Department of Computer Science & Engineering
The University of Texas at Arlington

System Requirements Specification
CSE 4316: Senior Design I
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Runtime Terrors
Turing Board

Sahaj Amatya
Sarker Nadir Afridi Azmi
Kendall Buchanan
Keaton Koehler
Happy Ndikumana
Lydia Sarver

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Contents

1 Product Concept **8**

1.1 Purpose and Use . . . 8

1.2 Intended Audience . . . 8

2 Product Description **9**

2.1 Features & Functions . . . 9

2.2 External Inputs & Outputs . . . 9

2.3 Product Interfaces . . . 9

3 Customer Requirements **10**

3.1 Forward Propulsion System . . . 10

3.1.1 Description . . . 10

3.1.2 Source . . . 10

3.1.3 Constraints . . . 10

3.1.4 Standards . . . 10

3.1.5 Priority . . . 11

3.2 Turning mechanism . . . 11

3.2.1 Description . . . 11

3.2.2 Source . . . 11

3.2.3 Constraints . . . 11

3.2.4 Standards . . . 11

3.2.5 Priority . . . 11

3.3 Weight sensor . . . 11

3.3.1 Description . . . 11

3.3.2 Source . . . 11

3.3.3 Constraints . . . 11

3.3.4 Standards . . . 11

3.3.5 Priority . . . 12

3.4 GPS . . . 12

3.4.1 Description . . . 12

3.4.2 Source . . . 12

3.4.3 Constraints . . . 12

3.4.4 Standards . . . 12

3.4.5 Priority . . . 12

3.5 Remote . . . 12

3.5.1 Description . . . 12

3.5.2 Source . . . 12

3.5.3 Constraints . . . 12

3.5.4 Standards . . . 12

3.5.5 Priority . . . 12

3.6 Computer Vision . . . 12

3.6.1 Description . . . 12

3.6.2 Source . . . 13

3.6.3 Constraints . . . 13

3.6.4 Standards . . . 13

3.6.5 Priority . . . 13

3.7 Path finding . . . 13
3.7.1 Description . . . 13
3.7.2 Source . . . 13
3.7.3 Constraints . . . 13
3.7.4 Standards . . . 13
3.7.5 Priority . . . 13

4 Packaging Requirements 14
4.1 Board Design . . . 14
4.1.1 Description . . . 14
4.1.2 Source . . . 14
4.1.3 Constraints . . . 14
4.1.4 Standards . . . 14
4.1.5 Priority . . . 14
4.2 Frontend . . . 14
4.2.1 Description . . . 14
4.2.2 Source . . . 14
4.2.3 Constraints . . . 14
4.2.4 Standards . . . 14
4.2.5 Priority . . . 14
4.3 Dampeners . . . 15
4.3.1 Description . . . 15
4.3.2 Source . . . 15
4.3.3 Constraints . . . 15
4.3.4 Standards . . . 15
4.3.5 Priority . . . 15

5 Performance Requirements 16
5.1 Turning Angle . . . 16
5.1.1 Description . . . 16
5.1.2 Source . . . 16
5.1.3 Constraints . . . 16
5.1.4 Standards . . . 16
5.1.5 Priority . . . 16
5.2 Limited Slip Differential . . . 16
5.2.1 Description . . . 16
5.2.2 Source . . . 16
5.2.3 Constraints . . . 16
5.2.4 Standards . . . 16
5.2.5 Priority . . . 16
5.3 Battery . . . 17
5.3.1 Description . . . 17
5.3.2 Source . . . 17
5.3.3 Constraints . . . 17
5.3.4 Standards . . . 17
5.3.5 Priority . . . 17

