Scope of Work

Project F45 – Treadmill Platform for Quadrupedal Robots

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Abstract:

Cal Poly Legged Robots, led by Professor Revfem and Professor Xing, has been leading Cal Poly's attempts to simulate, produce, and test their legged robots. In developing these robots, the organization has reached the point where they need a reliable way to test the robots effectively (with proper data collection) and safely for both the robots themselves and those testing the robots. Our responsibility as a team is to deliver a platform that allows Cal Poly Legged Robots to test the locomotive capabilities of their robots with data acquisition and a built-in fail-safe mechanism to prevent damage to the robot or personal injury to those performing the tests. Thus far, we have done some preliminary research by interviewing both Professor Revfem and Dr. Xing, by performing technical research with relevant academic journals and patents, and by researching what has already been done by Boston Dynamics, MIT, the University of Zurich, and others. Additionally, we have created a tentative Gantt chart and generated the House of Quality as part of the QFD process to retain organization, fully understand the problem, and to design SMART Engineering specifications that will address all the customer needs and as many of the customer wants as possible. This will allow us to stay on track for the duration of this project and will give us a means to be able to test our design against others via our Engineering specifications. Through this process, we have identified that documentation regarding our methods and maintaining organization throughout is a quality that Professor Refvem and Dr. Xing hold with utmost priority and therefore it will be a priority for our group as we progress this project. Additionally, we have limited the locomotive capabilities of our platform to just forward locomotion under the guidance of Professor Refvem to maintain our timeline. We are creating this testing platform in hopes that it can allow Cal Poly Legged Robots to further the development of Legged Robots and to generate interest both at Cal Poly and hopefully around the world for this area of study that all members of our group have a passion for.

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Appendices

1. Introduction

The design challenge that is tasked to our group is to create a testing platform for the Cal Poly Legged Robots group. More specifically, the Cal Poly Legged Robots group wants a treadmill platform to test their quadrupedal robot. The platform is a testing platform, so it has ways for collecting data and benchmarking the performance of robot when it is performing different locomotion movements. The platform also needs to have a mechanism in place to ensure that the robot is operated safely and falls of the robot can be prevented. The members of our senior project group working on this design challenge are Mechanical Engineering ungraduated Baxter Bartlett, Jack Butler, Phillip Shafik, and Tarun Sreesaila Ganamur. All four of us are concentrating in mechatronics. The current stakeholders for this design project are Professors Xing and Revfem, and any future students who are a part of the Cal Poly Legged Robots group. Professor Xing and Professor Revfem are also the sponsors of this project and will be further referenced as the sponsors as well. The document will cover the background of the design challenge as well as the project objectives and will help with the future decision making for the design challenge.

2. Background

Legged locomotion can be conveniently described with gaits, or regimes of legged motion. Different gaits are only useful for certain things – a horse cannot gallop slowly. Animals switch between gaits on the fly according to their current needs. These gait changes are a major challenge of designing robust legged locomotion systems, due to their inherent instability [1], [2]. Additionally, testing is difficult, because a locomoting robot would need to be moving at a fairly high speed, and would risk falling [3], [4]. Because of this, robots are often placed on specialized treadmills to develop gait-change algorithms.

2.1 Stakeholders & Needs

The Cal Poly Legged Robotics Group has a unique set of needs. There are three main stakeholders for this project – Professor Refvem, Professor Xing, and future student workers on the robot. The needs of these stakeholders roughly fell into three categories: safety, documentation, and performance – examples of needs in each category are included in

Table 1. These needs were predominantly gathered via interview, in which both specific and open-ended questions were asked to quantify the problem. This sometimes yielded vague results, like “enough sensors to evaluate robot performance”. To bring in some specificity, we turned to our product research. Continuing with the same example, we searched academic journals and textbooks to determine which sensors were needed to evaluate the robot performance.

We still have more work to do investigating some of the specifics, namely the existing fall-prevention mechanisms and what sensors are most important for interfacing with the robot. There is a lot of grey area for both needs, and while it is very tempting to implement as many sensors as possible and the most complex fall-prevention mechanism we can, we also need to ensure that we do not bite off more than we can chew. In the coming weeks, we hope to narrow down the sensing requirements of the unit and determine a solid direction for a fall-prevention mechanism.

Table 1. Stakeholder Wants/Needs

Category	**Examples**
Safety	- Must not pose the threat of injury to operators - Must not pose a threat to its environment
Documentation	Must be easy for new operators to understand Must have documentation covering strengths *and weaknesses*
Performance	Must have a top speed of at least 6 mph Must interface with the Speedgoat over CAN

2.2 Existing Products/Solutions

Several universities have done their own work on legged robots and have developed their own treadmills. These range from desktop treadmills for fist-sized robots to treadmills the size of a room, for robots the size of a large dog. As they are all designed for different use cases, each has a unique set of strengths and weaknesses when applied to our own set of wants and needs. For example, because of our limited budget, our sponsors recommended we purchase a used treadmill and retrofit it for our purposes.

2.2.1 Treadmill

One requirement for our treadmill is that it must be modular, or able to support a wide variety of robots. MIT's large treadmill [5] is an excellent model for modularity – it is about the size of a small room, three or four feet wide, and can run faster than ours would need to (see Figure 1). Its size allows for it to accommodate a number of different robot designs, and also integrate things like obstacles for the robot to jump over. Our treadmill, however, cannot be nearly as big, as it needs to fit through a door and be easily moved for storage.

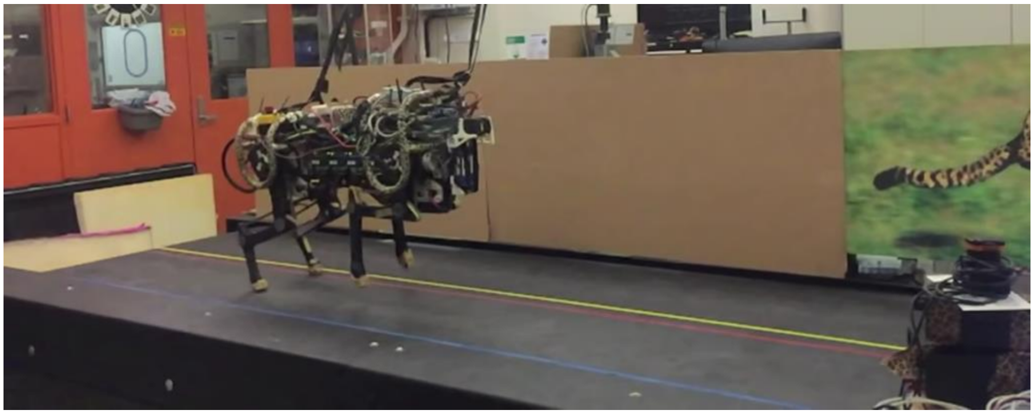


Figure 1. MIT's Bigdog running on their treadmill [5]

On the opposite end of the spectrum is the University of Zurich's treadmill [6]. As seen in Figure 2, it is small enough to fit on a tabletop, but does not reach nearly the speed we need, and is not quite as modular as we would like ours to be. Regardless, it is a masterclass in space saving – the belt goes nearly to the edges of the unit, and all of the electronics to run it are contained well within the small package. By taking some inspiration from this treadmill, we hope to make the most of our limited footprint.

