input voltage source, the bridge output can be measured. Since the output is a linear function of strain, we can use the output to approximate the load placed on the load-sensing component.

Figure 12 illustrates the placement of the strain gages on the load-sensing component that will maximize the sensitivity of the output.

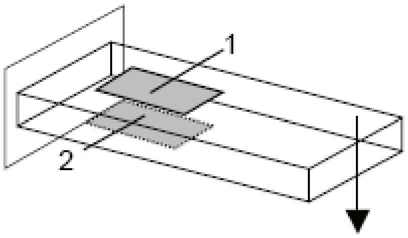

Figure 12: Load-sensing Component Showing Placement of Strain Gages [11]

The shaded boxes represent the strain gages and the arrow represents the direction of the bending force. The first strain gage is adhered to the top of a thin aluminum beam, while the other strain gage is adhered to the other side of the beam directly below the first gage.

The load-sensing components will be mounted on the backrest as shown in Figure 3, with the possibility of adding more components for increased accuracy during implementation. As the backrest adjusts forward and touches the user, the output voltage will change drastically and the adjustment will stop.

5.2.2 DC Motor

The DC motor turning the screw needs to overcome a load of 356 N as specified for the seat depth adjustment in Table 1. To meet an adjustment time of 60 seconds, the motor requires a rotational speed of 200 RPM to turn a 1/2" diameter screw.

6 Backrest

The backrest will evenly distribute the pressure of the user's back across its surface. Besides distributing the pressure, the backrest will also support the user's lumbar area through an expandable air pocket. This air pocket will also move up and down to suit the user's lumbar location.

6.1 Physical and Mechanical Design

The lumbar support has to cover a position range of 100 mm, while the depth range is about 50 mm [1].

6.1.1 Lumbar Support Size Adjustment Mechanism

The lumbar support system contains valves, sensors, and an air source. The system is shown in the block diagram in Figure 13.

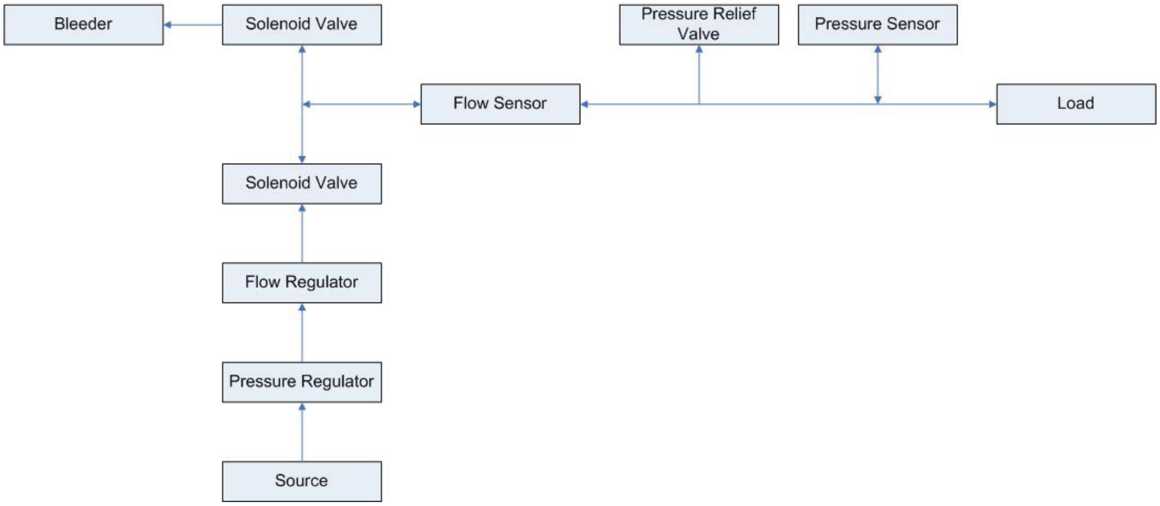

Figure 13: Lumbar Support Size Adjustment System Block Diagram

The regulators will control the flow and pressure of the air used to inflate the load, which is the actual lumbar support. The flow and pressure sensors will monitor the volume and pressure of air inside the lumbar support for adjustment and safety purposes. The pressure relief valve will automatically let out air if the pressure reaches an unsafe level. The bleeder will expel air when the lumbar support deflates normally. The various valves, the air source, and the load will be connected through a series of tubes and fittings.

The lumbar support itself is an inflatable latex object like a football bladder. In deciding the material for the lumbar support, we inflated several common household items such as balloons, condoms, and latex gloves. We found that latex is very resistant to breakage and has an even expansion when filled with air.

In this proof-of-concept prototype, an air compressor will act as the air source due to time and budget constraints. Future iterations of the ACE Chair will seek to reduce the size, noise level and power consumption of the air source. A future air source will be small and light so that it may be mounted on the chair.

6.1.2 Lumbar Support Height Adjustment Mechanism

The lumbar support system will be mounted on the backrest through the back, and will move through the use of a motor and power screw similar to the armrest and seat depth mechanisms. The design for the linear motion is shown in Figure 14. The motor is coloured green, the power screw is black, and the nuts are shown in yellow.

6.1.3 Other Designs

Another design that we strongly considered is the use of multiple air pockets instead of the motor and screw to adjust the lumbar support height. However, multiple air pockets will have complex interactions with each other as they expand, and they all need to be monitored to ensure safety. The increment of height adjustment is also not as fine.

