Smart Shoes

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Abstract: New fitness trackers and smartwatches are released to the consumer market every year. These devices are equipped with different sensors, algorithms, and accompanying mobile apps. The goal of these devices is to collect physical activity data that can be used as an addition to existing methods for health data collection in research. Furthermore, data collected from these devices have possible applications in patient diagnostics and treatment. But not everyone has the purchasing power to buy these fitness trackers and smartwatches just to keep track of their physical activities and health quantifiers. We propose the use of shoes which are universally worn and available, to be embedded with processors, sensors and digital communication technologies to enable the user to track their fitness records and enable them to view the metrics using a projector embedded in the shoe. This project aims to provide a proof of concept for this technology.

Introduction

We are witnessing the advent and the evolution of a revolutionary computing paradigm that promises to have a profound effect on the way we interact with the computers, devices, physical spaces, and other people. This new paradigm, called "ubiquitous computing", envisions a world where embedded processors, computers, sensors, and digital communication technologies are inexpensive commodities that are available everywhere from users clothing to watches from homes to offices. It is because of this boom in the ubiquitous computing, we see our mobile phones, watches, cars, homes and even headphones to be packed with sensors, computers and communication technologies.

With the recent growth in awareness and interest of people to live a fit and healthier lives and to keep track of as many biological changes in body as possible, and also with advancement of sensors and wireless technology, there is a growing trend among consumers to get a wearable fitness tracker to keep track of their food habits, weight, distance they covered, amount of time they slept, their heart rate etc. The most common and most popular fitness tracker in this area is Fitbit which is a wearable smart watch with app and dashboard that allows the user to keep track of their daily activity and it works by rewarding the user by completion of set goals. Another major player is Apple watch, which offers similar services like Fitbit and much more. Also, with individual apps available on Android and App Store, smartphones can also be used as activity trackers. Besides these, there are many other brands like MI, Oppo and Samsung which offer activity tracking services in form of a smartwatch.

Though these major players and trusted brand names are present in the market, yet we do not find everyone around us wearing a smartwatch or a Fitbit or any fitness tracker for that matter. This is because of the cost of the product and also due to the fact that these are not medical grade accurate and thus, their values cannot be taken at face value but they do provide a rough estimate to an individual and that is enough in most cases to keep track of an individual's health. Another reason for this is that people don't find it worth their money to get a product just for keeping track of their sleep and step counts and food habits.

So, we thought of providing a solution to some of these problems to encourage more people to buy these fitness trackers by finding a wearable that is universally present and is easily worn and thus, we thought of shoes. Everyone around the world wears shoes and if we offer health tracking benefits as an additional service to the shoes, we think that it will encourage more people to join the wearable fitness tracking revolution. Even if they don't want to use this service, it will always be present with them and thus, they will not ever have to pay extra for it.

Smart Shoes components

Raspberry Pi Processors

The Raspberry Pi 3 Model B+ is the latest product in the Raspberry Pi 3 range, carrying an updated 64-bit quad core processor running at 1.4GHz with built-in metal heatsink, dual-band 2.4GHz and 5GHz wireless LAN, faster (300 mbps) Ethernet, and PoE capability via a separate PoE HAT. It has Bluetooth capabilities as well. It will be running on Raspbian Stretch OS which is a LINUX distribution.

Figure 1. Raspberry Pi 3 Model B+

Figure 2. Raspberry Pi 3 Model B+ Pin Layout

Pulse Rate Sensor

The pulse rate sensor works by using a technology called photoplethysmography or PPG, to measure heart rate. It tests how much green light it can see when in contact with the skin. Blood is red because it absorbs green light, so when the heart beats, there is more blood flow in the body and hence, more green light absorption. So, between heart beats, there is less absorption of green light. The circuitry on the sensor analyzes this minor change in received light and thus, measures heartbeats.

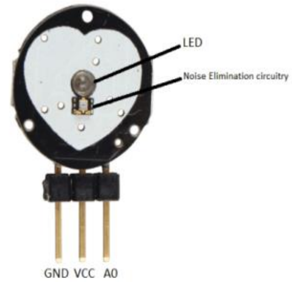


Figure 3. Pulse Rate Sensor

Velostat/Linqstat Pressure Sensor

Velostat also known as Linqstat is a conductive material which is a pressure sensitive sensor. Its resistance decreases on increasing pressure or squeezing and hence, it can be used to make flexible sensors. It is used in the project to measure the step counts.