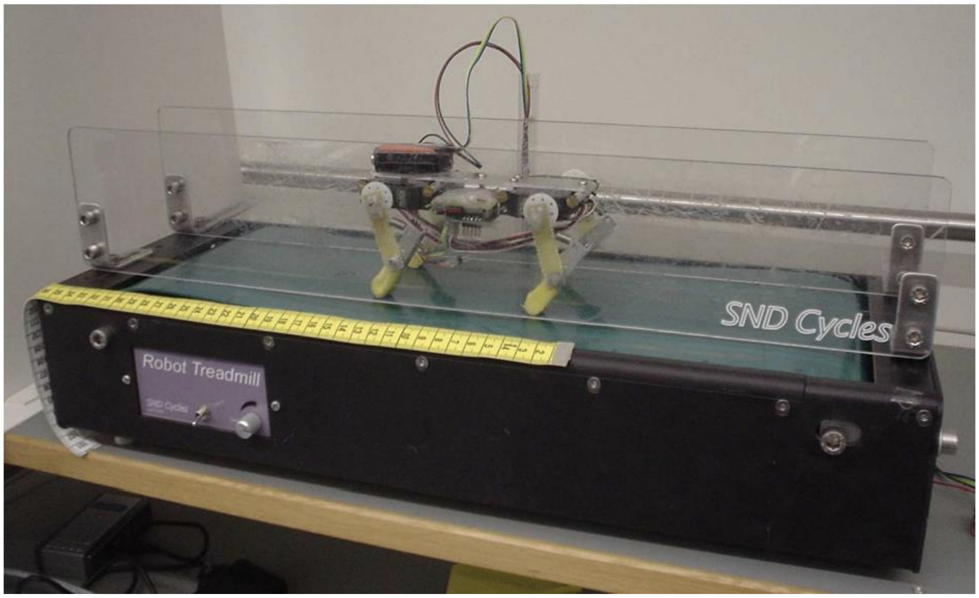


Figure 2. University of Zurich's treadmill and robot [6]

A solid middle ground would be ITT's treadmill [7]. It is just a bit bigger than a normal treadmill and looks to have a lot of the same bells and whistles we are looking for (see Figure 3). Its crippling flaw, however, is its lack of portability. The fall-prevention mechanism is mounted to the ceiling, so that the treadmill can only be operated directly below. From each of these designs, though, we can learn something.

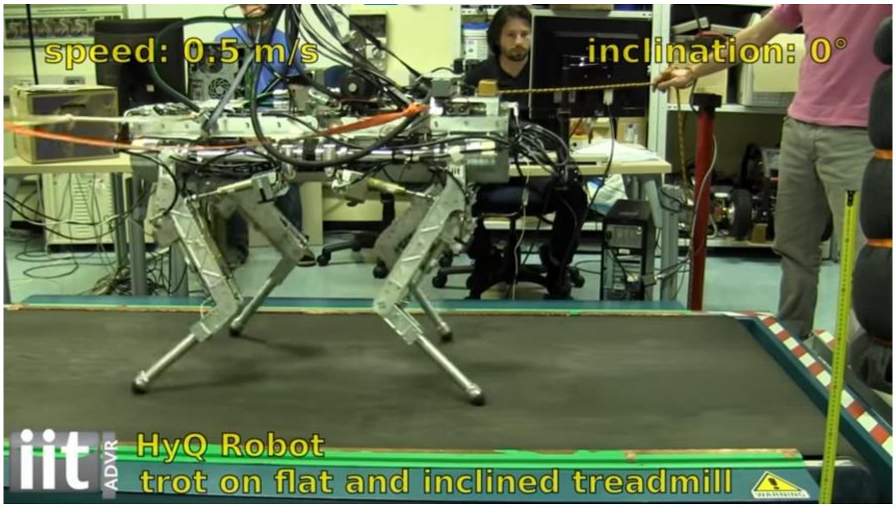


Figure 3. IIT's HyQ robot on their treadmill [7]

2.2.2 Fall Prevention

As for fall prevention mechanisms, there are several current examples. Boston Dynamics illustrates one such example [8] in a video of a cheetah-like robot running on a treadmill. The system is made of paracord and appears very unobtrusive to a robot's movement (see Figure 4). Judging by the video, the fall prevention mechanism is very responsive and does not jerk or twist the robot in any potentially dangerous ways. It does not look like it scales very well between different shaped robots, however. Additionally, manual operation is great for using like an e-stop button but having the potential for electrical operation at a detected fault may also be useful for reacting before an operator can.

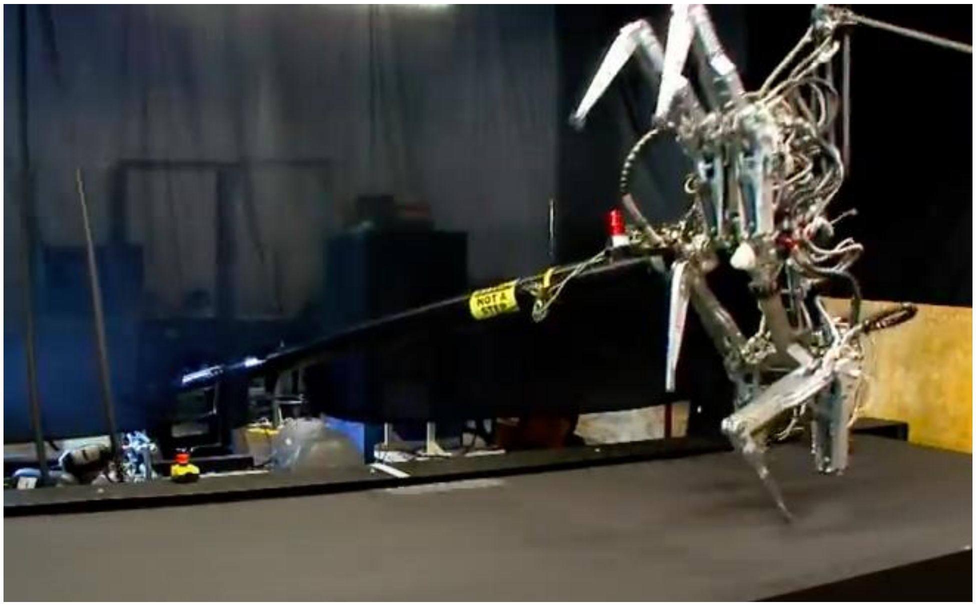


Figure 4. Boston Dynamics fall prevention mechanism [8]

ITT's fall prevention mechanism [7] is somewhat similar – a thick piece of orange strap mounted to the ceiling, which an operator can pull to lift the robot (look back at Figure 3). Theirs, however, lacks a pulley, so the operator would likely have to hang on it to lift a heavier robot. The thick strap also looks like it may impair robot motion, which would skew testing. This system is much more adaptable to other robots, though, as the strap can be secured on robots of most shapes.