6 Safety Requirements **18**
6.1 Laboratory equipment lockout/tagout (LOTO) procedures . . . 18
6.1.1 Description . . . 18
6.1.2 Source . . . 18
6.1.3 Constraints . . . 18
6.1.4 Standards . . . 18
6.1.5 Priority . . . 18
6.2 National Electric Code (NEC) wiring compliance . . . 18
6.2.1 Description . . . 18
6.2.2 Source . . . 18
6.2.3 Constraints . . . 18
6.2.4 Standards . . . 18
6.2.5 Priority . . . 18
6.3 RIA robotic manipulator safety standards . . . 19
6.3.1 Description . . . 19
6.3.2 Source . . . 19
6.3.3 Constraints . . . 19
6.3.4 Standards . . . 19
6.3.5 Priority . . . 19
6.4 Weather Proof Casing . . . 19
6.4.1 Description . . . 19
6.4.2 Source . . . 19
6.4.3 Constraints . . . 19
6.4.4 Standards . . . 19
6.4.5 Priority . . . 19
6.5 Alarm or Buzzer for Improper Use . . . 19
6.5.1 Description . . . 19
6.5.2 Source . . . 19
6.5.3 Constraints . . . 20
6.5.4 Standards . . . 20
6.5.5 Priority . . . 20
6.6 Board Response to Accidents . . . 20
6.6.1 Description . . . 20
6.6.2 Source . . . 20
6.6.3 Constraints . . . 20
6.6.4 Standards . . . 20
6.6.5 Priority . . . 20
6.7 Mode Switch . . . 20
6.7.1 Description . . . 20
6.7.2 Source . . . 20
6.7.3 Constraints . . . 21
6.7.4 Standards . . . 21
6.7.5 Priority . . . 21

7 Maintenance & Support Requirements **22**
7.1 Firebase Authentication Admin Portal 22
7.1.1 Description 22
7.1.2 Source 22
7.1.3 Constraints 22
7.1.4 Standards 22
7.1.5 Priority 22

8 Other Requirements **23**
8.1 Follow Along 23
8.1.1 Description 23
8.1.2 Source 23
8.1.3 Constraints 23
8.1.4 Standards 23
8.1.5 Priority 23

9 Future Items **24**
9.1 Weather Proof Casing 24
9.1.1 Description 24
9.1.2 Source 24
9.1.3 Constraints 24
9.1.4 Standards 24
9.1.5 Priority 24
9.2 Alarm or Buzzer for Improper Use 24
9.2.1 Description 24
9.2.2 Source 24
9.2.3 Constraints 24
9.2.4 Standards 24
9.2.5 Priority 24
9.3 Board Response to Accidents 24
9.3.1 Description 24
9.3.2 Source 25
9.3.3 Constraints 25
9.3.4 Standards 25
9.3.5 Priority 25

List of Figures

1 User Interface Screenshots 10

1 Product Concept

The Turing Board is a concept autonomous longboard which is capable of exhibiting self-driving capabilities using computer vision. Users of the Turing Board will be able to take advantage of various features such as having the board follow you autonomously and having the board summon itself to you from a parked location, in addition to functioning as a standard electric longboard capable of recording and analyzing all trip data. Users will be delighted with how the Turing Board may also function as a load carrier, relieving them from the burden of carrying everyday items like backpacks, boxes, etc. if desired.

1.1 Purpose and Use

The purpose of the Turing Board is to improve the overall user experience of an electric longboard using highly interactive software as a catalyzing agent. The user interfaces with the board via either a native Android or iOS app on their mobile device. It is through the mobile app that the user will be able to control the speed of the board when in manual mode, and send requests to the board to perform tasks it is able to do autonomously.

1.2 Intended Audience

The intended audience of this board is the electric longboarding community who share a passion for technology. Since this is an open source project, users are invited to tinker with their own forks of the code to optimize the board to their own standards, all the while furthering the light of knowledge to solve self-driving vehicles.

2 Product Description

This section provides the reader with an overview of the Turing Board. The primary operational aspects of the the Turing Board, from the perspective of end users, are defined here. The key features and functions found in the Turing Board, as well as critical user interactions and user interfaces, are described in detail.