Figure 4. Velostat sheet

Capacitive Touch Sensor

As the name suggests it is a sensor that detects human touch. The MPR121 is a capacitive touch sensor controller driven by an I2C interface. It is incorporated in the project to serve the role of push buttons but by fingers touch to provide much better feel to the user while navigating the user GUI interface.

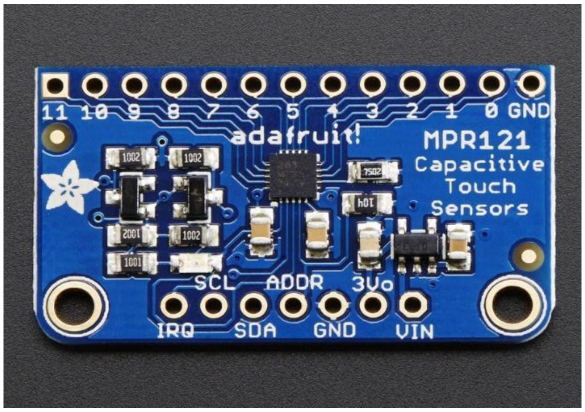


Figure 5. 12 Key Capacitive Touch Sensor

DLP2000 EVM Projector

The LightCrafter Display 2000 EVM is a Pico projector development board by Texas Instruments (TI) which has an I^2C interface for control and display of data at a brightness of 30 lumens. The projector has a resolution of 640 x 360 and 76 cm x 54cm in size.

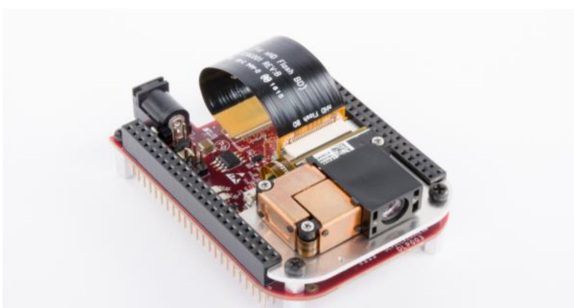
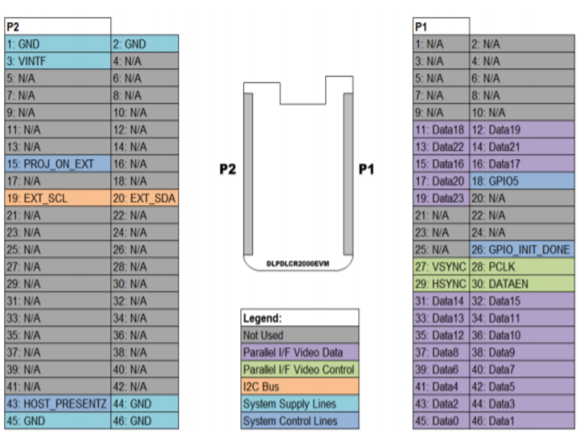


Figure 6. DLP LightCrafter Display 2000 EVM



P2	
1: GND	2: GND
3: VINTF	4: N/A
5: N/A	6: N/A
7: N/A	8: N/A
9: N/A	10: N/A
11: N/A	12: N/A
13: N/A	14: N/A
15: PROJ_ON_EXT	16: N/A
17: N/A	18: N/A
19: EXT_SCL	20: EXT_SDA
21: N/A	22: N/A
23: N/A	24: N/A
25: N/A	26: N/A
27: N/A	28: N/A
29: N/A	30: N/A
31: N/A	32: N/A
33: N/A	34: N/A
35: N/A	36: N/A
37: N/A	38: N/A
39: N/A	40: N/A
41: N/A	42: N/A
43: HOST_PRESENTZ	44: GND
45: GND	46: GND

Legend:
Not Used
Parallel I/F Video Data
Parallel I/F Video Control
I2C Bus
System Supply Lines
System Control Lines