2.2.3 Other Needs

Previous work for the Cal Poly Legged Robot Group utilized Nucleo microcontroller boards to gather data from sensors, so we will most likely use them too [9]. We will specifically need to gather data from sensors measuring the speed of the treadmill for two reasons. First, the sponsors desire to control the speed during test runs of robots, so a measurement of the speed is required to create a closed loop controller for the speed, which is more advantageous than an open loop controller since the former does not require the user to continually adjust the treadmill speed until the desired speed is reached (closed loop controllers adjust the speed based off the speed measurement until the desired speed is reached) [10]. Second, knowledge of the treadmill speed will be useful for verifying the robot speeds at which the various regimes of locomotion occur (as the treadmill speed is supposed to simulate how fast the robot would be running if it was on still ground), another item the sponsors wish to use the treadmill for.

We will additionally desire communication between the Speedgoat (the device with the robot commands) and the Nucleos (the devices that execute commands). This will be done using the CAN communication protocol, as has been done on other work for the group [9]. Much of the work creating CAN drivers and libraries has already been done previously by the group, so we will build off their work for this specific application. To implement vision systems, it can be useful to implement obstacle placement [1], [2]. For some applications, a split-belt treadmill can be useful [11], but the sponsors of this project did not want this implemented.

2.2.4 Patent Research

The following are patents that we have identified that have aspects that are pertinent to our project. It is important to note that, though most of them are not specifically for our application, there are aspects that we have identified to potentially be helpful to our research:

The first patent (shown in Figure 5) is a support system used to restore the direction of locomotion [12]. With respect to the project, this support system could be implemented to ensure that the robot is always parallel to the treadmill. The support system can also be implemented as a fail-safe to ensure that the robot never falls while on the treadmill.

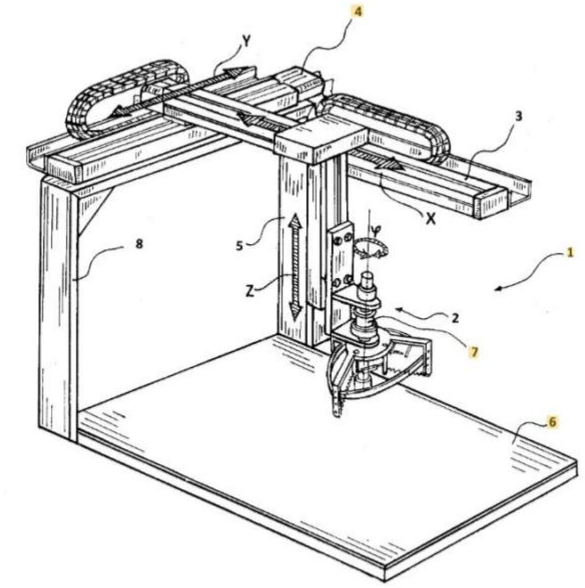


Figure 5: Drawing of Patent 1 apparatus [12]

The second patent is more of an abstract concept rather than a physical system [13]. This patent is related to the architecture for controlling the robot (see Figure 6 for a high-level view of the architecture). This can be used for the treadmill platform as a basis of how the control system and various sensing devices are implemented to the design.

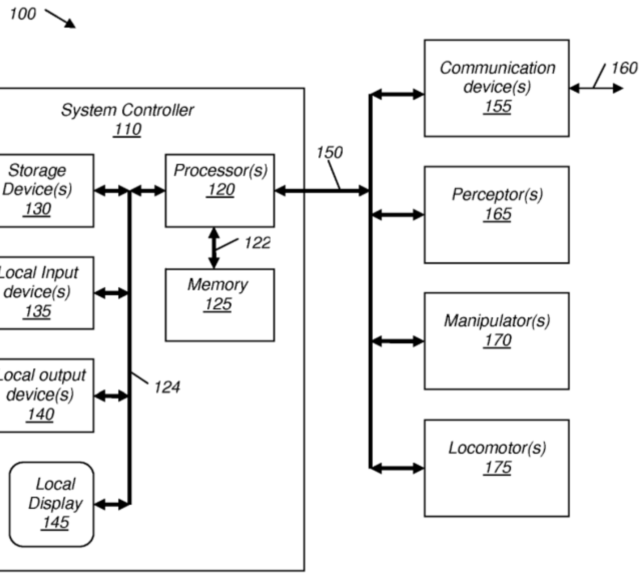


Figure 6: Patent 2 high level view of general control architecture [13]

The third patent (depicted in Figure 7) describes a device that is meant to be used for humans who have a hard time walking [14]. It implements a safety device that catches the person when they are falling. This design could be modified to use for the quadruped robot as the fail-safe.

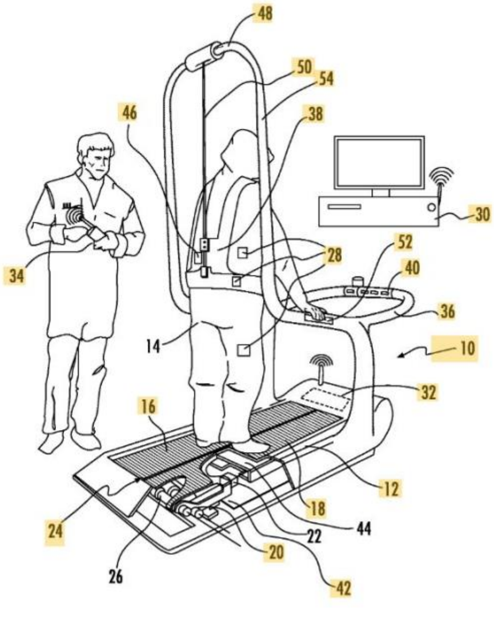


Figure 7: Drawing of Patent 3 apparatus [14]

This next patent provides a potential means of testing the propensity of a vehicle to fall over (see Figure 8) [15]. Although the platform is designed for a 4 wheeled vehicle, the testing method could be implemented for some similar test for our robot if that were something that came up to be a concern. It could also be used in combination with a treadmill to simulate non-level surfaces or unsteady conditions for implementation of the robot in a moving vehicle or perhaps a ship.