We also considered a fixed-sized cushion that would vary its depth by moving towards and away from the user's back, in addition to moving up and down. The advantage of this method is that we have similar mechanisms for the armrest and seat depth. A disadvantage is that conformation to the user's lumbar is not as effective as the chosen lumbar support system. In addition, a user's back exerts a large force, which would require a powerful motor and thick screw.

Another mechanism that could have been used is a fluid-filled pocket system instead of the air-filled system. A fluid-filled lumbar support could be more comfortable, but is also more difficult to work with because the lumbar support will deform with water inside. In addition, more safety measures would need to be implemented to protect the electronics from damage.

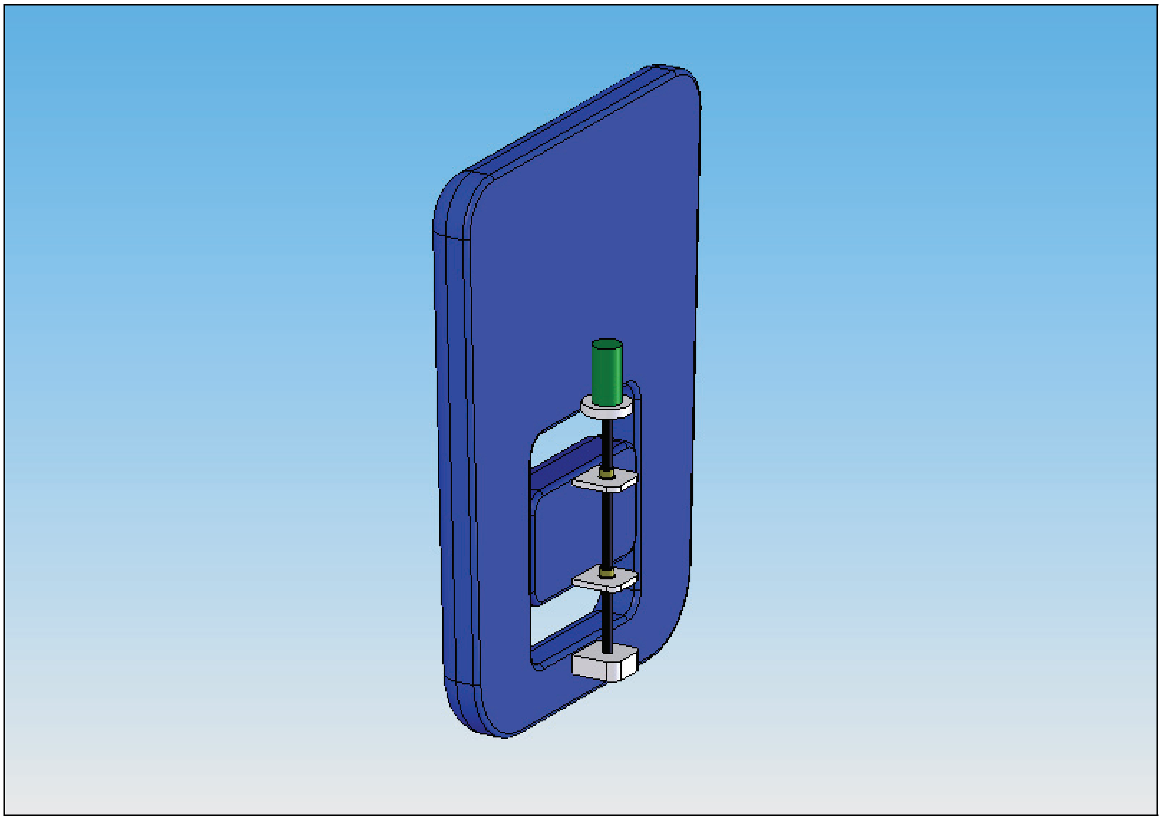

Figure 14: Lumbar Support Position Adjustment Mechanism

6.2 *Electronic Design*

Many sensors are needed in this system, both for adjustment and safety. Strain gages will be used to determine the proper height of the lumbar support. The pressure sensors will indicate the correct size for the lumbar support. The pressure sensors will also be used in conjunction with the flow sensors to monitor the airflow during adjustment.

6.2.1 Strain Gages

As the lumbar support expands and changes position, force from the user's lumbar area and surrounding back area will be exerted on the strain gages. The load-sensing components will be placed at the top and bottom of the lumbar support, as shown in Figure 15.

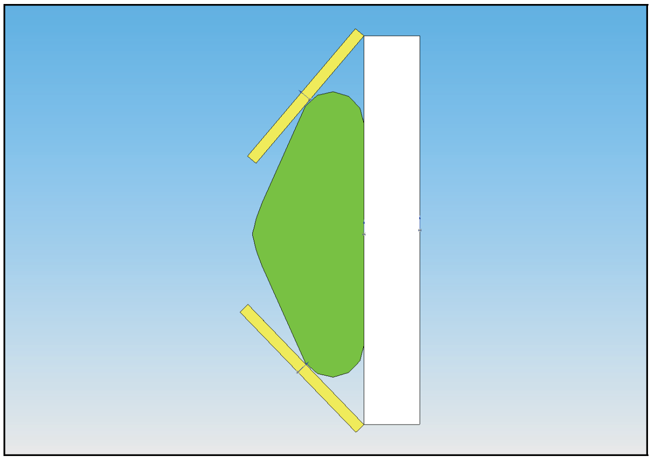

Figure 15: Strain Gages on the Lumbar Support

The load-sensing components will sense if the proper position for the lumbar support has been achieved. As the lumbar support moves up and expands, the upper and lower part of the lumbar support will exert pressure on the load sensing components. When the output value of both load sensors is equal, the lumbar support is deemed to be in the correct position and the height adjustment ends.

