1- Introduction

1.1- Objective

Currently, indoor running at treadmill plays a significant role in people's daily life. However, running at treadmill is not as safe as road running due to the inherent nature of a machine dictating the speed of people's stride. Thus, it is a common behavior for gym patrons to hold on the rails of treadmill in order to get the sense of safety. Although there are tons of protective features on treadmill, including safety clips (used to break the circuit connection to the belt), several stop buttons and handrails, it is still very difficult to get rid of the fear of losing balance at the high-speed belt after long-term running. Specifically, the key issue triggering the sense of unsafety is the lack of natural speed control, which restricts runners to reach out to the control board to adjust the belt speed. However, after long-term running, if exhausted runners do not adjust the speed appropriately, it might be very dangerous when losing balance.

Our solution to this problem is to build the treadmill that automatically matches the gait of the runner. Upon start-up, the belt will have a slow initialization speed. The treadmill will then naturally control the belt speed according to runner's speed and position on the belt. Specifically, we divide the belt into three areas: at the front area, the control system will increase the belt velocity; if the runner is at the rear area, the belt will slow down in response. The center of the belt will be the zero position, indicating the current speed is comfortable for runners. The system also adjusts the velocity of the belt based on the runner's velocity relative to the belt, accelerating and decelerating in response to a difference. This natural speed control system will prevent unexpected injury because the system will increase the belt speed in pace with the runner which allows them to warm-up, and to not be forced to run at a predetermined pace, allowing for a run that feels more natural, and is safer.
1.2- Background

Historically indoor vs outdoor running has been a subject of debate on a variety of different fronts. Most evident is the fact that outdoor running tends to be considerably more challenging due to the forces that are needed to be generated by the runner to accommodate velocity changes. While the debate of whether one is more challenging or better than the other remains questionable, the fact that the two differ in execution is not up for debate. The evident presence of the electromechanical devices predicates the necessity for the user to tamper with these devices while moving. This being an evident deterrent to a hardcore outdoor runner may be part of the reason why so many exercise enthusiasts avoid the usage of a treadmill. Yet, despite this disparity among elite athletes vs the average runner this does not diminish the popularity of this piece of equipment. According to the Consumer Report Safety Commission, over 50 million Americans use a treadmill for activity needs [1]. This being the case, there is clearly a large interest in the treadmill as a viable piece of exercise equipment among the fitness community.

In addition to the popularity of the treadmill there is, more importantly, the risk of injury associated with its use. There are plethora of articles and information related to treadmill related injuries such as there being over 70,000 mechanical exercise based injuries between the years 2007 and 2011 [1]. While the numbers are not as high as say automobile related injuries, there is still reason for concern especially considering the easy access to young children. While there are a number of safety mechanisms embedded in the electromechanics of a current day treadmill, it does not eliminate the need for safety concerns.

1.3- High-Level Requirements

- Sensor subsystem must be very accurate and report the data in real time for quick adjustment of the belt speed
- Control system schema must eliminate latency on feedback within reasonable controllability (responsive)
- Motor should be able to rapidly approach normal human jogging speed (approximately 5mph) within 1 to 3 seconds based on user velocity and acceleration.
- System must stop within 1 to 3 seconds depending on current velocity when nothing is detected by sensors, when sensors detect that the user is standing still, or when the stop button is pressed.
2- Design

A traditional treadmill needs three central components to function: a power supply, a control unit, and a motor. Treadmills typically take in power via a wall outlet and pass it through an AC/DC converter that supplies the controls unit with 5V, and a variable amount to the motor based on input from the control unit. In the control unit, we process data from four different sources to produce a single output signal that will adjust the velocity of the motor. Finally the motor will take in a range of voltages from the power supply and drive the treadmill, whilst feeding back its current velocity data to the control unit.
2.1- Power Supply

The power supply will take power from a wall outlet, which is a 120v, 60Hz AC Source, and output 5v to power the control unit, and 5-20v to power the motor.

2.1.2- Controls Voltage Regulator

The controls voltage regulator will need to be an AC/DC adapter that steps down the wall outlet voltage.

Requirement: Must be able to convert a 120v AC signal to an approximately 5v DC signal, since the output signal must be able to power a microcontroller, we use an ATmega328p as an example.

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<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
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<tbody>
<tr>
<td>Must be able to convert a 120v AC signal to within .25v of 5v DC.</td>
<td>Use a voltmeter to read across the output terminals of the regulator to see if they read between 4.75 and 5.25v.</td>
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2.3- Motor

The motor will take in voltage values from the supply unit, and respond accordingly in a timely manner, whilst also providing data related to its current rotational speed to the microcontroller.