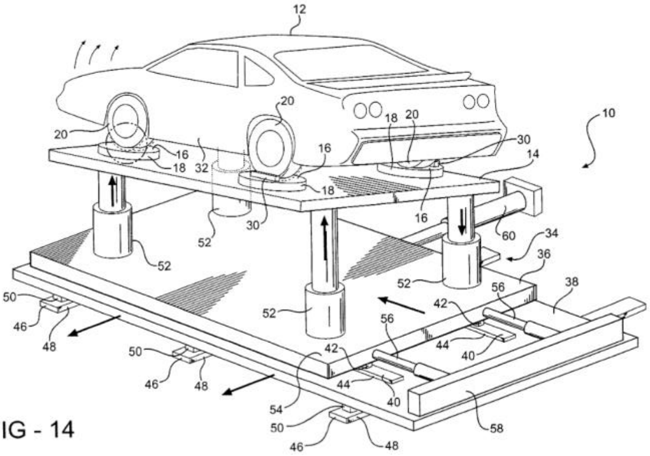


FIG - 14

Figure 8: Drawing of Patent 4 apparatus [15]

Another patent that we have identified is primarily a means of methodizing the implementation of additional sensors to make a robot more 'intelligent' [16]. Additionally, the patent gives multiple potential desired senses for the robot that allows us to see what potential data a robot might collect as 'Bruce' (the current robot that the sponsors are in possession of) gets more sophisticated. Figure 9 depicts a diagram of these desired senses. These desired senses could influence any additional sensing that we might want to design for.

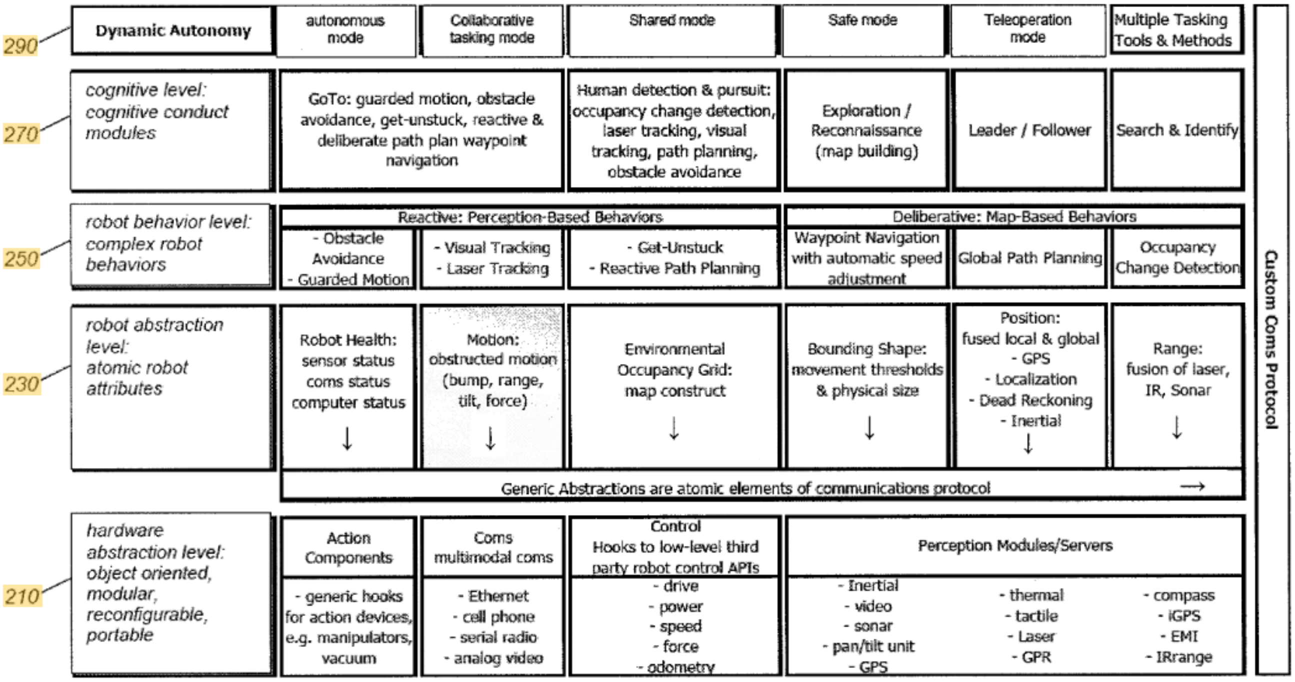


Figure 9: Patent 5 high level modality and sensory architecture [16]

The next patent is a European Patent that addresses human movement research [17]. This patent, though designed for humans, shows us a means of isolating control of a specific joint if desired as well as gives us an idea for a potential fail-safe mechanism. A diagram from the patent illustrating how to isolate control of a specific joint is shown in Figure 10.

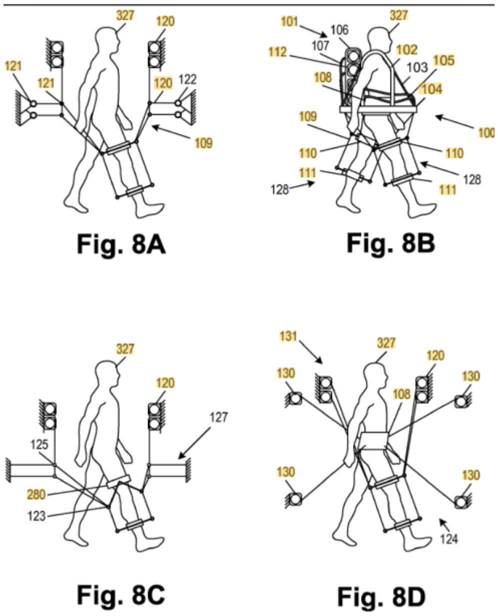


Fig. 8A Fig. 8B

Fig. 8C Fig. 8D

Figure 10: Drawing of Patent 6 apparatuses [17]

Another European Patent that we have found describes a device meant to assist humans with locomotion through controlled weight support, detection of position of center of gravity of wearer, control of speed of wearer, and detection of joint angle which all could be useful when deciding what sensing would be useful and how to implement those sensory inputs as well as what to control [18]. An image of the device is shown in Figure 11.

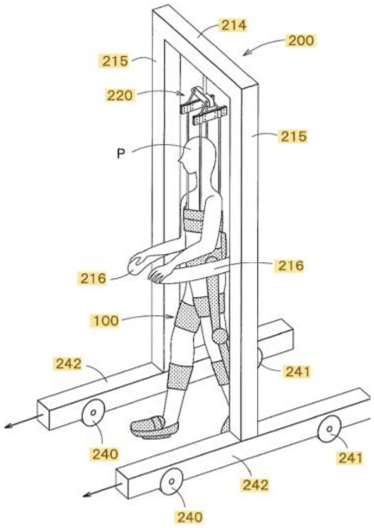


Figure 11: Drawing of Patent 7 apparatus [18]

The final patent that we found describes a design architecture for building autonomous systems which could be useful if we wanted to see how the robot might be programmed/made and how we should design our platform to best test the capabilities of said robot [19]. A diagram from the patent of the design architecture is shown in Figure 12.