2.1 Features & Functions

When desired, the Turing Board will follow the user side-by-side at a walking pace. When called upon, it will direct itself to the user's location from a parked spot. However, users will not be able to take advantage of the autonomous features when they mount the board. The change in inertia spawned by a computer generated movement of the longboard puts the user at great risk of losing balance when taking off, braking, and turning especially. This changes the balance of the system as a whole. Such a problem is not an issue in household autonomous vehicles such as a self-driving car because the change in inertia only affects the balance of the user and not the car in any significant way.

Visually, the Turing Board is anticipated to share the form of any regular electric skateboard, with the only difference being that it is going to have a camera mounted on the nose end. The parts will consist of a deck, underneath the deck will comprise of an encasing that will house the battery and computation module, as well as the turning mechanism hardware, trucks and motorized wheels. The placement of the camera module is anticipated to be on the underside of the board.

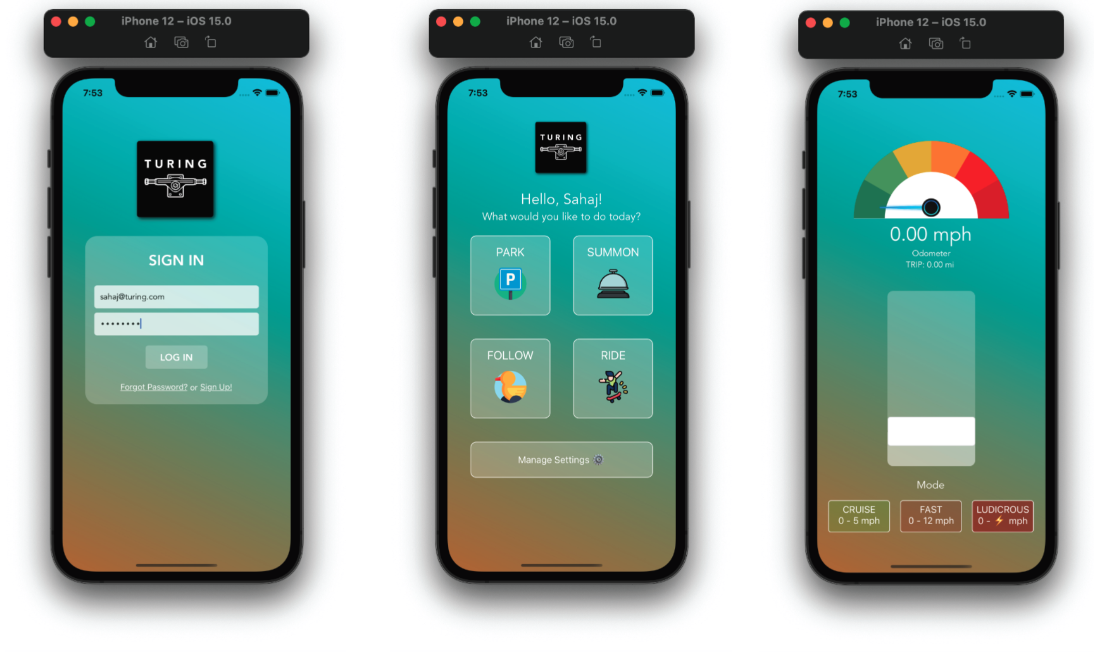
On the software side, the items include native Android and iOS apps to interface with the Turing Board. The feature set of the Turing Board also consists of the collection and display of ride analytics.

2.2 External Inputs & Outputs

GPS information is a critical aspect that will be involved in both external input and output scenarios. We will need to account for the GPS information of both the user and the board. The user authentication is handled by the Google Firebase Authentication API paired with the Google Firebase Cloud Firestore API acting as a cloud database.

2.3 Product Interfaces

Included are some of the screenshots of what the application interface will look like for the end-user (Figure 1).



Login Screen UI | Dashboard Screen UI | Throttle Screen UI

Figure 1: User Interface Screenshots

3 Customer Requirements

Specific requirements for the Turing Board were established with the enjoyment and convenience of the user in mind. In order to have an electronic longboard with autonomous capabilities, the majority of the customer requirements are based on functionality.