6.2.2 Pressure Sensor

The pressure sensor will be mounted behind the air pocket connected to a tube because it is difficult to mount the sensor directly on the air pocket. The pressure sensor will still be able to detect the pressure inside the air pocket by measuring the pressure through the tube. As the lumbar support makes contact with the user's lumbar area, the pressure inside the air pocket will increase. Monitoring this pressure ensures that the lumbar support is at a sufficient size to support the lumbar without risk of the air pocket bursting.

6.2.3 Flow Sensor

The flow sensor helps to determine the volume of air currently in the air pocket by measuring the airflow to and from the air pocket. To maintain safety, airflow should stop before a predetermined maximum volume is reached.

6.2.4 Air Compressor

We have an air compressor readily available so we will use this as an air source to fill the inflatable latex object. As mentioned earlier, testing was performed on different materials so we know that the compressor is sufficient to supply the required air.

6.2.5 Solenoid Valves

The solenoid valves control the inflation and deflation of the air pocket. The valves are normally closed and open while a signal is received from the computation unit. Opening and closing the appropriate valves connects the air pocket to either the air source or the outside atmosphere through the bleeder. The bleeder provides a mechanically regulated rate of deflation. The solenoids require too much current to be driven directly from the computation unit; instead, the CU sends logic signals to the solenoid driver circuit.

6.2.6 DC Motor

The DC motor turning the screw needs to overcome the force for the lumbar height adjustment in Table 1. To meet the adjustment time requirement in Table 1, the motor needs to have a rotational speed of 200 RPM in moving the 3/8” screw.

7 Input Signal Conditioning Unit

The signals from the various sensors, the user interface, and the motor drivers (for current sensing) need to be modified before they can be processed by the signal processing unit.

7.1 Analog Signal Amplification

The signals from the analog sensors need to be amplified in order for the signal to be processed properly. We will use an op-amp or a custom amplifier circuit to amplify the sensor signals.

7.2 Analog Filtering

Some sensor signals, such as those coming from the strain gages on the lumbar support, may need to be filtered using low-pass filters. In addition, we are putting bypass capacitors on all ICs and all power pins to ensure steady voltages and reduce noise.

7.3 Digital Filtering

Among the digital sensors, the armrest height switches and strain gages for the seat presence need to be filtered. They can be filtered by thresholding, a technique where the sensors will only turn on after pressure in a specified range is applied. Another filtering method could be averaging, where the amount of pressure will be taken over a larger time period to obtain a more consistent value.

7.4 A/D Converter

The total number of A/D channels needed is no less than 15, as shown in Table 3. While some microcontrollers contain this many channels on-chip, they also have more than enough I/O lines for our needs. Therefore, we are going to choose a microcontroller with 8 or 16 A/D channels and a separate A/D chip to supply another 16 channels.

7.5 Sampling Frequencies

The sensors have to be sampled regularly depending on the importance and accuracy of the data. Table 2 shows the sampling frequencies for all the sensors used in the chair.

Table 2: Sampling Frequencies

Sensors	Frequency (Hz)
Encoders	1000
Current Sensors	50
Limit Switches	∞
Distance Sensors (Armrest Width)	50
Switches (Armrest Height)	∞
Flow Sensor (Lumbar Support Size)	100
Pressure Sensor (Lumbar Support Size)	100
Strain Gages (Lumbar Support Height and Seat Depth)	100
Thresholded Strain Gages (Seat Presence)	1

The limit switches and armrest height switches have an infinite frequency to indicate that they will be sampled immediately once they are hit. The encoders are sampled the fastest to ensure that the motors and screws are moving properly.

8 Output Signal Conditioning

The motors need to receive properly conditioned signals from the signal processing unit in order to turn.

8.1 Pulse-Width Modulation

The chair uses five motors, so we require five pulse-width modulated (PWM) outputs. The motors turn at different speeds in order to move the screws within the required adjustment time. As such, each PWM output will control the speed of one motor. These PWM outputs are part of the microcontroller's on-chip hardware resources.

8.2 Motor Drivers

The motor drivers will deliver the required power to the motors. They will have H-bridges with built in current sensors and enable lines for the PWM signals. The motor drivers will drive a minimum of 12 V to the motors. The supplied current will range from a minimum of 1 A during continuous operation to a maximum of 12 A when a stall occurs. Because of the heavy power requirements of the motors, large heatsinks are needed to ensure that the motor driver ICs do not overheat and become damaged.

8.3 Solenoid Drivers

The solenoid valves in the lumbar support need drivers because of the current requirements of solenoid valves. The valves require approximately 200 to 500 mA of current while the microcontroller can only directly provide 50 mA. Therefore, the solenoid drivers will supply the valves with the correct current needed to properly open and close them. As mentioned in Section 3.6, the drivers will be placed on a separate ground plane. This is done to minimize the effects of large transient voltage and current spikes caused by switching the motors and solenoid valves on and off.

9 Signal Processing and Computation Unit

This section describes the design of the processing unit for the ACE Chair. Design considerations for this unit are outlined in detail in their respective subsections.