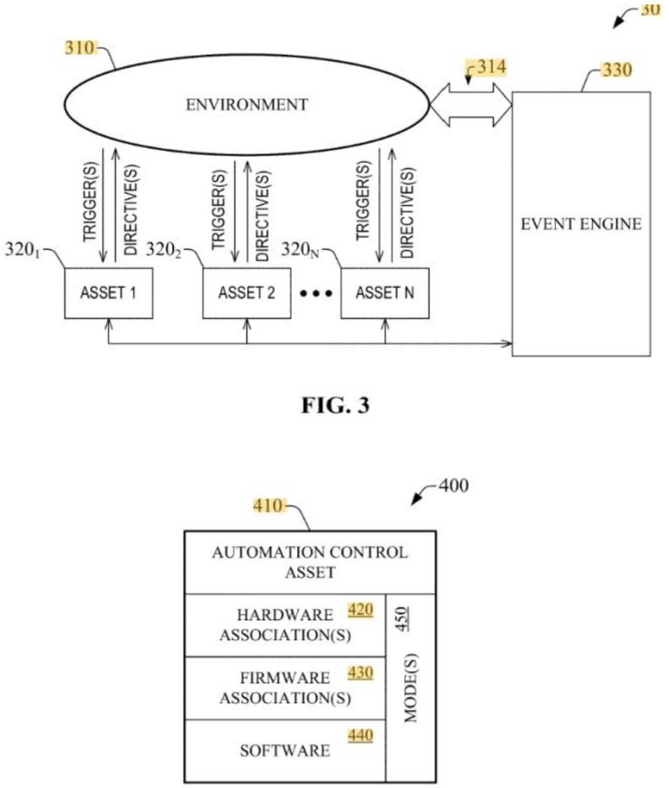


Figure 12: Patent 8 high level view of architecture between hardware/software [19]

2.3 Technical Challenges

What we expect to be the most notable challenge with designing this treadmill is sensing. Our sponsors have indicated that they want the design to measure the normal force exerted on each robot leg in order to verify their dynamic model of the robot. This is not typical; it is standard to integrate most of the sensing into the robot *without* sensors, instead opting for motor feedback to back-calculate normal forces [20]. The reason for this is the difficulty in measuring normal forces through the moving tread at specific leg locations. This will be part of the challenge for us.

Additionally, portability might be a challenge. All the existing treadmills made for robots of comparable size are permanent installations in their respective laboratories, so for us to incorporate the full functionality of a treadmill *and* a fall-protection mechanism in a portable design will be quite a challenge [5], [7], [8]. Mounting the whole thing on casters may be a good option, otherwise weight will have to be strongly taken into account.

3. Project Scope

3.1 Boundary Diagram

Figure 133 depicts a boundary diagram for the design problem at hand. The scope of this project focuses around designing a controllable, moving surface with some apparatus that prevents the robot from falling. The design also includes some way to collect data. Therefore, these three things are pictured inside the boundary. The robot is located outside the diagram since the scope of the project does not involve redesigning the robot. The Speedgoat (the accessory that relays commands to the design) is also outside the boundary since the Speedgoat is not being redesigned and merely facilitates the actions of the design.

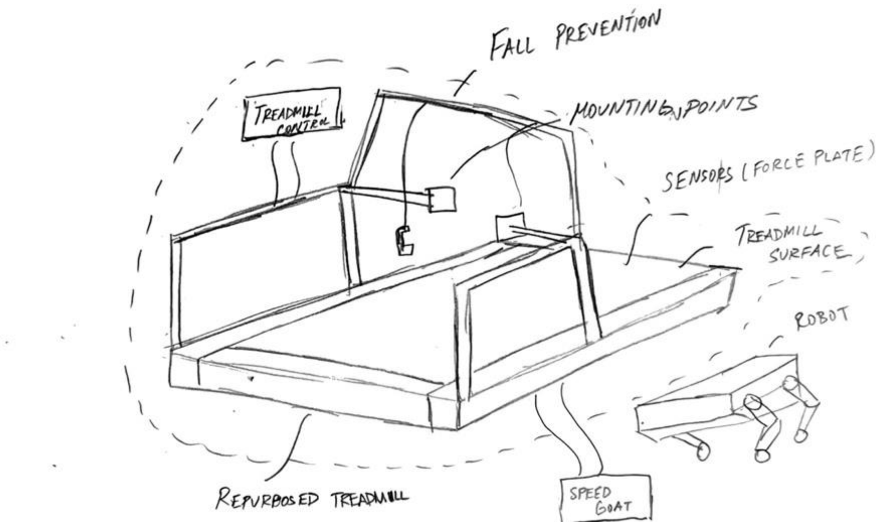


Figure 13. Senior Project Group F45 Boundary Diagram

3.2 Needs/Wants

Table 2 details the needs and wants of Professors Xing and Refvem. The needs primarily focus on the functionality of the moving surface and fall prevention mechanism while the wants focus on how the design will be interfaced with.

Table 2. Customer Needs/Wants Table

Needs	**Wants**
Way to control speed of surface	Portable
Cost under $5000	Durable
Fall prevention mechanism cannot influence design of robot	Force plate under surface
Fall prevention mechanism cannot impede on walking dynamics of robot	Sensors for motion of robot
Rigorous testing plans /documentation	Real-time interfacing with Speedgoat

3.3 Planned Deliverables

The planned deliverables for this project include a controllable, moving surface with a fall prevention mechanism and some sort of data acquisition. A repository containing all control algorithms for the design will also be shared. Additionally, all CAD files, drawings, assembly guidelines, and a bill of materials will be provided. Lastly, documentation of rigorous testing plans and resulting successes and failures will be delivered.

4. Objectives

Gait changes are an integral part of effective legged locomotion. Without switching gaits, a robot is limited to a single mode of operation, limiting its range of speed and maneuverability. Gait changes are usually tested on a large treadmill with a fall prevention mechanism stiffly attached to the ceiling above – currently, Cal Poly has neither a treadmill nor a space where a fall prevention mechanism can be mounted.

4.1 Problem Statement

Professors Revfem and Xing, the leaders of Cal Poly’s attempt to model, simulate, and test legged robots, need a way to reliably test the walking capabilities of their robots and collect various data regarding robot dynamics. It is imperative that this design have a fail-safe to prevent the robot from falling down or destroying itself during testing. Having a controlled environment to do so will allow them to continue conducting the research necessary to advance the design of their robots.