P1	
1: N/A	2: N/A
3: N/A	4: N/A
5: N/A	6: N/A
7: N/A	8: N/A
9: N/A	10: N/A
11: Data18	12: Data19
13: Data22	14: Data21
15: Data16	16: Data17
17: Data20	18: GPIO5
19: Data23	20: N/A
21: N/A	22: N/A
23: N/A	24: N/A
25: N/A	26: GPIO_INIT_DONE
27: VSYNC	28: PCLK
29: HSYNC	30: DATAEN
31: Data14	32: Data15
33: Data13	34: Data11
35: Data12	36: Data10
37: Data8	38: Data9
39: Data6	40: Data7
41: Data4	42: Data5
43: Data2	44: Data3
45: Data0	46: Data1

Figure 7. EVM Pin Layout

DLP LightCrafter Display 2000 EVM consists of 2 sud-systems:

- Light engine: Consists of the optics, RGB LEDs and a 640x360 DLP2000 DMD. It also includes the power electronics drives to drive the LED and the DMD.
- Driver board: Includes DLP chipset DLPC2607 to control the display and DLPA 1000 PMIC/LED driver to time and drive the RGB LEDs.

DLP technology is based on an optical semiconductor, called a Digital Micromirror Device (DMD), which uses mirrors made of aluminum to reflect light to make the picture. The chip can be held in the palm of your hand, yet it can contain more than 2 million mirrors each, measuring less than one-fifth the width of a human hair. The mirrors are laid out in a matrix, much like a photo mosaic, with each mirror representing one pixel. If you look closely at a DMD, you would see tiny square mirrors that reflect light, instead of the tiny photographs. From far away (or when the light is projected on the screen), you would see a picture. The number of mirrors corresponds to the resolution of the screen.

Project Architecture & Framework

For this project, we have embedded heart rate sensor, capacitive touch sensor for application navigation and Velostat pressure sensor for step count on the left shoe while the Raspberry Pi on the right shoe communicates with left shoe via Bluetooth and gathers the data and displays them via the DLP2000 EVM projector.

The smart shoe functionality is split into two shoes, one shoe which handles only the projection has an DLP2000 EVM connected to a Raspberry Pi model 3b+. There are two power sources, one to power the DLP 2000 EVM and other to power the Raspberry Pi. This was done so because our DLP 2000 EVM doesn't support power-sharing and runs on a higher voltage level (6V). This Raspberry Pi consists of the GUI to display both the heart rate and the step-count measurements when requested. It receives the data for the heart rate and the step count from the other Raspberry

Pi (on the left shoe). The Heart Rate GUI displays the current heart rate, a graph showing trend in the variation of previous heart rate readings and statistics related to them like mean, median, max and min. The Step Counter GUI displays the current Steps taken and the progress bar to represent the completion towards a set goal.

1		P2_6: 5V	
	P1_27: VSYNC		
	P1_29: HSYNC		
	P1_16: Data17	P1_38: Data9	
		P1_36: Data10	
	P1_45: Data0	P1_46: Data1	
		P2_20: EXT_SDA	
		P2_19: EXT_SCL	
	P1_42: Data5		
	P1_32: Data15		
	P1_39: Data6	P1_31: Data14	
		P1_33: Data13	
	P1_28: PCLK	P1_30: DATAEN	
	P1_34: Data11		
	P1_35: Data12	P1_40: Data7	
	P1_37: Data8		
	P1_43: Data2	P1_15: Data16	
		P1_44: Data3	
	P2_46: GND	P1_41: Data4	40