3.1 Forward Propulsion System

3.1.1 Description

Two six-hundred watt brush less DC motor's are=== embedded into the rear truck and will be powered through the on board battery. Utilizing an electronic speed controller, the motors will be driven to a specific RPM that corresponds to the users desired speed.

3.1.2 Source

Runtime Terrors

3.1.3 Constraints

The forward propulsion system must use a control loop that takes environmental factors into account and adjusts the torque to accommodate any change in variables. Within reason the user should expect to go the same speed regardless of body weight or slight changes to terrain.

3.1.4 Standards

Conforms to the Texas state motor-assisted scooter laws.

3.1.5 Priority

Critical

3.2 Turning mechanism

3.2.1 Description

The Turing Board will have a turning mechanism that will be utilized during autonomous mode. Normally, to turn a normal longboard, the user must lean toward the side they want to turn towards. To mitigate and simplify the turning mechanism for the Turing Board during autonomous mode, the board will have a rotating front truck controlled by a stepper motor and a gear box. The turning mechanism will have an inclusive rotation range of -45 to 45 degrees, with 0 degrees being the universal normal front truck position. When the Turing Board is in user mode, the turning mechanism will be rotated back into the normal position and locked at 0 degrees, using solenoids, and the user is in charge of turning the board by leaning toward the desired side, like on normal longboards.

3.2.2 Source

Runtime Terrors

3.2.3 Constraints

The turning mechanism has a turning range of 90 degrees. With 0 degrees being the origin, the range of this mechanism will be 45 degrees in either directions.

3.2.4 Standards

An inclusive turning range of -45 to 45 degrees

3.2.5 Priority

Critical

3.3 Weight sensor

3.3.1 Description

The Weight sensor's main role is to determine if a user, a small load or nothing is on top of the Turing board. With the provided information from the sensor, the appropriate mode will be set. If a user is on the Turing board, then the autonomous mode will be disengaged. This means the turning mechanism will be rotated and locked at 0 degrees. In any other case, a small load or nothing on the Turing board, then the autonomous mode can be engaged if it is needed.

3.3.2 Source

Runtime Terrors

3.3.3 Constraints

For small loads, we will have a maximum weight to never exceed. If exceeded, the Turing board will consider it as a person and the autonomous mode will be disengaged.
For user weight sensing, we will set a minimum weight to always exceed in order for the autonomous mode to be disengaged.

3.3.4 Standards

0 kg to Turing board's weight - considered "no load"
Turing board's weight to 23 kg (50lbs) - considered "a small load"
23 kg (50lbs) upwards - considered "a person"

3.3.5 Priority

Critical

3.4 GPS

3.4.1 Description

As part of the autonomous navigation system, the GPS will provide coordinate data which will allow the program to know the position of the longboard. This will be used to draw vectors to aid with navigation to a target coordinate. The GPS built into the phone will be used to get the current location of the longboard.

3.4.2 Source

Sarker Nadir Afridi Azmi

3.4.3 Constraints

The GPS capabilities of the user's phone. The GPS coordinates provided by the phone should be precise without jumping from one value to another too much.

3.4.4 Standards

Conforms to the standard Global Positioning System.

3.4.5 Priority

High

3.5 Remote

3.5.1 Description

Instead of having a separate remote, a free-to-download app will be made available which can be used to summon the board, enable the follow-me feature, and control the speed of the wheels when the user is riding it. The app will will be created using React Native to support both Android and iOS. It will use Bluetooth to make the process of data transfer very simple and easy.

3.5.2 Source

Runtime Terrors

3.5.3 Constraints

Latency of data from remote to board should be minimized. Since the rider of the longboard will be going quite fast, the transmission of data needs to be reduced as much as possible.

3.5.4 Standards

Bluetooth 4.0/5.0 for maximum compatibility.