4.2 QFD

The Quality Function Deployment is a great tool for specifying and quantifying what’s necessary for the project to be successful. This process is depicted as a House of Quality Diagram (our House of Quality Diagram is in Appendix A). In the ‘Who’ section, we placed Professor Xing, Professor Refvem, and future members of the Legged Robotics Group – this is not a consumer product, so no consumers needed to be specified. In the ‘What’ section, we placed the wants and needs of these people, then rated the needs on a scale from one to ten for each group in the ‘Who’ section. The ‘how’ section contains the engineering specifications of the project – in comparing the ‘what’ against the ‘how’, we were able to determine how correlated our specifications were such that they sufficiently quantified success of the project. The ‘now’ section was filled with current products/solutions, which were scored on our engineering specifications. The house of quality provided a framework for us to better understand exactly what our stakeholders need and how these needs can be best met.

4.3 Engineering Specifications

Table 3 depicts the specifications which will be used to assess the final design.

Table 3. Engineering Specifications

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Weight	250 lbs	±5 lbs	M	T
2	Size	34in	±2 in	H	A, T, I
3	Software Reliability	0 bugs	0	H	T
4	Durability	5 years	Min	H	A, T
5	Quickness of Fall Prevention Mechanism	Lift 30 lb rectangular object in 1 second off platform	Min	M	A,T
6	Speed	6 mph	Min	M	T, I
7	Attachment Points	3 Points	Min	M	I
8	Ease of Operation	Sponsor approval	n/a	M	T
9	Safety	Sponsor approval	n/a	H	T, I
10	Price	$5000	Max	L	I

* Risk of meeting specification: (H) High, (M) Medium, (L) Low

** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

Each specification is as follows:

1. Weight: The unit must be 250 lbs or less. The unit must be portable, so much higher than this would pose a significant impediment to portability.
2. Size: The unit must fit through a doorway. Again, were the unit unable to fit through a doorway, it would seriously limit portability and would be unusable for our sponsors.
3. Software reliability: The software (especially CAN communication) must operate as expected without bugs – future researchers should not have to worry if they are getting bad data or if the machine is just faulty. This will likely be tested with loopback testing.
4. Durability: The design must last for about 5 years. The methods of evaluating the durability will be approved by sponsors, who have expertise in what constitutes a valid test of durability.
5. Quickness of Fall Prevention Mechanism: The Fall Prevention Mechanism must be able to quickly remove the robot from the treadmill if the robot falls. A 30 lb mass will be used to test this specification.
6. Speed: The unit must operate at a max speed of at least 6 mph.
7. Attachment points: The unit must have a minimum of three attachment points. This is an effort to quantify modularity, but it does not feel like it is the best measure. We are still looking for a better way of quantifying modularity.

8. Ease of operation: The unit should be easy to operate. Ideally, the unit should not pose a significant impediment to the workflow of someone developing something on a robot. This is to be deemed successful or unsuccessful by the sponsors.
9. Safety: The unit must not pose a danger to its operators, bystanders, or surrounding environment.
10. Price: The unit must cost less than $5000.

5. Project Management

The design process will begin with a group brainstorm and construction of several ideation models. After homing in on a design, a concept CAD model will be built. The design of the fall prevention mechanism will be based around the existing CAD model of the current quadrupedal robot. FEA (Finite Element Analysis) will be conducted on the design to verify its durability. A dynamic analysis will also be conducted to ensure that that fall prevention mechanism does not interfere with the robot's motion. In addition, planning for methods of data collection will take place. After manufacturing, the control algorithm for the design will be developed and tested. The methods of data collection will also be evaluated.

Table 4 lists the key milestones for this project and the tentative dates set by the Senior Project coaches. The milestones are further broken down in the Gantt chart in Appendix B.

Table 4. Key Milestones

Milestone	Tentative Date
Preliminary Design Review (PDR)	11/17/2022
Interim Design Review (IDR)	1/24/2023
Critical Design Review (CDR)	2/16/2023
Manufacturing and Test Review	3/16/2023
VP Sign-Off	4/2/2023
DVPR Sign-Off	4/23/2023
Expo	6/2/2023
Final Design Review (FDR)	6/9/2023

Between now and the next milestone (the PDR), the focus will be on innovating and modeling a solution. As previously mentioned, the first task will be to brainstorm and come up with several ideas. From there, several ideation models will be built out of craft materials to help visualize ideas. Further discussion will ensue on these models about how to combine the best aspects from each model, leading to a concept selection. Once a concept has been selected, a concept CAD (Computer Aided Design) model will be developed, preliminary analysis will be conducted, and a concept prototype will be built. These tasks will form the basis of the PDR.

6. Conclusion

Cal Poly Legged Robots led by Professor Revfem and Dr. Xing has been leading Cal Poly's attempts to simulate, produce, and test their legged robots. In developing these robots, the organization has reached the point where they need a reliable way to test the robots effectively (with proper data collection) and safely for both the robots themselves and those testing the robots. The purpose of this document is to verify our interpretation of the problem and scope with Dr. Xing and Professor Refvem and additionally give them a progress update on the steps that our group has taken to give them the best product that addresses all their needs and as many wants as possible with the given problem constraints. Our intent is that if there are any misconceptions/concerns with our interpretation of the problem, scope, or the Engineering specifications that we have created to address the needs/wants by Dr. Xing or Professor Refvem, they are flushed out as a result of this document. Additionally, this document will serve to give a tentative timeline for the progression and deliverables for this project in order to maintain transparency with our sponsors. Our next deliverable will be our Preliminary Design Review (PDR) which will take place (tentatively) on 11/17/2022. Please confirm that the problem and the scope are correct and additionally confirm that, in both of your opinions (Dr. Xing and Professor Refvem), the engineering specifications are sufficient to effectively address all of the needs and a reasonable amount of wants to do what you are hoping to do with this solution.