9.1 Overview of the Computation Unit (CU)

Due to the high number of sensors and actuators available on the ACE Chair, the chair requires a considerable amount of processing power. The CU needs to have numerous timers, PWM channels, and general I/O lines to deal with the large amount of input data coming from the sensors on the chair. Time-critical analog data will have its own dedicated A/D converter, while the rest of the analog inputs will be multiplexed to reduce the number of required A/D converters.

In total, we determined that the CU has fourteen general tasks to perform in order to deliver the auto-adjusting capabilities as outlined in the functional specifications. We believe that a multithreaded environment will be better suited to our chair, rather than a distributed system of processors. Although a distributed system would be able to better execute some tasks concurrently (mainly relating to motor control), coordination, synchronization, and communication between the processors would be extremely difficult. From past experience working with arbitrating a shared bus, the main controlling processor will still be required to wait during communications with the slower processors. As well, communication would only be possible with one pair of processors at a time, and as the number of sub-processors increases, the main processor has to devote more resources to arbitrating the communications bus. Our initial approach to a distributed system included more than 5 processors, an unwieldy number. Thus, we have selected a single monolithic processor running a multithreaded environment.

9.2 Control Hardware

The selection criteria for hardware of the CU are reviewed in this section. We considered the number of analog and digital I/O lines, the number of required A/D channels, the number of PWM lines to control the motors, the number of timers, built-in communication hardware and protocols, the packaging, and the pin-count of the microcontrollers. Cost, available size and type of on-board memory, interrupt capabilities, and other built-in peripherals were also examined. In the end, we were offered a wide number of choices between 8-bit and 16-bit microcontrollers with a pin-count of over 40. The final decision of which microcontroller to use in the ACE chair will be determined upon cost and availability of samples and development tools associated with the chip.

Table 3 outlines the different input and output signals from sensors for our chair. The system requires 15 analog inputs. Time critical analog signals will occupy a dedicated channel for the A/D converter onboard the microcontroller, while the rest of the analog signals are multiplexed to a single A/D channel. In the end, we probably will need the microcontroller to have at least 4 or 8 A/D channels.

Table 3: Analog Inputs

Name	Type of signal	I/O	Mux	Number	Description
Distance Sensors	Analog	I	Y	2	Used in armrest width determination
Flow sensor	Analog	I	Y	1	Flow rate of lumbar support
Motors	Analog	I	Y	5	Current sensing for stall protection for each motor
Multiplexed input	Analog	I	N/A	1	
Pressure sensor	Analog	I	Y	1	Internal pressure of lumbar support
Load Sensing Components	Analog	I	Y	5	Measures force exerted by user on chair
User buttons	Analog	I	Y	1	lumbar size dial

Table 4 shows the different digital input signals to the processing unit. A total of 44 digital input lines are required. However, the signals other than the optical encoders are not time critical and therefore can fit on a 32-to-1 multiplexer connected to the microcontroller. After multiplexing, we will need 11 general input pins.

Table 4: Digital Inputs

Name	Type of signal	I/O	Mux	Number	Description
Armrest height switches	Digital	I	Y	2	Used in armrest height determination
Encoders	Digital	I	N	10	Quadrature encoders, 2 input lines per motor encoder
Limit switches	Digital	I	Y	6	Detects if limits of motion range for the screws reached or not (1 side of each screw will have the switch. Chair calibrates at every homing.)
Multiplexed input	Digital	I	N/A	1	
Seat presence sensor	Digital	I	Y	4	Used to determine if user is sitting on the seat or not
User buttons	Digital	I	Y	16	5 up-down pairs, power, start, stop, 3 custom functions

Table 5 summarizes the different output signals and the number of lines required. We will need 29 general digital output lines. We plan to directly drive each of the digital outputs because of the increased complexity related to introducing demultiplexers and latches. Each of the five motors will need a PWM enable signal to vary motor power during adjustments. The LCD will require a USART connection, which is a 2-line serial protocol (note that this protocol is different than the I2C protocol). In total there will be at least 36 output lines coming out of the microcontroller.

Table 5: Outputs

Name	Type of signal	I/O	Number	Description
Display	Digital	O	7	Status LEDs
Motor Direction control	Digital	O	11	2 directions lines per motor + 1 total enable
A/D MUX	Digital	O	4+1	Addressing, enable
Digital MUX	Digital	O	5+1	Addressing, enable
Motor Power control	PWM	O	5	PWM lines for motor power output control. Linked to enable lines in power driver.
LCD	USART	O	1	Asynchronous serial data, 9600 baud

Summing up all the different input and output lines, we need at least 55 usable I/O pins on the microcontroller. Hence, we need a microcontroller that comes with at least 64 pins. The largest microcontrollers in through-hole DIP packages have a total of 40 pins. We are forced to select TQFP and related surface mount packages with a pin count of at least 64.

With no need for more accurate 16-bit operations, we decided that the use of a large 8-bit microcontroller would be sufficient. Numerous microcontrollers suit our application, such as microcontrollers from the MegaAVR (Atmel), PIC18, MSP430 (TI), and HC08 (Freescale) families. Microcontroller samples from these companies are widely available and can be obtained in a relatively short amount of time. The only cost associated with the microcontroller will come from the development tools, such as programmers, in-circuit emulators, and C programmers and translators. The amount of available memory varies depending on the specific microcontroller, but we aim to use flash-based microcontrollers because of ease of reprogramming. Other selection considerations for our microcontroller include the capability to handle a large number of interrupts and the availability of hardware peripherals such as a hardware multiplier.

