Smart Ladder

Project Proposal

TA: Luke Wendt

Bradden Pesce : bpesce2

Lingying Cai : lcai12

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1. Introduction

1.1. Statement of Purpose

Improper use of ladders often causes them to fall and this is a safety hazard in both the workplace and around the home. Falls are one of the leading causes of injury mortality, and according to the CDC 43% of all fatal falls involve a ladder; there are around 30,000 injuries per year from falling ladders based on numbers from previous years. Our ladder solves this problem by first determining the center of gravity of the ladder relative to the base of stability, and then displaying how close the ladder is to falling. The user would also be warned if certain conditions for using the ladder are not ideal such as cold temperatures and weight surpassing the ladder rating. Currently there is no way for someone to know how stable the ladder they are using is or if they are pushing the ladder too far.

1.2. Objectives

1.2.1. Goals and Benefits

1. Prevent ladder related injuries due to falls from improper use
2. Increased work efficiency from stability assurances
3. Prevent users from using the ladder if the conditions are unsafe before use
4. A user would be able to use the ladder if placed on both four and two legs

1.2.2. Functions and Features

1. Determine center of gravity relative to the base stability of the ladder
2. Calculate and display a percent margin of stability
3. Audibly warn the user if the margin of stability is below 50%
4. Sound override button to disable the warning
5. Detect and display with an LED if the temperature outside is below freezing
6. Detect the user's weight and active a LED if too much weight is being applied
7. If the user climbs too high a switch will trigger to warn them not to continue
8. Power management system
9. The ladder will be 11 ft tall on two legs and 5.5 ft tall on four legs.
10. If the angle between the ladder and the surface it is leaning against is greater than 75.5° then the ladder is unsafe based on OSHA regulations and the warning will activate.