References

[1] C. Boussema et al. “Online Gait Transitions and Disturbance Recovery for Legged Robots via the Feasible Impulse Set,” *IEEE Robotics and Automation Letters*, vol. 4, no. 2, pp. 1611-1618, 2019

[2] G. Bledt et al., “MIT Cheetah 3: Design and Control of a Robust, Dynamic Quadruped Robot,” *2018 IEEE International Conference on Intelligent Robots and Systems*, 2019

[3] P. Biswal and P. Mohanty, “Development of quadruped walking robots: A review,” *Ain Shams Engineering Journal*, vol. 12, no. 2, pp. 2017-2031, 2021

[4] D. Hyun et al., “Implementation of trot-to-gallop transition and subsequent gallop on the MIT Cheetah I,” *The International Journal of Robotics Research*, vol. 35, no. 13, pp. 1627-1650, 2016

[5] Massachusetts Institute of Technology, “MIT cheetah robot lands the running jump,” 28 May, 2015. [Online]. Available: https://www.youtube.com/watch?v=_luhn7TLfWU. [Accessed 29 September, 2022]

[6] F. Iida, G. Gomez, and R. Pfeifer, “Exploiting body dynamics for controlling a running quadruped robot,” *International Conference on Advanced Robotics*, 2005, pp. 229-235

[7] Dynamic Legged Systems Lab, “IIT’s Hydraulic Quadruped Robot – Balancing and First Outdoor Tests,” 14 May, 2012. [Online]. Available: https://www.youtube.com/watch?v=AnwetZpRtFE. [Accessed 29 September, 2022]

[8] Boston Dynamics, “Cheetah Robot runs 28.3 mph; a bit faster than Usain Bolt,” 5 September, 2012. [Online]. Available https://www.youtube.com/watch?v=chPanW0QWhA. [Accessed 29 September, 2022]

[9] C. Elwell et al., “8 DOF Hopping Robot Senior Project Report,” 3 June, 2022. [Online]. Available: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1767&context=mesp. [Accessed 29 September, 2022]

[10] M Diehl and K. Mombaur, *Fast Motions in Biomechanics and Robotics: Optimization and Feedback Control*. SpringerLink, 2006

[11] S. Aoi et al. “Fast and Slow Adaptations of Interlimb Coordination vis Reflex and Learning During Split-Belt Treadmill Walking of a Quadruped Robot, *Frontiers in Robotics and AI*, vol. 8, no. 10, pp. 33-39, 2021

[12] G. Courtine, S. Micera, and J. Von Zitzewitz, “Apparatus and method for restoring voluntary control of locomotion in neuromotor impairments,” U.S. Patent 10406056B2, 30 May, 2012

[13] D. Bruemmer, “Robotic guarded motion system and method,” U.S. Patent 7668621B2, 5 July, 2006

[14] J. Chu, R. Greenwald, and D. Johnson, “Training system and method using a dynamic perturbation platform,” U.S. Patent 8246354B2, 28 April, 2005

[15] K. Kemp, H. Oral, and M. Hoenke, “Vehicle testing apparatus for measuring a propensity of a vehicle to roll over,” U.S. Patent 7058488B2, 3 May, 2002

[16] C. Nielsen et al., “Robots, systems, and methods for hazard evaluation and visualization,” U.S. Patent 835581B2, 3 September, 2009

[17] S. Agrawal, V. Vashista, J. Kang, and X. Jin, “Human movement research, therapeutic, and diagnostic devices, methods, and systems,” European Patent 3133998B1, 21 April, 2014

[18] Y. Sankai and T. Hayashi, “Ambulation training device and ambulation training system,” Eurpoean Patent 2671559B1, 2 March, 2011

[19] D. Patel et al., Systems and methods for autonomous adaptation of an automation control service,” U.S. Patent 10983487B2, 29 April, 2014

[20] J. Di Carlo et al., “Dynamic Locomotion in the MIT Cheetah 3 Through Convex Model-Predictive Control,” *2018 IEEE International Conference on Intelligent Robots and Systems*, 2018, pp. 1-9

Appendix A: QFD House of Quality Table

Correlations	
Positive	+
Negative	−
No Correlation	

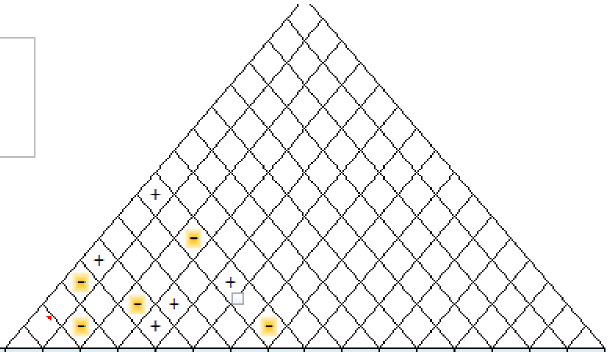
Relationships	
Strong	●
Moderate	○
Weak	▽

irection of Improvemen	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Quadrupedal Robot Treadmill