Using a Minertia small size DC p-series (P09S) servo motor we will not need to use a driver. The motor will be rated at a max voltage of 23.8V with a max torque of .5N*M at approximately 4000rpm. We wish to use a high RPM low voltage motor as they tend to be cheaper and it is relatively easy to control the speed of them.
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<td>1) Motor must be able to adjust to a range of input voltages between 5 and 20v within a timeframe of less than 10ms.</td>
<td>1) a. Attach input terminals of motor to a DC power supply. b. Attach output of encoder to the microcontroller, and attach that to a PC to read total output. c. Vary the value of the power supply from 5v to 20v, changing the step size from 1v up to 5v, and record via data from the encoder how quickly the motor reaches a steady state value, and make sure the maximum time frame any step requires to adjust speed is at most 10ms.</td>
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<tr>
<td>2) Motor must be able to move up to a minimum max speed of 10mph.</td>
<td>2) a. See steps 1-a and 1-b b. Set the power supply to 23.8v. Make sure the steady state output read by the encoder is greater than or equal to 10mph.</td>
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2.4- Supporting Material

![Figure 3. DC motor Speed-Torque characteristics](image)

Figure 3. DC motor Speed-Torque characteristics [8]
2.5- Tolerance analysis

The most important tolerance to keep track of in our system will be in our sensors. We will be comparing different sensors in different configurations to determine a setup that best suits our needs. The two types of sensors we wish to test are laser and ultrasonic sensors, and there are three different configurations we will test with in mind. A single sensor at one of the rear corners, two sensors at both rear corners, and four sensors occupying each corner. Because the data we actually need is how far the user is from the rear of the treadmill, we will take the data from the sensors and put them through a few equations:

For a rear sensor

\[ \text{Distance} = \sqrt{\text{SensorData}^2 - (18\text{''})^2} \]  
Eq.1

For a front sensor

\[ \text{Distance} = 36\text{''} - \sqrt{\text{SensorData}^2 - (18\text{''})^2} \]  
Eq.2

Then average the different distance values.
In order to compare the data from these various configurations, we need a base, objective value to compare their outputs to. To achieve this we will use a simple tape measurer, attach the tape end to the object whose distance is being measured, attach the other end to the rear center of the treadmill, then move the object whilst capturing the measurements on video. Then compare the real values found via this method to the test values using the following equation:

$$\text{Error} = \frac{\text{RealDistance} - \text{FinalDistance}}{\text{RealDistance}} \times 100\%$$

Eq. 4

If the error value for a given sensor/configuration is outside of 5%, then it falls outside of our tolerance range, and we don’t use it.

5- Ethics and Safety

Treadmills pose a number of safety and ethical risks. The most readily apparent risk is the fact that people can easily get hurt on a treadmill, violating IEEE code of ethics #1: "to hold paramount the safety, health, and welfare of the public [...]" and #9: “to avoid injuring others [...]” [2]. On a typical treadmill people must match the speed of the treadmill, if the speed is too quick for them they will lose their footing and fall. The objective of our design is to help alleviate this issue by designing a prototype treadmill that will match the speed of the user, rather than forcing the user to match the speed of the tread. However in the event that a fall still occurs, we will ensure that safety rails to help catch the user and an emergency stop button is installed to help prevent it. In addition we will use our sensors to automatically stop the treadmill if it is sensed that the user is at a standstill or is no longer in view of the sensors. In addition, the testing procedure would be incredibly dangerous if we were to use a live subject, so for this reason we have opted to use a scaled down treadmill and an RC car to do testing, since no live subject will be needed that way.

Treadmills are also very large and difficult to move around, and since we will be making ours in a an environment shared by our peers, this could be seen as violation of IEEE code of ethics #10: “to assist colleagues and co-workers in their professional development [...]” [2], since we would be disrupting the work environment of our peers and possibly inhibiting their ability to do their work properly. As such we have decided to use a scaled down model of a treadmill to prototype our design, since this would greatly
reduce the footprint we have in the shared workspace. However, scaling down the treadmill may pose a problem with both IEEE code of ethics #1 and #9 as stated above, and in IEEE code of ethics #3: “to be honest and realistic in stating claims or estimates based on available data” [2]. This breach in ethics is caused by the fact that a treadmill at a smaller size such as this may not scale up to a human size and function correctly still, which means that if we scale it up without testing, it may bring harm to someone, and if we lie about the test results or the scalability of our system on a conceptual level, we would be violating those codes. As such we have decided to use an algorithm that uses positional tracking and velocity measurement to drive our control system, as that is a more linearly scalable system than if we were to use pressure or force detection.
References