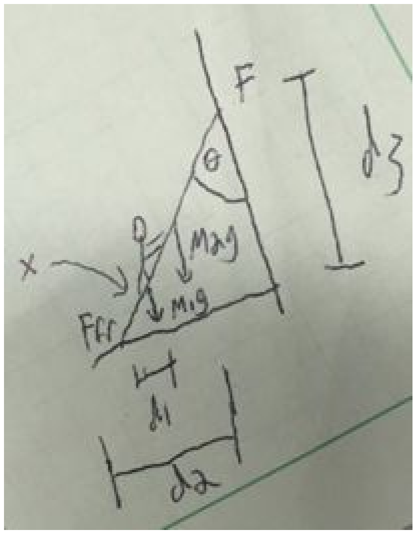

Figure 1: Scenario One where ladder is on two legs

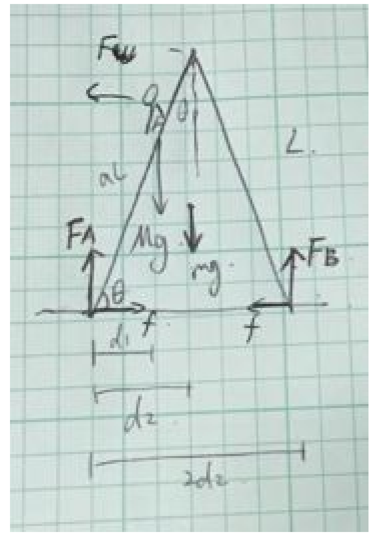

Figure 2: Scenario Two where ladder is on four legs

2. Design

2.1 Block Diagram

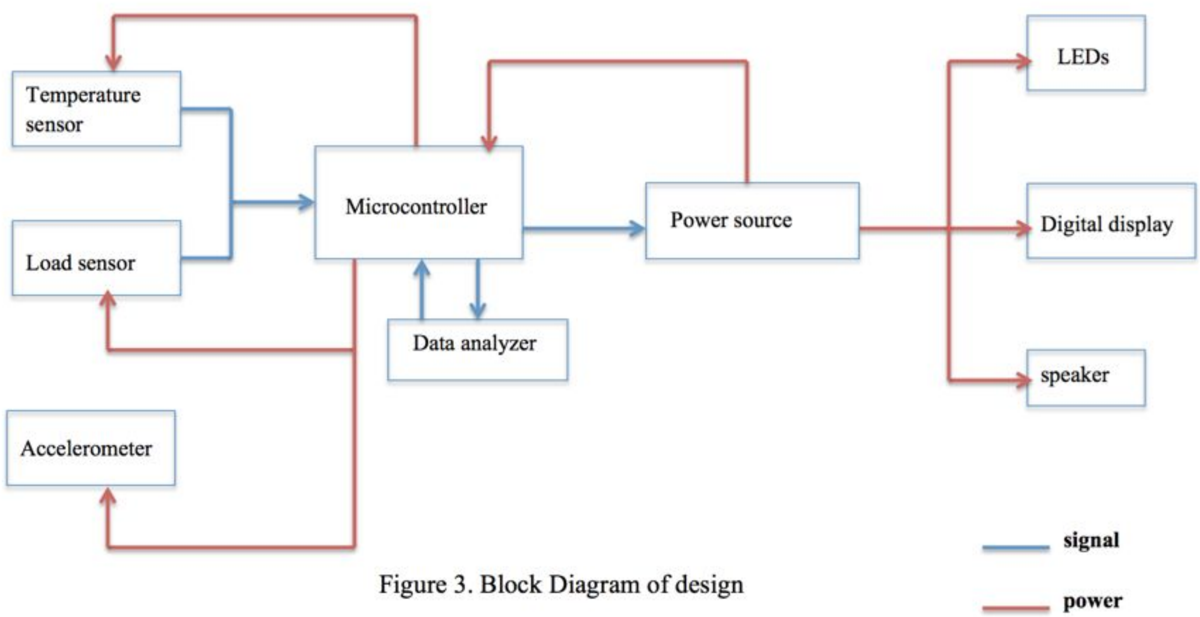

Figure 3. Block Diagram of design

2.2 Description of Blocks

2.2.1. Microcontroller

Temperature sensor and load sensor will be connected to microcontroller. Then it will analyze the data and determine whether the ladder is safe or not and send a signal to LED, Digital Display and speaker. This part is important because it will analyse the data collected by temperature sensor and load sensor and determine the degree of safety of the ladder.

2.2.2. Data Analyzer

This module receives and stores data from the microcontroller and uses the information in computing the center of gravity of the ladder relative to the base stability; the safety margin of the ladder is computed and the signal goes back to the microcontroller.

2.2.3. Temperature Sensor

We will use this sensor to detect if the temperature outside is v in order to warn the user that there could be ice present on either the ground or the ladder. This sensor will be connected to the microcontroller that will send a signal to a blue LED if the conditions outside are too cold.

2.2.4. Power Source

The power source will have a switch which will be controlled by a signal sent by microcontroller. If the switch is on, the LED, digital display and speaker will show their behaviors respectively. i.e. blue LED will be turned on if outside is too cold, red LED will be turned on if there is too much weight on the ladder, digital display will show the safety and speaker will be on if the condition is considered as unsafe.

2.2.5. Load Sensors

We will place load sensors at the base of the ladder in order to detect the directions of the all the forces being applied, including gravity. This information will be used to detect the center of gravity of the ladder relative to the base of stability and will be sent to the microcontroller. More load sensors are going to be placed on the first step of the ladder to determine if the ladder can handle the weight of the person and whatever they might be carrying. These sensors are also connected to the microcontroller.

2.2.6. Digital Display

This module will receive a signal from the microcontroller to display to the user how safe and stable the ladder currently is. If the center of mass of the ladder is completely stable, a 100% reading would be displayed; if the ladder is falling 0% would be displayed.

2.2.7. LEDs

There will be two LEDs; the first would be blue and would only be on if the temperature outside is below 0°C. The second would be red and would only be on if there is too much weight being applied on the ladder's first step than it would theoretically be able to handle. Both of these LEDs would receive their signal from the microcontroller.

2.2.8. Speaker

This module will receive a signal from the microcontroller if the ladder is reaching a point of about 50% its safety margins where it would be close to falling. It will then play a warning to the user to caution them that the ladder will fall if they continue.

2.2.9. Accelerometer

This modules is used to determine the gravity vector of the ladder. It is also used to determine if the angle the ladder makes with the wall is within OSHA regulations of 75.5° by measuring the static acceleration due to gravity.

2.2.10. Switches

This module determines which rung of the ladder the user is currently on in order to determine the height of the center of gravity and then sends this information to the microcontroller. There will be a switch on each rung, and a signal will be sent when the switch is triggered.

3. Requirements and Verification

3.1. Requirements and Verification Table

Requirements	Verification	Points
1. Load Sensors: Must be able to determine the value and direction of all the forces acting on the base of the ladder and on the first step of the ladder. The tolerance is within +/- 0.035 kg.	Load Sensors: Use a force gauge to determine an applied force and compare it to the value measured from the load sensor by measuring the current change due to added resistance by using a ammeter.	20
2. Load Sensor: The load sensor on the first rung of the ladder must be able to determine the user's weight within +/1 0.035 kg.	Load Sensor: Use a force gauge to determine an applied force and compare it to the value measured from the load sensor by measuring the current change due to added resistance by using a ammeter.	5