9.3 Control Software

The control software for the ACE chair will consist of multiple threads that will implement the list of processes shown in Table 6. A main process and a task scheduler will coordinate and communicate with the other processes.

Table 6: List of Processes

Process	Priority	Amount of Processing	Frequency of Execution (Hz)	Description
Scheduler	1	Heavy	100	Schedules and prioritizes all the tasks to ensure seamless operation of chair
Limit Switches	2	Light	N/A (Interrupt)	Checks if motors have exceeded the allowable range of motion and notifies the main process if exceeded
Current Sensing	3	Light	50	Implements stall protection for the motors
Lumbar Support Volume	4	Medium	100	Checks the flow sensors and performs numerical integration to find the lumbar support volume
Motor	5	Heavy	Max 1000	Ensures that motors are

Feedback Control				following the commands sent by the main process
Encoders	6	Light	1000+	Reads and counts encoder pulses
User Control	7	Light	10	Allows for manual adjustment of the chair
Main Process	8	Heavy	0	Plans for and deals with the automatic adjustments. Issues commands to the appropriate process to get tasks completed. Yields CPU time while waiting for other tasks to complete.
Load Sensing	9	Heavy	100	Measures and interprets force data from user sitting on chair
Lumbar Support Pressure	10	Light	100	Notifies the main process if the pressure inside the lumbar support exceeds the maximum allowable pressure. A pressure relief valve will automatically relieve pressure.
Armrest Width Determination	11	Medium	50	Measures and calculates suitable a separation distance for the armrests
Armrest Height Determination	12	Light	N/A (Interrupt)	Determines a suitable height for the armrest
Display Process	13	Medium	10	Controls the status LEDs and LCD display.
User Presence	14	Light	1	Detects presence of the user to determine how long they are away from the chair

The scheduler process arbitrates control of the available processing power between the different processes. Because it has the highest priority, the scheduler will be in control until it terminates or sleeps. Other processes will message the scheduler process and wait for the scheduler to yield control of the processing unit. After task completion, the process in control will sleep and control will be handed back to the scheduler process.

Other high priority processes include processes that monitor the limit switches, motor currents, and the lumbar support volume. The first two of these processes check and prevent the adjustable sections of the chair from exceeding the allowable range of motion and will cut off the power to the motors upon detection of unusually high motor currents or extreme movement positions. The lumbar support volume process reads the flow sensor to calculate the rate of air going into and out of the lumbar support. This process is also responsible for discretely integrating the rate of airflow to find the current volume of the lumbar support and to regulate the maximum allowable size of the lumbar support.

Next in priority are the optical encoder and the motor feedback control processes. The encoder process is responsible for counting the encoder pulses and calculating the angular speed of the motor for use in the motor feedback control. The motor feedback control process ensures that the motors are responding accurately to commands. The feedback control process takes into account the speed and the position of the motors to determine the amount of adjustment required by the motors in order to satisfy the motor commands.

The medium priority processes are the user control process and the main process. The user control process determines which buttons have been pressed and sends the user commands to the main process for determination of the next action. The main process examines the chair's current state and determines the next action that needs to be performed. The main process is described in more detail in the next section.

The low priority processes include one for displaying information and one for reading the various onboard sensors. The display process communicates with the LCD and controls the status LEDs that notify the user about the current state of the chair. The different sensing processes include the sensing of load, lumbar support pressure, armrest width, armrest height, and user presence. They send the interpretation of the sensor readings to the main process.

9.3.1 Main Process

The main process carries out the automatic adjustment sequence. The flowchart for the automatic adjustment sequence is shown in Figure 16.

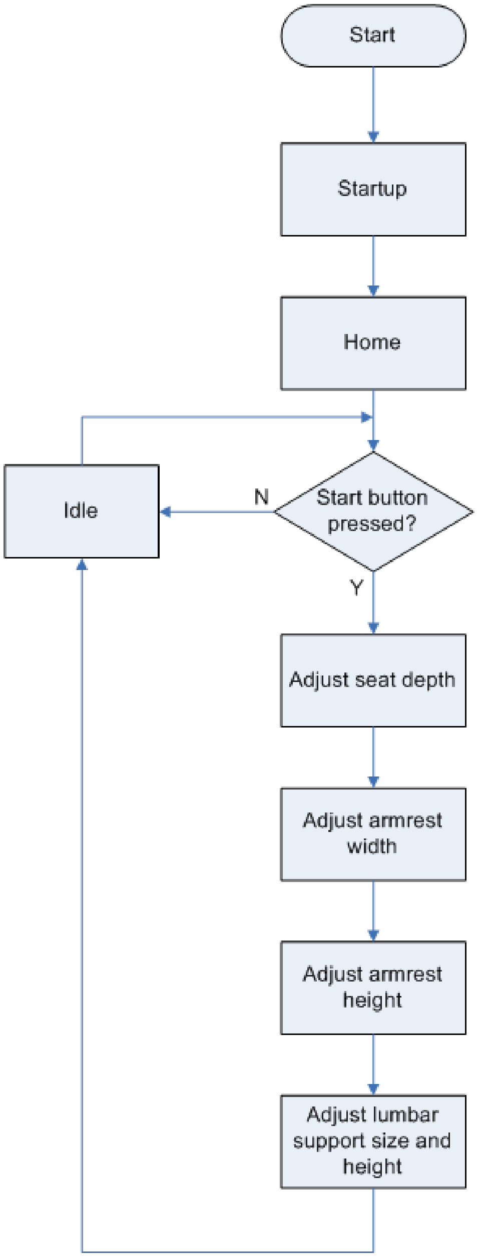

Figure 16: Automatic Adjustment Flowchart

When the power is turned on, the main process starts running. During startup, the motors are initialized. Then, the main process creates the threads for the other processes stated in Table 6 and starts the scheduler. The LCD displays the status of the chair and is accompanied by a lit LED.