3.5.5 Priority

Critical

3.6 Computer Vision

3.6.1 Description

The Turing Board utilizes an Intel RealSense Depth Camera D435. It has two that will be used for detecting objects to avoid and also tracking a specific marker in its view to command the board to follow (see "Other" section for more information on this feature). The object detection is handled by Single Shot Detectors (SSDs). An SSD-MobileNet V2 model on a 91 class COCO dataset will be deployed.

3.6.2 Source

Sahaj Amatya Sarker Nadir Afridi Azmi

3.6.3 Constraints

The pre-built library for the computer vision only works on x86 architecture. Since our controller, the NVIDIA Jetson TX 2, was built to work with Intel ARM architecture a kernel has been built to allow communication between the two. Also, due to the nature of what the computer vision of the Turing Board will do, the Jetson TX 2 will need to use it's CUDA cores to process the input appropriately. For this reason, a kernel was also built for OpenCV.

3.6.4 Standards

N/A

3.6.5 Priority

Critical

3.7 Path finding

3.7.1 Description

The Turing Board will utilize a Greedy Best First search for its path finding algorithm. The board generates a trapezoidal trajectory map in front of it with progressive width equal to its own width plus some padding width. If an object is detected within the trajectory, the path finding algorithm will seek a path to avoid the object.

3.7.2 Source

Sahaj Amatya & Sarker Nadir Afridi Azmi

3.7.3 Constraints

The camera used on the board is able to only see up to 20ft ahead. This will need to be taken into consideration when deciding how to best avoid an object.

3.7.4 Standards

N/A

3.7.5 Priority

Critical

4 Packaging Requirements

The Turing Board will be shipped pre-assembled which would include the turning mechanism, camera, and Jetson already screwed onto a standard longboard. The only thing not plugged in would be the batteries which the user has to connect themselves. The firmware for the product will come pre-installed where the user would only be required to pair the device with the mobile app to make use of it. An ankle bracelet with ArUco Tags for the follow me feature and a power supply for charging the batteries would also be included as part of the purchase.

4.1 Board Design

4.1.1 Description

The look and feel is incredibly important for a final product. It is the polish that makes the shoe shine, after all. The finished longboard topside will have a minimalist look similar to a normal longboard or eboard, custom protective housings for all electrical components on the underside, and Turing Board custom grip tape signed by all team members.

4.1.2 Source

Runtime Terrors

4.1.3 Constraints

The electronics and casing mounted to the underside must be thin enough to avoid scraping or bottoming out on bumpy sidewalks.

4.1.4 Standards

The underside will be where all electrical components are mounted, with holes drilled and milled accordingly for each mounting screw. The topside will, preferably, be flush with no screws/nuts sticking out or epoxy left un-sanded. All components will have widths short enough to fit within the constraints of the board dimensions leaving no overhanging objects. Grip tape will be applied after all drilling, milling, and sanding has been done to leave a clean topside.

4.1.5 Priority

Medium

4.2 Frontend

4.2.1 Description

The Turing Board's remote will be controlled via a phone app available on iOS and Android. The app was built using React Native. The backend is being handled by Google's Firebase API.

4.2.2 Source

Runtime Terrors

4.2.3 Constraints

N/A

4.2.4 Standards

N/A

4.2.5 Priority

Critical

4.3 Dampeners

4.3.1 Description

Excessive vibrations within the electronic housing can cause destructive resonance and render the board non-functional. In order to absorb these vibrations foam dampeners will be installed around all essential parts of the internal components.

4.3.2 Source

This requirement comes from the hardware engineers responsible for designing the internal components.

4.3.3 Constraints

Foam that is rigid enough to absorb vibrations caused by fast movement over uneven terrain but will not compress enough to cause damage to the internals.

4.3.4 Standards

No standards will be used.

4.3.5 Priority

High

5 Performance Requirements

The Turing board should be able to follow a target user and it should be able to be summoned from a parking location. The board should be able to use computer vision, the turning mechanism and the propulsion mechanism to navigate. The board should also be able to function as a normal electric long-board when a user is on it. Throughout this section, each major performance requirement will be examined in detail, including its constraints, standards and priority.