3. Temperature Sensor: Must be able to determine if the temperature outside reaches values below 0°C with +/- 5% accuracy.	Temperature Sensor: Compare the data obtained from the sensor with the official temperature outside.	5
4. Data analyzer: Must analyze the data collected from microcontroller, calculate how close the ladder is to falling with the center of gravity relative to the base of stability, and then provide an appropriate percentage within +/- 1% to send back to microcontroller. It must also reduce the safety margin by 1% to account for the tolerance error of the load sensors. i.e. The ladder will never read 100% safe; 99% would be the maximum value displayed.	Data analyzer: Theoretically work out the safety margin percentage based on the current stability of the ladder and insure the value that the data analyzer calculates is within the required tolerance.	15
5. Microcontroller: must send appropriate threshold voltages to activate the loads such as LEDs, digital displays and speakers. Power to the circuit board elements is controlled through transistor gates.	Program the microcontroller to send a HIGH to turn on LEDs, digital displays and the speaker.	25
6. Power Source: Must be able to provide a 9V +/- 0.9 V DC output for the digital display, a 3V +/- 0.2 V DC output for the LEDs, and a 2V +/- 0.1 V DC output for the speaker.	Power Source: Measure the current across a resistor and if the measured values are within the theoretical values then the power source is operating correctly.	5

7. Power Source: Must be able to last an 8 hour workday before needing to be recharged.	Power Source: Turn on all the devices at once and determine how long the battery lasts.	5
8. Accelerometer: Must be able to determine the gravity vector acting on the ladder and the angle the ladder makes with the ground with a tolerance of +/- 10% or 100 mg.	Accelerometer: Physically measure the angle the ladder makes with the ground and compare to the accelerometer signal value: as the sensor is rotated about a single axis, the values of one axis should increase and another axis should decrease.	10
9. Speaker, Digital Display and LEDs: Must all turn on at the appropriate time. i.e at 50% safety, if too much weight is applied on the ladder (200 to 375 pounds depending on ladder rating), or show the percentage of safety, or if the temperature is below 0°C.	Speaker and LEDs: Measure the theoretical values and compare to the value displayed and see if the signal should or should not be sent.	5
10. Switches on Rungs: Must be able to determine if the user is currently on which rung of the ladder.	Switches on Rungs: If a person steps on a rung, a high signal should be sent to the microcontroller to determine the user's position on the ladder.	5

4. Tolerance Analysis

The load sensors matter the most because they provide the information to determine the center of gravity of the ladder. There would be a major flaw if the digital display shows that the ladder is safe for use but it still falls, and therefore it is important to know how the tolerance will affect the safety margin outcome. The tolerance is determined from the two scenarios further below. To test the tolerance we would first use a force gauge to determine an applied force of an object. We would then use an ammeter to detect a change in current from changes in resistance due to pressure being applied to the load sensor; since the pressure from the load sensor is proportional to the change in resistance, we can convert to Newtons and compare it to the force gauge to see if the specified tolerance is achieved.

4.1. Scenario One: Two legs (figure 1)

If the ladder is placed on two legs against a wall, then the force of the ladder against the wall must be greater than the force of the ladder against the base or the ladder will slip and fall. We would use load cells at the base of the ladder to determine the total force acting on the base. This value is then compared with the equation: $F = (M1 * g * x * sin\theta + M2 * g * (1/2) * sin\theta) / cos\theta$ where F is the force of the ladder against the wall; M1 is the mass of the user which is determined by a load cell placed on the first rung of the ladder; x is the fraction of the ladder height the user is currently located which is determined by switches placed on each rung of the ladder (if the user is on two rungs at one an average is taken); θ is the angle the top of the ladder shares with the wall; M2 is the mass of the ladder which is equal to 10 kg for the ladder we plan on using and 3 kg more for all the sensors and components added on; g is gravity and equal to 9.8 m/sec^2.

For the sake of determining the tolerance effect, M1= 70 kg, θ = 14.5° (based on the angle with the base being 75.5°, which is the maximum angle allowed for safety), x = 0.73 (based on the maximum height the person of this weight can theoretically climb before the ladder will slip and fall based on the total force acting on the base which would be around 162.68 N if the friction coefficient is 0.2: Ffr = g(M1+M2) * μ), and in a worst case scenario the friction against the wall would be 0. The total F = 162.46 N. The percent safety margin for this specific scenario would be 0.1352% safe with no tolerance. Since the load cells we are using have a maximum error of 0.05%, the mass of the person would be detected as 70 kg +/- 0.035 kg. Plugging in 70.035 kg instead of 70 kg in the above equations with all other parameters the same yields F = 162.52 N and Ffr = 162.75 N; the safety margin would now read 0.1405% safe. The difference between the two safety margin values is about 0.0053%, and therefore our tolerance would be +/- 0.005%; This value is extrapolated a tolerance of +/- 1% which will cover all possible unaccounted for sources of error.