After startup is complete, the main process will home each adjustable part, one at a time. The backrest will move backwards so that the seat depth is at maximum. The armrests will move to the lowest and widest point. The lumbar support will move to the lowest position and deflate if not already deflated. During homing, the user may push the start button to start the adjustment, but the adjustment will only start once homing has completed. Ideally, the user should only push the start button after they manually adjust the seat height.

Once homing is complete, the chair will enter an idle state where it waits for the user to indicate automatic adjustment or manual adjustment through the manual control buttons. If the user pressed the start button during homing, then the adjustment begins immediately, skipping the idle state.

The main process first starts adjusting the seat depth. It gives up control of the CPU to the load-sensing process so that the load-sensing components on the backrest can be read. Once the load-sensing components have been read, control returns to the main process. If the load-sensing components indicate that the user's back is already on the backrest, then no further adjustment needs to take place. Otherwise, the main process moves the motor to turn the screw, which will push the backrest forward by 20 mm, the minimum adjustment increment as indicated in Table 1. This process is repeated until the user's back is rested on the backrest.

The next adjustment is the armrest width adjustment. Similar to the backrest adjustment, the main process yields control to the armrest width determination process so that the distance sensors can be read. If the sensors indicate that the armrests are not yet below the user's arms, control returns to the main process which simultaneously moves the both armrests toward the user by 5 mm each, as specified in Table 1. The steps are repeated until the armrests are under the user's arms.

After the armrest width is adjusted, the armrest height adjusts next. The main process lets the armrest height determination process read the switches. If the switches are not toggled yet, then the main process regains control of the processor and moves the armrests up by 5 mm. The steps are repeated until the switches are firmly pressed, indicating that the armrests are at the correct height.

The lumbar support is adjusted next. Unlike the other adjustments, the lumbar support size and height adjustment will occur together. The main process allows the lumbar support volume process to run. The lumbar support volume process then reads the flow sensor to check that the volume of the lumbar support can still be increased. Next, the pressure sensor is read to determine whether the pressure has reached a predetermined comfortable pressure, X. If this pressure has not been reached, the lumbar support pressure increases to this pressure. The load-sensing process then reads the two load sensors mounted on the lumbar support to see if the forces on the top and bottom of the lumbar support are balanced. If the force is unbalanced and the user is not yet supported by the lumbar support, then the height increases by 5 mm. The entire process repeats until pressure X has been reached and the load-sensing components give equal readings, signifying that the lumbar support supports the user's lumbar area entirely. A flowchart for this process can be found in Appendix B: Lumbar Support Process Flow Diagram.

After all the adjustments are finished, the chair returns to the idle state, waiting for the user to indicate another automatic adjustment or a manual adjustment.

During the adjustment process, whether automatic or manual, pressing the stop button will halt adjustment. Also, since all processes are initialized, interrupts may be triggered by user input or by the user leaving the chair. While the chair is adjusting, interrupts from the power button will be ignored.

If, during the automatic adjustment process, the user should press a button for manual control, the first step is to stop the adjustment of the current part. The second step is to adjust the part in the direction specified by the user. When the user stops pushing the button, the part stops moving and the main process waits for one second. If no further input is detected during this time, the automatic adjustment begins on the next part.

When the user leaves the chair, the adjustment process aborts after 20 minutes[1] and the chair returns to the home position.

10 User Interface Unit

The user interface allows the user to manually control the adjustable parts. It consists of 4 pairs of buttons for moving the armrests, seat depth, and lumbar support height. It will also have a dial to finely adjust the lumbar support size. The user interface will also feature an LCD and LEDs for displaying messages to the user and for debugging. The interface will be mounted near the armrests.

10.1 User Interface Hardware

The hardware will consist of the LCD, LEDs, buttons, and dials.

10.1.1 LCD and LEDs

The LCD will display status and error messages. LEDs will be used for the status of each adjustable part. Both LCD and LEDs will be used for debugging purposes.

The data from the microcontroller will be formatted for display on the LCD and then prepared for transmission using a USART. The USART on the microcontroller will be used to convert the parallel data from the microcontroller to serial data for the LCD to display.

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[1] Determined by Accomodarsi Solutions as the time taken for a long coffee break.

10.1.2 Buttons

Each adjustable part except the lumbar support size will be adjusted using two buttons. Table 7 lists all the user input functions and the number of buttons associated with each.

Table 7: Button Specifications

Function	Number of buttons
Armrest height adjustment	2
Armrest width adjustment	2
Seat depth adjustment	2
Lumbar height adjustment	2
Start	1
Stop	1
Power	1
Debugging	4

10.1.3 Dial

The lumbar support size will be adjusted using a dial. We decided to use a dial to control the lumbar support size manually because it is more intuitive and has more degrees of freedom in adjusting an air pocket than a pair of buttons.