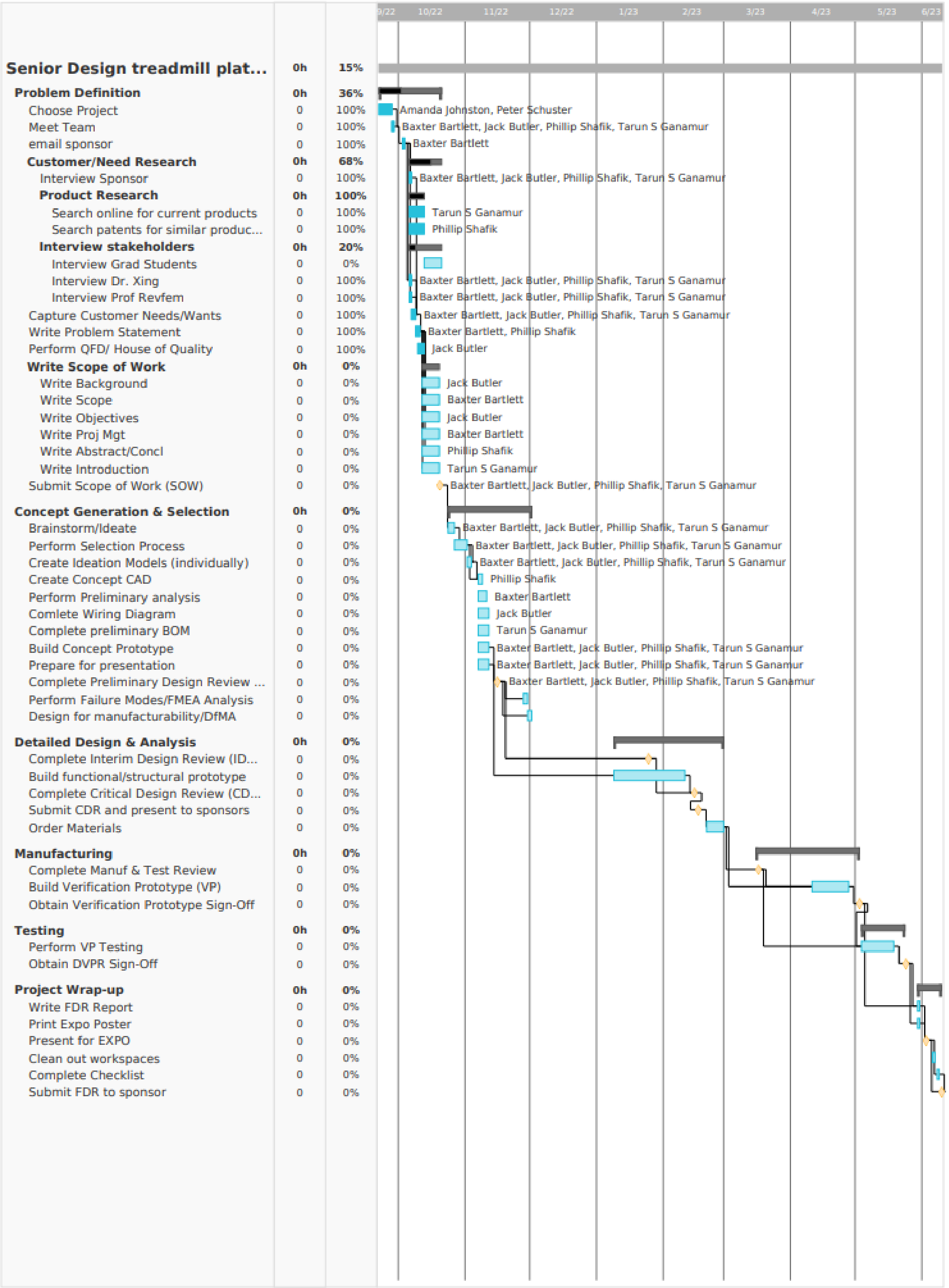
Revision Date: 10/11/2022



	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**NOW: Curr.**					
								Direction of Improvement	◇	▼	◇	▲	▲	▲	◇	▲	▼													
Row #	Weight Chart	Relative Weight	Dr. Xing	Professor Refvem	Future Workers on the Robo		Maximum Relationship	**HOW: Engineering Specificati** **WHAT: Customer Requirements (Needs/Wan**	Deemed safe by sponsors	Time to learn how to operat	Attachment points	Top speed >8 mph	Hardware reliability	Software reliability	Size	Linear + Torsional Stiffness	Weight								Regular Treadmill	MIT's Treadmill	IIT's Treadmill	University of Zurich's Treadmill		Row #
1	▮▮▮▮▮▮	13%	10	10	10		9	Safety	●	▽			▽	▽											4	8	8	9		1
2	▮▮▮▮	10%	7	7	9		9	Documentation	▽	●			▽	▽											7	10	8	6		2
3	▮▮▮▮	8%	5	7	8		9	Modularity			●		○	○	▽										1	7	6	5		3
4	▮▮▮	8%	8	6	5		9	Top Speed	▽			●	○	○		○									10	10	10	3		4
5	▮▮▮▮	9%	8	6	7		9	Communication		○				●											1	10	10	7		5
6	▮▮▮▮▮	11%	9	9	9		9	Fall prevention	○		●		●		○	▽									1	9	7	1		6
7	▮▮▮▮	9%	8	8	5		9	Compact							●										10	2	4	10		7
8	▮▮▮▮▮	10%	8	8	8		9	Stiffness of constraint					●			●									1	7	7	1		8
9	▮▮▮▮▮▮	13%	10	10	10		9	Can fit the robot on it			▽				●										5	8	7	1		9
10	▮▮▮▮▮	10%	8	9	8		9	Portable							●		●								5	1	4	5		10
11		0%																												11
12		0%																												12
13		0%																												13
14		0%																												14
15		0%																												15
16		0%																												16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	MUCH: Target Values	Approval from sponsor	Approval from sponsor	Minimum 4 possible attachments	Minimum top speed 6 mph	Operates as expected under load	No lost CAN messages	Must fit through a door	Adequately constrains the robot for testing	Under 250 lbs							
	Max Relationship	9	9	9	9	9	9	9	9	9							
	Technical Importance Rating	164	125	189	71	262	150	327	125	94	0	0	0	0	0	0	0
	Relative Weight	11%	8%	13%	5%	17%	10%	22%	8%	6%	0%	0%	0%	0%	0%	0%	0%
Curr. Products	Regular Treadmill	0	9	0	10	10	10	7	5	5							
	MIT's Treadmill	10	6	7	10	9	9	1	9	1							
	IIT's Treadmill	10	6	7	10	9	9	4	9	6							
	University of Zurich's Treadmill	10	6	4	2	9	9	6	8	9							
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B: Project Gantt Chart



Senior Design treadmill plat...	0h	15%	
Problem Definition	0h	36%	
Choose Project	0	100%	Amanda Johnston, Peter Schuster
Meet Team	0	100%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
email sponsor	0	100%	Baxter Bartlett
Customer/Need Research	0h	68%	
Interview Sponsor	0	100%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Product Research	0h	100%	
Search online for current products	0	100%	Tarun S Ganamur
Search patents for similar produc...	0	100%	Phillip Shafik
Interview stakeholders	0h	20%	
Interview Grad Students	0	0%	
Interview Dr. Xing	0	100%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Interview Prof Revfem	0	100%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Capture Customer Needs/Wants	0	100%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Write Problem Statement	0	100%	Baxter Bartlett, Phillip Shafik
Perform QFD/ House of Quality	0	100%	Jack Butler
Write Scope of Work	0h	0%	
Write Background	0	0%	Jack Butler
Write Scope	0	0%	Baxter Bartlett
Write Objectives	0	0%	Jack Butler
Write Proj Mgt	0	0%	Baxter Bartlett
Write Abstract/Concl	0	0%	Phillip Shafik
Write Introduction	0	0%	Tarun S Ganamur
Submit Scope of Work (SOW)	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Concept Generation & Selection	0h	0%	
Brainstorm/Ideate	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Perform Selection Process	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Create Ideation Models (individually)	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Create Concept CAD	0	0%	Phillip Shafik
Perform Preliminary analysis	0	0%	Baxter Bartlett
Comlete Wiring Diagram	0	0%	Jack Butler
Complete preliminary BOM	0	0%	Tarun S Ganamur
Build Concept Prototype	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Prepare for presentation	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Complete Preliminary Design Review ...	0	0%	Baxter Bartlett, Jack Butler, Phillip Shafik, Tarun S Ganamur
Perform Failure Modes/FMEA Analysis	0	0%	
Design for manufacturability/DfMA	0	0%	
Detailed Design & Analysis	0h	0%	
Complete Interim Design Review (ID...	0	0%	
Build functional/structural prototype	0	0%	
Complete Critical Design Review (CD...	0	0%	
Submit CDR and present to sponsors	0	0%	
Order Materials	0	0%	
Manufacturing	0h	0%	
Complete Manuf & Test Review	0	0%	
Build Verification Prototype (VP)	0	0%	
Obtain Verification Prototype Sign-Off	0	0%	
Testing	0h	0%	
Perform VP Testing	0	0%	
Obtain DVPR Sign-Off	0	0%	
Project Wrap-up	0h	0%	
Write FDR Report	0	0%	
Print Expo Poster	0	0%	
Present for EXPO	0	0%	
Clean out workspaces	0	0%	
Complete Checklist	0	0%	
Submit FDR to sponsor	0	0%	