Figure 8. Raspberry Pi mapping to DLP2000 EVM

The fitness tracking and body vitals sensing is done on the other shoe which has various sensors like Pulse rate sensor, Velostat and the capacitive touch buttons connected to the Raspberry Pi. This design choice was taken for two main reasons, first because the DLP 2000 EVM connected to the other Raspberry Pi (on the right shoe) takes up most of the pins leaving very few GPIO pins which did not meet our requirements, and the other reason being in case of ergonomics having two Raspberry Pi on two shoes makes it somewhat balanced in weight and more natural to use. The Pulse rate sensor and the Velostat to count steps are connected to channel 0 and channel 1 of the MCP3008 8-channel, 10-bit ADC respectively which is then connected to the Raspberry Pi and it also has a MPR121 12-way Capacitive touch module to detect 3 gestures, one to display the heart rate, one to show step count and the last one to exit from the GUIs. Both the Raspberry Pis are connected via Bluetooth to one another to have a two-way communication to send and receive data. The Raspberry Pi on the left shoe processes the sensor data and sends it over to the Raspberry Pi on the right shoe upon request via Bluetooth so that the data can be projected over the Projector in the GUI. Depending on what type of capacitive touch button is pressed its corresponding sensor data and the GUI command to display its corresponding screen is sent via Bluetooth. The sensor data of the previous readings is maintained in a database so that it can be recovered for analysis and medical study.

Table 1. Raspberry Pi Mapping to MCP3008 ADC

Raspberry Pi	MCP3008
Pin 1 (3.3V)	Pin 9, Pin 10
Pin 6 (GND)	Pin 11, Pin 16
Pin 24 (SPI_CE0)	Pin 15
Pin 23 (SPI_SCLK)	Pin 12
Pin 21 (SPI_MISO)	Pin 13
Pin 19 (SPI_MOSI)	Pin 14

Table 2. Pulse Rate sensor and Velostat sensor mapping to Raspberry Pi and MPC3008 ADC

Pulse Sensor – S	MCP3008 Pin1
Pulse Sensor +ve	RPi Pin 1 (3.3V)
Pulse Sensor -ve	RPi Pin 6 (GND)
Velostat Lead 1	MCP3008 Pin2
Velostat Lead 2	RPi Pin 1 (3.3V)

Table 3. Raspberry Pi Mapping to MPR121 Capacitive touch.

Raspberry Pi	MPR121
Pin 1 (3.3V)	VIN
Pin 6 (GND)	GND
Pin 3 (I2C_SDA)	SDA
Pin 5 (I2C_SCL)	SCL