4.2. Scenario Two: Four legs (figure 2)

If it is a step ladder with four legs. We can compute the total torque of the system:

$$\sum \tau = \sum r \times F = M1*g*x*L*sin\theta + M2*g*L*sin\theta - F_B*2*L*sin\theta - F_w*x*L*sin\theta = 0$$

M1 is the mass of the user which is determined by a load cell placed on the first rung of the ladder; x is the fraction of the ladder height the user is currently located which is determined by switches placed on each rung of the ladder (if the user is on two rungs at one an average is taken); θ is the half angle between two legs; FB is the supportive force of the side without the user $FB = g*(M1*\mu + M2)/2$, and is found from load cells; FA is the supportive force of the user side $FA = (1-\mu/2)*M1*g + (1/2)*M2*g$, and is also found from load cells. The formula for scenario one is now changed to: $Fw = (M1*g*x*sin(\theta) + M2*g*sin(\theta) - FB*2*sin(\theta))/(x*cos(\theta))$; M2 is the mass of the ladder which is equal to 10 kg plus 3 kg for the ladder and devices; g is equal to 9.8 m/sec^2. To prevent rotation of the ladder, we need to make sure Fw + FB is small enough so that the total torque is equal to zero.

For the sake of determining the tolerance effect, M1= 70 kg, θ = 14.5° (based on the angle with the base being 75.5°, which is the maximum angle allowed for safety), for this scenario x = 0.73 was chosen as before for tolerance measuring; if the friction coefficient is 0.2, then FB = 132.3 N, FA = 681.1 N, and Fw = 128.806 N. If FA is greater than the sum of FB and Fw then the ladder will rotate about the point where FA is located and fall. The percent safety margin for this specific scenario would be 61.7% safe with no tolerance. Since the load cells we are using have a maximum error of 0.05%, the mass of the person would be detected as 70 kg +/- 0.035 kg as before. Plugging in 70.035 kg instead of 70 kg in the above equations with all other parameters the same yields FB = 132.33 N, Fw = 128.873 N, FA = 681.41 N, and a safety margin of 61.67% safe. The difference between the two safety margin values is about 0.03%, and therefore our tolerance would be +/- 0.03%, and a tolerance of +/- 1% would be extrapolated as in scenario one which will cover all possible unaccounted for sources of error.

5. Cost and Schedule

5.1. Cost Analysis

5.1.1 Labor Costs

Name	Hourly Rate	Total Hours Invested	Total Labor Costs (Hourly Rate * 2.5 * Total Hours Invested)
Brad	30.00 $/hour	225	$16,875.00
Lingying	30.00 $/hour	225	$16,875.00
Total		450	$33,750.00

5.1.2. Parts

Item	Quantity	Total Cost
25SP015 0.1 Watt Speaker	1	$4.26
Adafruit 878 LED 7-Segment Digital Display	1	$9.95
1PCX 200 kg Load Cell	5	$75.72
LED 117 Blue LED	1	$0.55
HLMP1340 Red LED	1	$0.12
CAT# TS-12 Digital Temperature Sensor from -55°C to 125°C	1	$5.75
MSP-EXP430G2 Microcontroller	1	$10.00
ADXL362 Accelerometer	1	$14.95
#00001 Black Foot Switches	12	$36.00
Total		$157.30

5.1.3. Grand Total

Section	Total
Labor	$33,750.00
Parts	$46.63
Grand Total	$33,796.63

6. Weekly Schedule

Week	Task	Responsibility
Sep 12	Finish Project Proposal	Brad
	Finish Project Proposal	Lingying
Sep 19	Order sensors, devices, and ladder	Brad
	analyze the data(figure out formula)	Lingying
Sep 26	Run tests on sensors	Brad
	Begin microcontroller	Lingying
Oct 3	Implement and test power source	Brad
	Design the data analyzer (program part)	Lingying
Oct 10	Finish microcontroller	Brad
	Test external devices (speaker, display, LEDs)	Lingying
Oct 17	Assemble prototype circuitry	Brad
	Test prototype circuitry	Lingying
Oct 24	Write the individual progress and R&V table	Brad

	Write the individual progress and R&V table	Lingying
Oct 31	Solder modules together	Brad
	Solder modules together	Lingying
Nov 7	Prepare for/finalize mock demo and R&V table	Brad
	Prepare for/finalize mock demo and R&V table	Lingying
Nov 14	Run tests on final project	Brad
	Finalize software changes	Lingying
Nov 21	Solve Final Issues	Brad
	Solve Final Issues	Lingying
Nov 28	Final Demos and Presentation	Brad
	Final Demos and Presentation	Lingying
Dec 5	Final report	Brad
	Final report	Lingying