10.2 User Interface Software

The software will take the inputs from the buttons and dial and process them. Within 500 ms, the adjustment that corresponds to the pressed button or turned dial will be made [1].

10.2.1 Button Identification

The buttons will be mapped to interrupts so that when they are pressed, an interrupt service routine will execute to determine which button was pressed. In order to properly read a button input, the button input must be first debounced. Debouncing can be done by introducing a small delay before sampling the button input. The required delay time will be determined through testing.

10.2.2 Dial Identification

The dial adjustment increments will also be mapped to interrupts, like the buttons. Unlike the buttons, no debouncing is required for the dial.

10.2.3 Display

The LCD will display information to indicate which part is currently being adjusted. Any status changes over the course of the chair adjustment will be reflected on the LCD and LEDs. If any errors occur, the software will use a look-up table to determine which error occurred and display the appropriate message.

10.3 User Interface Verification

To test the user interface, we must perform the following tests.

1. Pushing the buttons and turning the dial cause an interrupt to occur.
2. Display error messages on the LCD.
3. Light the LED corresponding to a part, and display the status of that part when it is being adjusted.
4. When the Power, Start, and Stop buttons are pressed, the corresponding LED is lit and the LCD displays a message.

11 System Test Plan

The five adjustable parts of the chair will be tested first. After individual part testing is finished, the ideal operation of the automatic adjustment of the chair is examined as well as other normal and extreme cases.

11.1 Unit Testing

To verify that the adjustable parts of the chair are working properly, we plan to test each adjustable part separately. To confirm that a part is adjusted properly, the following tests must be performed.

1. Activate the sensors and actuators only for the part that is being tested, leaving all others off.
2. Start the automatic adjustment process for a test subject such that only one part will home and adjust to a final position.
3. Monitor the sensors and verify that they are able to send a signal to the input signal conditioning unit.
4. Verify that the input signal conditioning components relevant to the sensors are able to take that signal and pass it to the CU.
5. Verify that an output signal is passed to the output signal conditioning components relevant to the actuators.
6. Monitor the actuators and verify that they are moving within the adjustment range
7. Observe the adjustment time and compare with the target adjustment time specified in Table 1.
8. To test the maximum adjustment range, move the part manually using the user interface and make sure that the limit switches are triggered when trying to adjust past the maximum. In the case of the lumbar support, ensure that the pressure relief valve activates when the dial is turned to the maximum.

11.2 Normal Case 1: User in Correct Sitting Position

User Input: The User presses Start.

Conditions: The User is sitting with a straight back, arms by their sides, and elbows flexed at 90°. The User is also sitting in the chair as far back as possible with a little space (about 10 cm) between the seat and back of the knees. The User has already adjusted the seat height and turned the power on.

Expected Observation: The armrests, backrest, and lumbar support move to the home position if they are not homed yet. The adjustment proceeds as shown in the flowchart in Figure 16.

11.3 Normal Case 2: User in Slouching Position

User Input: The User presses Start.

Conditions: The User is slouching such that his back is not in contact with both the top and bottom of the backrest.

Expected Observation: An LED lights up and the LCD displays a message that the user is slouching. The light continues to be on until the user straightens his back. Once the user readjusts, after a few seconds the adjustment proceeds as in Normal Case 1. The LED turns off.

11.4 Extreme Case 1: Motor Limit Switch is Activated

User Input: The User presses the + button for the armrest height multiple times until the maximum height is reached.

Conditions: The User is sitting normally in the chair after the automatic adjustment is done.

Expected Observation: An LED lights up and the LCD displays a message that the maximum armrest height has been reached. The motor that adjust the armrest height stops. The LED turns off.

11.5 Extreme Case 2: Maximum Pressure inside the Lumbar Support

User Input: The User turns the dial to the maximum so that the lumbar support size is as large as possible. The User then leans back on the lumbar support.

Conditions: The chair has stopped automatically adjusting. Or, the chair is in the process of automatically adjusting the lumbar support size and height.

Expected Observation: An LED lights up and the LCD displays a warning message that the pressure is too high inside the lumbar support. The lumbar support deflates as air is released through the pressure relief valve. The LCD displays a message that the pressure is normalized and the LED turns off.

12 Conclusion

The proposed design solutions to meet the functional specification of the ACE chair have been discussed in this document. During the actual development, these design specifications will be adhered to as much as possible to meet the functional specification. Through the test plans included in the design specifications, we can ensure that all the required functionality of the chair is present. The design specification provides clear goals for the development of the chair prototype.

Appendix A: Mechanical Drawings

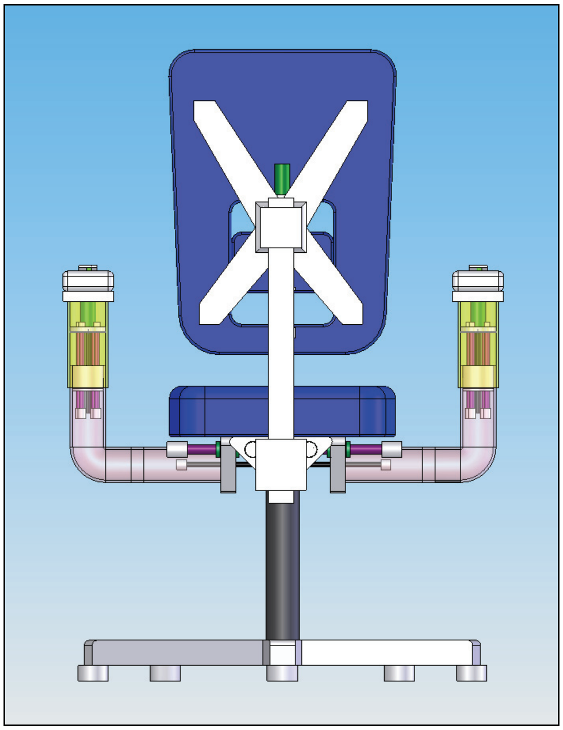

Figure 17: Mechanical Overview of the ACE Chair (Back view)