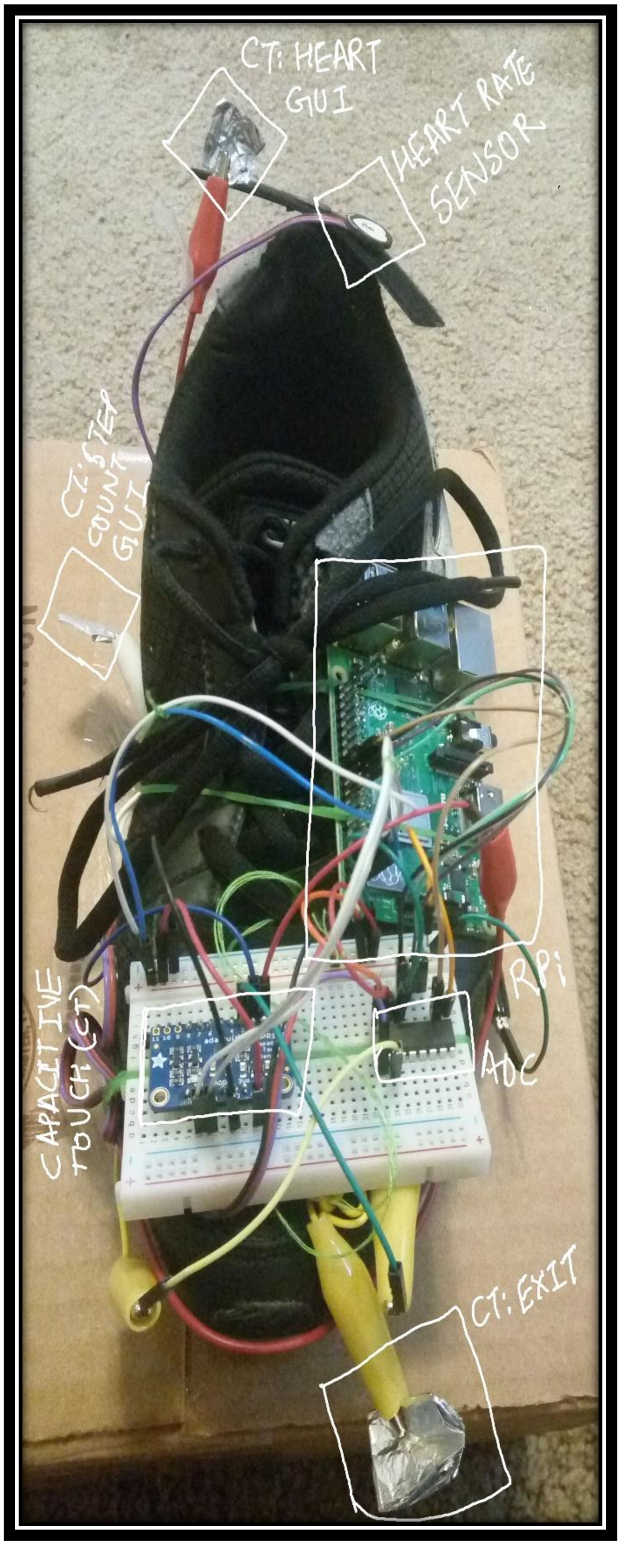


Figure 9. CLOSEUP: Left Shoe (Sensing Shoe)

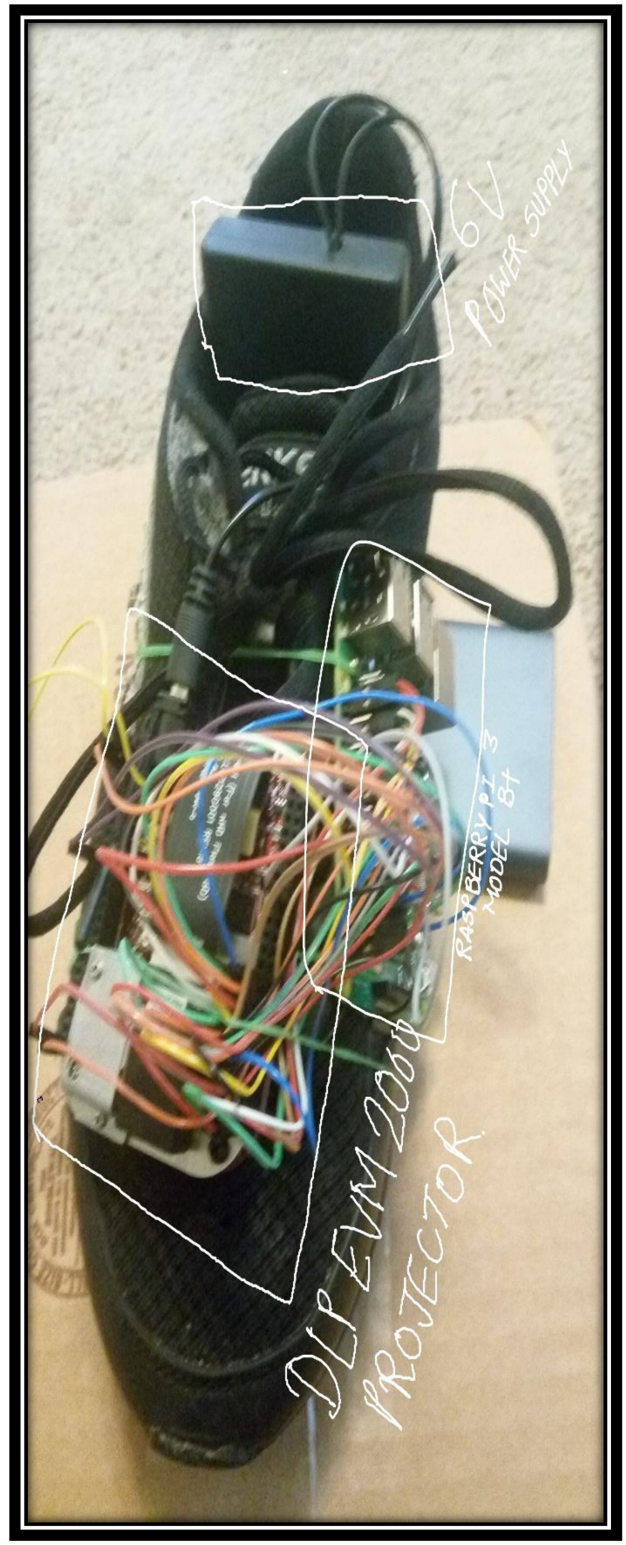


Figure 10. CLOSEUP: Right Show (Projector Shoe)