5.1 Turning Angle

5.1.1 Description

For our autonomous turning mechanism, the front wheels will only be able to turn with an angle of $\pm 30°$ from the neutral position ($0°$ A.K.A. facing forward).

5.1.2 Source

Kendall Buchanan (Runtime Terrors)

5.1.3 Constraints

The turning angle should be constrained to $\pm 30°$ to allow the board decent turning angles while not overextending and causing the board to topple over.

5.1.4 Standards

Based on research conducted when determining a maximum possible turning angle, the standard car has a turning angle of $\pm 30°$.

5.1.5 Priority

High

5.2 Limited Slip Differential

5.2.1 Description

A limited slip differential (LSD) to help with turning smoothly and efficiently in autonomous mode.

5.2.2 Source

Happy Ndikumana (Runtime Terrors)

5.2.3 Constraints

Since the trucks of a longboard are designed as a single piece (mostly) with an embedded axle, it is only be able to implement this LSD on the rear, motor-driven wheels. Also, how the rear wheels are constructed makes a physical LSD impossible. Therefore an electronic LSD will be coded into the motor controls.

5.2.4 Standards

As stated above, the physical construction of the longboard trucks, front and rear, make it impossible to implement a physical LSD. An electronic LSD would simply use the motor controller to simulate an LSD by making the inner wheel spin slower (or the outer wheel spin faster) when turning, thus making turning smoother and sharper.

5.2.5 Priority

Low

5.3 Battery

5.3.1 Description

A 288Wh, 8000mAh, 36 V battery will provide power to the entire system. For the preliminary design, the voltage will be stepped down using a Buck Converter providing 19V to the Jetson TX2. There will be an open 5V and 3.3V terminal if there is a need to connect external power to sensors and microcontrollers.

5.3.2 Source

Specified by the team member (Sarker Nadir Afridi Azmi)

5.3.3 Constraints

The power used by the entire system should be minimized to ensure the the longboard can operate for at least an hour or two with a rider before it needs to be charged.

5.3.4 Standards

288Wh, 8000mAh, 36 V

5.3.5 Priority

High

6 Safety Requirements

The Turing Board is a scientific achievement combining the power of electricity, the ingenuity of long-boarding, and the innovation of autonomous machine learning. This, however, also comes with a slew of safety concerns and features to be followed closely. The longboard must be kept in a dry place of a nominal temperature. Do not use around heavy machinery or vehicles. Do not use in the vicinity of sheer drops or falls. Do not use around children. Must be age 18+ to use. A helmet MUST BE WORN AT ALL TIMES. Recommended only for use by experienced boarders. Also, there are safety requirements that come with the machines and spaces that will be used to build this product.

6.1 Laboratory equipment lockout/tagout (LOTO) procedures

6.1.1 Description

Any fabrication equipment provided used in the development of the project shall be used in accordance with OSHA standard LOTO procedures. Locks and tags are installed on all equipment items that present use hazards, and ONLY the course instructor or designated teaching assistants may remove a lock. All locks will be immediately replaced once the equipment is no longer in use.

6.1.2 Source

CSE Senior Design laboratory policy

6.1.3 Constraints

Equipment usage, due to lock removal policies, will be limited to availability of the course instructor and designed teaching assistants.

6.1.4 Standards

Occupational Safety and Health Standards 1910.147 - The control of hazardous energy (lockout/tagout).

6.1.5 Priority

Critical

6.2 National Electric Code (NEC) wiring compliance

6.2.1 Description

Any electrical wiring must be completed in compliance with all requirements specified in the National Electric Code. This includes wire runs, insulation, grounding, enclosures, over-current protection, and all other specifications.

6.2.2 Source

CSE Senior Design laboratory policy

6.2.3 Constraints

High voltage power sources, as defined in NFPA 70, will be avoided as much as possible in order to minimize potential hazards.

6.2.4 Standards

NFPA 70

6.2.5 Priority

Critical

6.3 RIA robotic manipulator safety standards

6.3.1 Description

Robotic manipulators, if used, will either housed in a compliant lockout cell with all required safety interlocks, or certified as a "collaborative" unit from the manufacturer.