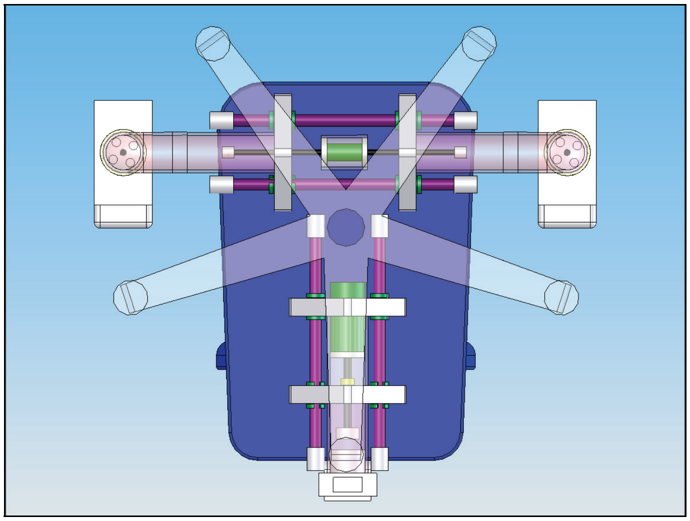

Figure 18: Mechanical Overview of the ACE Chair (Bottom view)

Appendix B: Lumbar Support Process Flow Diagram

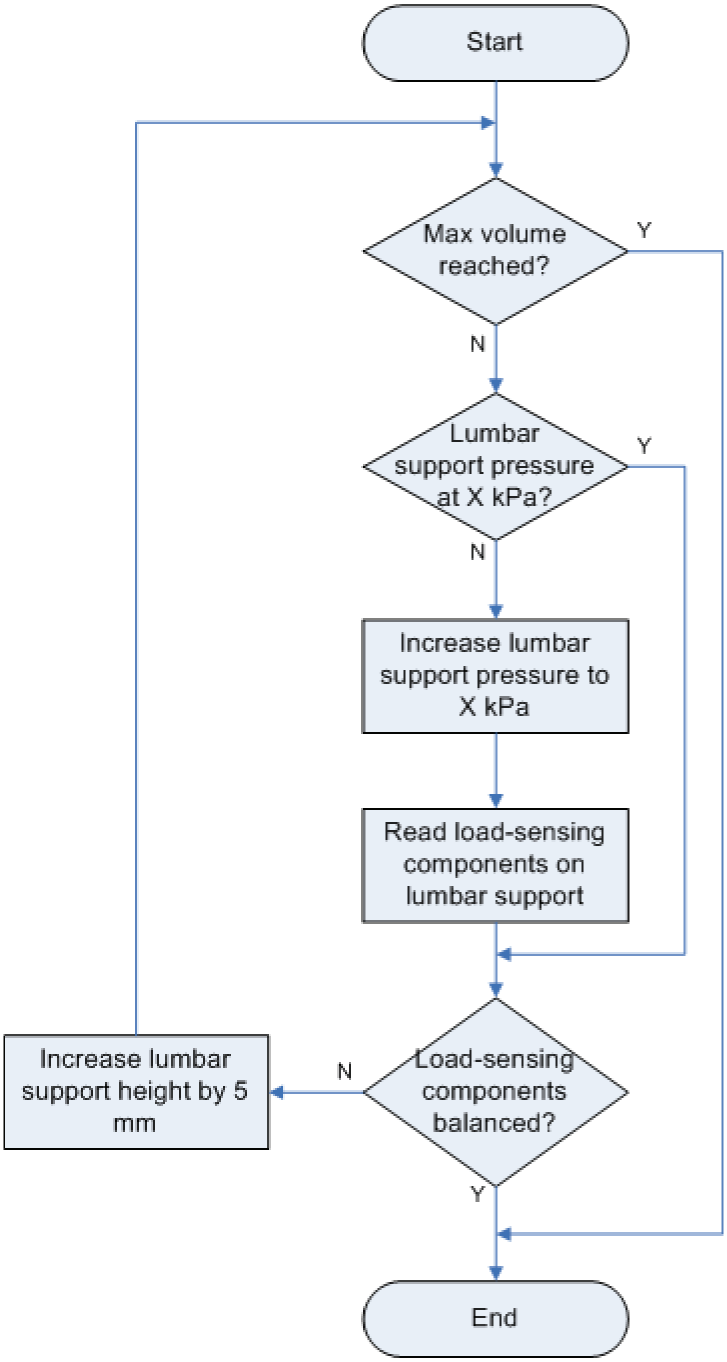

Figure 19: Lumbar Support Adjustment Flowchart

For the block labelled “Increase lumbar support pressure to X kPa”, the pressure X will be determined experimentally to be the pressure at which the back support feels comfortable if it is already at the correct height.

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