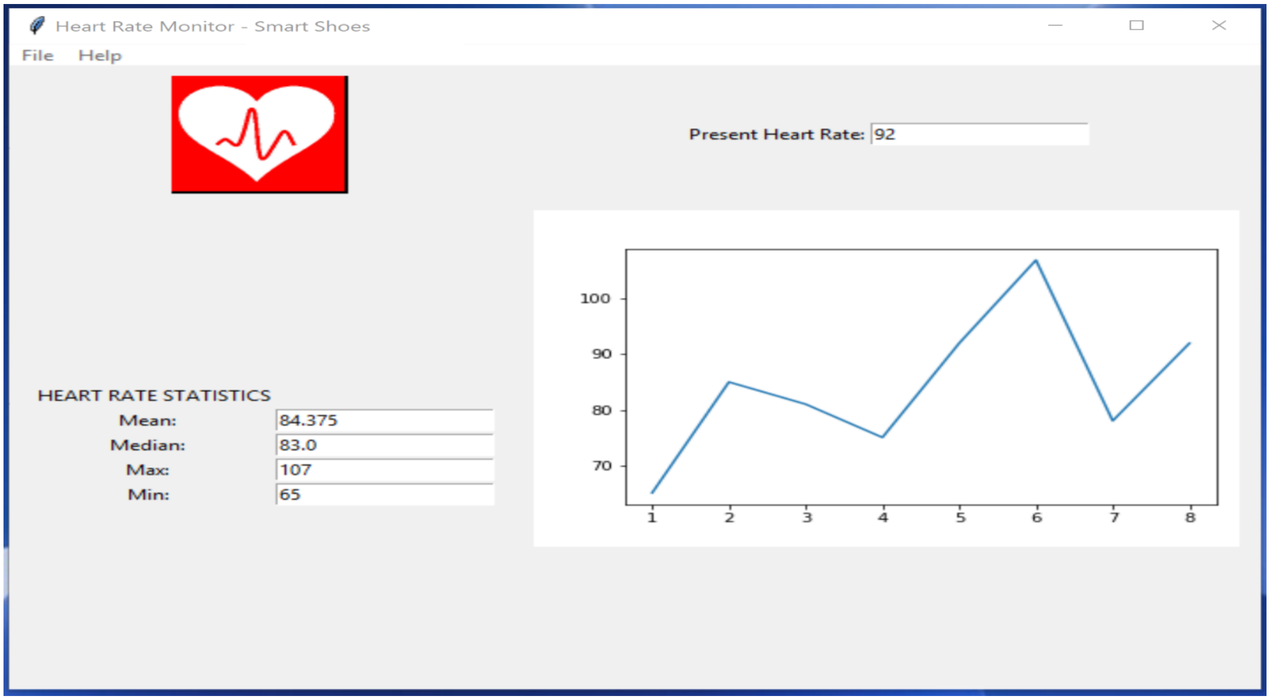


Figure 11. CLOSEUP: Heart Rate Monitor GUI

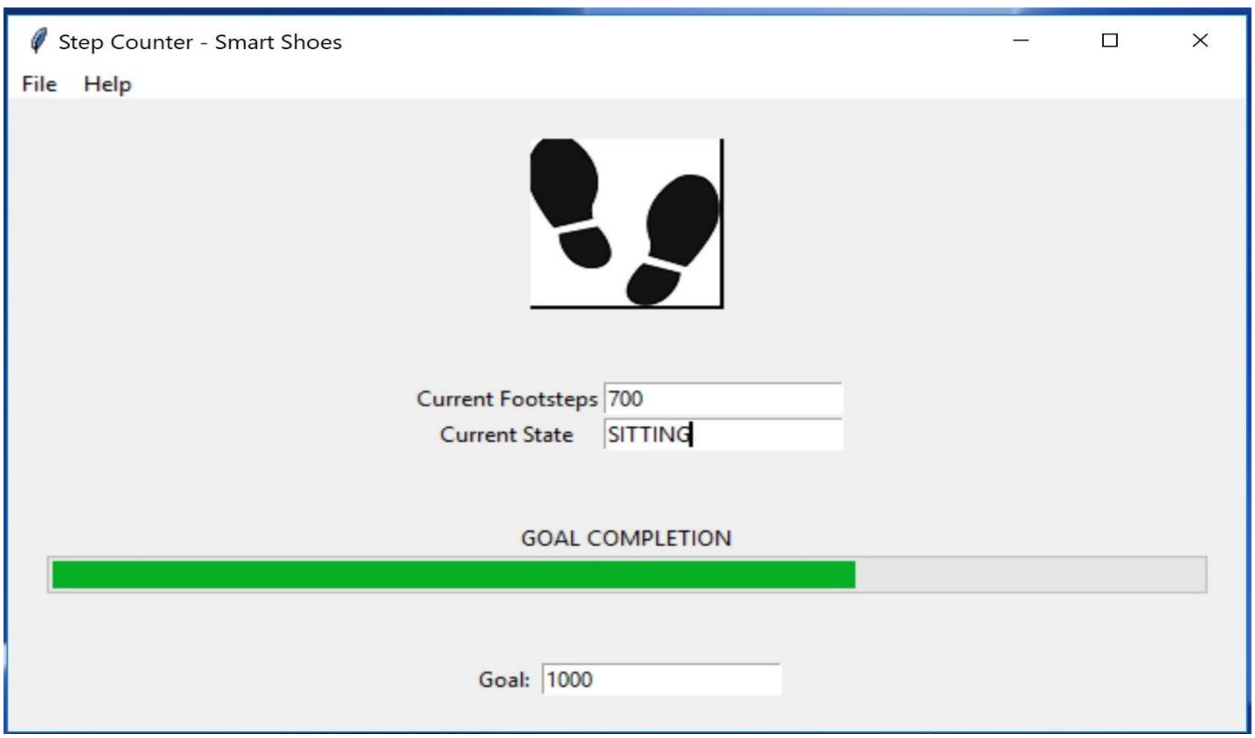


Figure 12. CLOSEUP: Foot Steps Counter GUI

Both the GUIs were created using Python Tkinter Library and thus, the user interface can be modified or changed as per user study and requirements. The aim of the GUI to be designed in such a manner, was to give an idea about how the data can be presented to the user via GUI elements and that how storage of data history and statistics drawn from it is helpful.

Future Scope of Work

Though the project is good, it is far from perfect. There are lot of changes that can be made in the project to make it a much better prototype for the fitness tracking smart shoes. Here are some of the features and services we plan to attach to the shoe:

- **Heart Rate Sensing Electrode:** We would replace the pulse rate sensor by a heart rate sensing electrode so that the user's heart rate can be measured even during running or moving through veins in the foot or we would use a much better pulse rate sensor to measure heart rate without placing finger on it.
- **Better Step Count:** For better step count, we will incorporate the velostat in both the shoes which couldn't be done at the current moment because of the lack of GPIO pins but this would done later by using an Arduino to collect data and send it to Raspberry Pi for processing.
- **GPS Sensor:** We would like to incorporate a GPS sensor in the shoe so that the user can get his/her location on a map and can also decide a near destination point.
- **Android App connectivity:** Currently all the data that is collected from the user is stored in the Raspberry Pi processor embedded in the shoe. In future, we would like to send this data to a server where it can be accessed by an app, so that user can visualize it without using the shoe as well.
- **More Information:** We would like to collect more data about the regions of foot that experience a lot of pressure during exercise or playing sports by mapping pressure values for the entire foot. This would be done by placing velostat pressure sensor at various regions inside the shoe.

Conclusion

The prototype of the smart shoes works perfectly and with dedicated hardware chip and sensors and with more design input, it can be developed as light weight fitness tracking shoes. The smart shoes present us with a fine example of ubiquitous computing and wearable electronics that can become a trend and be better fitness tracker solutions with much more added benefits than the original product.

With digital communication capabilities the shoes can communicate with a variety of elements in a user environment and help make user's life a much better experience.

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