6.3.2 Source

CSE Senior Design laboratory policy

6.3.3 Constraints

Collaborative robotic manipulators will be preferred over non-collaborative units in order to minimize potential hazards. Sourcing and use of any required safety interlock mechanisms will be the responsibility of the engineering team.

6.3.4 Standards

ANSI/RIA R15.06-2012 American National Standard for Industrial Robots and Robot Systems, RIA TR15.606-2016 Collaborative Robots

6.3.5 Priority

Critical

6.4 Weather Proof Casing

6.4.1 Description

A water-proof case is needed to protect the sensitive electronic components of the Turing board from environmental conditions. In addition to keeping out moisture the case will act as a barrier from any debris that could cause damage while the board is at high speeds (rocks, sticks, etc).

6.4.2 Source

This requirement is from the hardware engineers.

6.4.3 Constraints

The profile of the container must be slim enough to not touch the ground while the board is turning. The case must be strong enough to withstand limited physical stress. A rubber gasket or seal is necessary to prevent liquid from touching the sensitive equipment.

6.4.4 Standards

N/A

6.4.5 Priority

Future

6.5 Alarm or Buzzer for Improper Use

6.5.1 Description

The Turing Board's autonomous capabilities are not intended for use with a rider on the long board. A weight sensor will trigger a buzzer to sound if the user attempts to ride while under autonomous operations or if a change in weight is detected while the turning mechanism is engaged.

6.5.2 Source

This requirement is from both the hardware and software engineers.

6.5.3 Constraints

The buzzer will need to be loud enough to catch the attention of the user despite environmental distractions.

6.5.4 Standards

No standards were used.

6.5.5 Priority

Future

6.6 Board Response to Accidents

6.6.1 Description

The Turing Board's response to an accident is necessary. In the regretful case a user should fall off the board, the board must take the appropriate measures to make the user's life easier and keep bystanders safe. There are two main response expected if a user falls off the board. If the user falls of the board and the Turing Board is still in the user's vicinity, then the moment the sensor reading changes from "user weight" to "no weight", the Turing Board stops. This same mechanism applies in the case the user falls off and lands far away from the board. In these events, the board should autonomously find its way back to the user.

6.6.2 Source

These responses were specified by the group.

6.6.3 Constraints

The board must have a reliable weight sensor that will always return the right weight. A faulty reading could cause an accident itself by suddenly stopping the board.

6.6.4 Standards

If the Turing board is within 3 meters of the user after the user falls off, the board will automatically stop.
If the Turing board is outside of a 3 meters parameter of the user after an accident and emergency stop, the board must autonomously roll back to its user.

6.6.5 Priority

Future

6.7 Mode Switch

6.7.1 Description

The role of the mode switch is to disengage autonomous mode. With the help of the weight sensor, it will be determined if a user, a small load or nothing is on top of the board. When a user is on the Turing board, we must prioritize their safety. The way we will do this is by disengaging autonomous mode and making sure the turning mechanism is locked at 0 degrees. This will ensure the Turing board can be operated as a normal electric long-board and prevent any accidents that could be caused by a misaligned front truck.

6.7.2 Source

The role and mechanics of the mode switch were specified by the team.

6.7.3 Constraints

When a set weight is exceeded, meaning a user is on the board, autonomous mode will be disengaged and the turning mechanism will be rotated and locked at 0 degrees for the user's safety.

6.7.4 Standards

If a weight greater than 23 kg (50 lbs) is detected, the "mode switch" will be triggered. It will disengage autonomous mode, rotate the trucks back to 0 degrees and the trucks will be locked at that position using solenoids.

6.7.5 Priority

Critical

7 Maintenance & Support Requirements

The Turing Board is ultimately meant to be a full product sent to a customer ready to ride right out of the box. For this reason, the majority of the maintenance and support items are abstracted from the user's view. We will provide a user manual to the user, but other than that it would largely be up to the supporting team to resolve any technical issue with the board. For the app, we are hosting our login admin portal on Google's Firebase Authentication.

7.1 Firebase Authentication Admin Portal

7.1.1 Description

The Turing Board's authentication is hosted through Google's Firebase. It currently uses the free Spark Plan. Through this portal, an admin would have the ability to manage users, reset passwords, and monitor authentication usage.

7.1.2 Source

Sahaj Amatya & firebase.google.com/pricing

7.1.3 Constraints

The Spark Free plan for Firebase only allows for 10,000 authentications per month.

7.1.4 Standards

N/A

7.1.5 Priority

Moderate

8 Other Requirements

The Turing Board has important features that don't quite fit into the other requirements section criteria, leaving it for the other requirements section. These have just as important an impact on the product as other requirements. These are generally the more innovative requirements to implement special features. As our project progresses and grows, these requirements may grow as well, allowing new features to be added.

8.1 Follow Along

8.1.1 Description

An identifiable marker worn on the rider (around the ankle or back of a shoe) will be recognized and tracked by the CV on the longboard to allow it to follow along with the wearer as they walk or run. The CV will be able to track if the marker is to the left or the right of the camera center and also measure the distance to the marker to help it keep pace with the wearer.

8.1.2 Source

Sahaj Amatya (Runtime Terrors)

8.1.3 Constraints

Camera is only able to track/recognize up to 20ft. Low-light conditions or partially obscured markers will have trouble being recognized.

8.1.4 Standards

Must be easily tracked in multiple lighting conditions (mainly daytime conditions) and at multiple angles.

8.1.5 Priority

High

9 Future Items

Due to the limited amount of time we have to produce the Turing Board, not all requested requirements will be able to be implemented. In this section are the requirements that could be added on to the board at a later time to improve its quality.

9.1 Weather Proof Casing

9.1.1 Description

A water-proof case is needed to protect the sensitive electronic components of the Turing board from environmental conditions. In addition to keeping out moisture the case will act as a barrier from any debris that could cause damage while the board is at high speeds (rocks, sticks, etc).

9.1.2 Source

This requirement is from the hardware engineers.

9.1.3 Constraints

The profile of the container must be slim enough to not touch the ground while the board is turning. The case must be strong enough to withstand limited physical stress. A rubber gasket or seal is necessary to prevent liquid from touching the sensitive equipment.

9.1.4 Standards

N/A

9.1.5 Priority

Future

9.2 Alarm or Buzzer for Improper Use

9.2.1 Description

The Turing Board's autonomous capabilities are not intended for use with a rider on the long board. A weight sensor will trigger a buzzer to sound if the user attempts to ride while under autonomous operations or if a change in weight is detected while the turning mechanism is engaged.

9.2.2 Source

This requirement is from both the hardware and software engineers.

9.2.3 Constraints

The buzzer will need to be loud enough to catch the attention of the user despite environmental distractions.

9.2.4 Standards

No standards were used.

9.2.5 Priority

Future

9.3 Board Response to Accidents

9.3.1 Description

The Turing Board's response to an accident is necessary. In the regretful case a user should fall off the board, the board must take the appropriate measures to make the user's life easier and keep bystanders safe. There are two main response expected if a user falls off the board. If the user falls of the board and the Turing Board is still in the user's vicinity, then the moment the sensor reading changes from "user weight" to "no weight", the Turing Board stops. This same mechanism applies in the case the user falls off and lands far away from the board. In these events, the board should autonomously find its way back to the user.

9.3.2 Source

These responses were specified by the group.

9.3.3 Constraints

The board must have a reliable weight sensor that will always return the right weight. A faulty reading could cause an accident itself by suddenly stopping the board.

9.3.4 Standards

If the Turing board is within 3 meters of the user after the user falls off, the board will automatically stop.
If the Turing board is outside of a 3 meters parameter of the user after an accident and emergency stop, the board must autonomously roll back to its user.

9.3.5 Priority

Future

REFERENCES