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Digital Leg Tracker - Sensor Fusion: Proposal

Introduction

Problem:

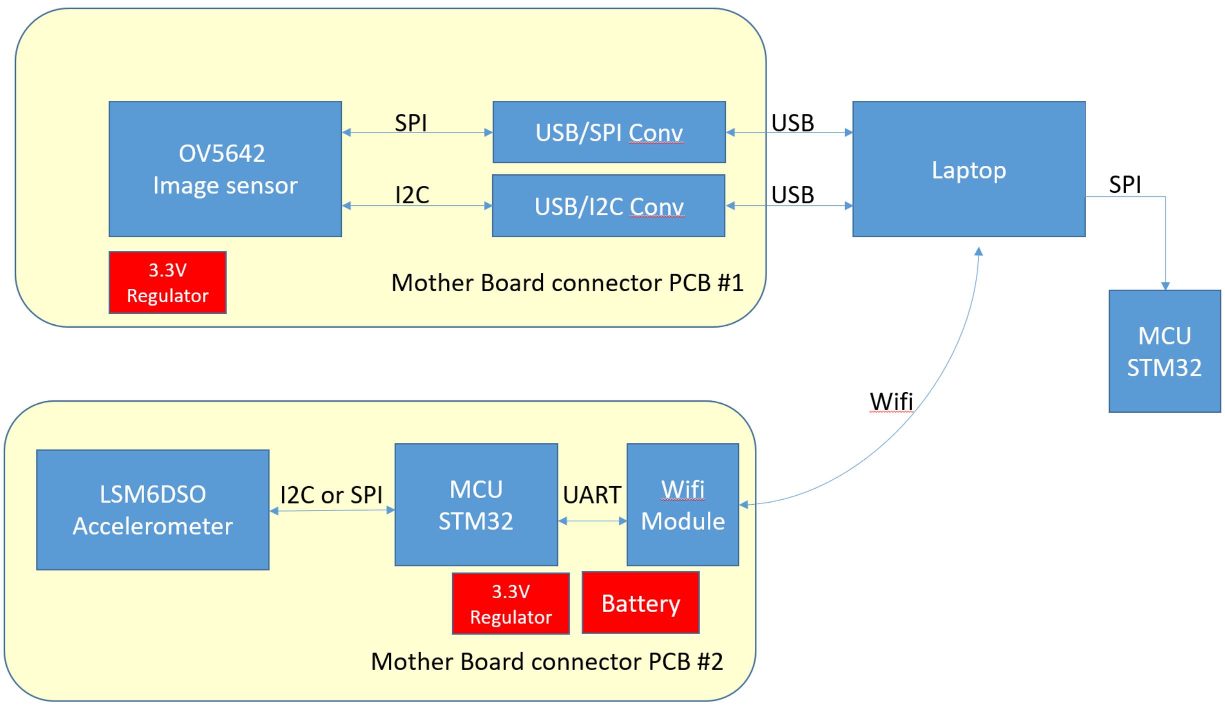
For many modern technologies, such as VR, hand gesture control is necessary for people to interact with the controller. The use of this space requires the user to be able to track a position and move in the physical plane to achieve any meaningful input; However, for people with disabilities, those actions may not be possible, thus limiting the potential of this technology. With the ever-growing use of these technologies in both commercial and business use, a solution to replace the need for hand gestures and allow these people to access these technologies is needed. Although motion tracking technology for other body parts, such as the leg, is already available in the market, they tend to use expensive cameras. This cost also hinders the growth of virtual reality and similar technologies, as the added fee to be able to access this equipment turns many consumers away. Without a middle ground between cost and efficiency, these new revolutionary technologies will not influence our world to the potential that they can.

Solution:

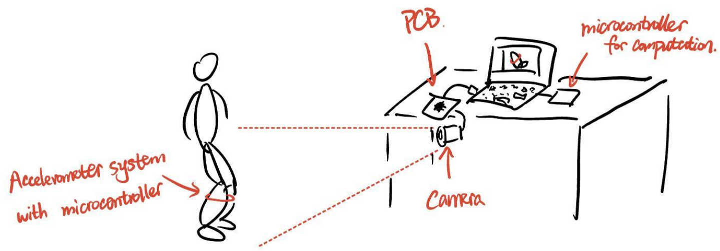
By creating a device that can track your leg movement, we can replace the need for hand gestures to serve as inputs for controllers which can help those who are impaired in their arms. We shall design a motion tracker that consists of lower frame rate cameras that will allow the user's leg to be registered as a motion digitally, allowing for more affordable controllers to exist using technology similar to the current controllers.

We will be using cameras to track the movement of the leg, as currently most motion tracking technology uses very high end cameras. We will be cutting costs by using cheaper cameras with a lower framerate but maximizing their usage. While the movement may seem choppy due to being a noticeable fps value, it will cut costs and make our product more affordable for manufacturing and for the user. We will also be using accelerometers that will be attached on the user's legs. Using these data, we can perform sensor fusion which will allow our device to track motion as if it was using a higher framerate camera.

Visual Aid:



Demo Aids.

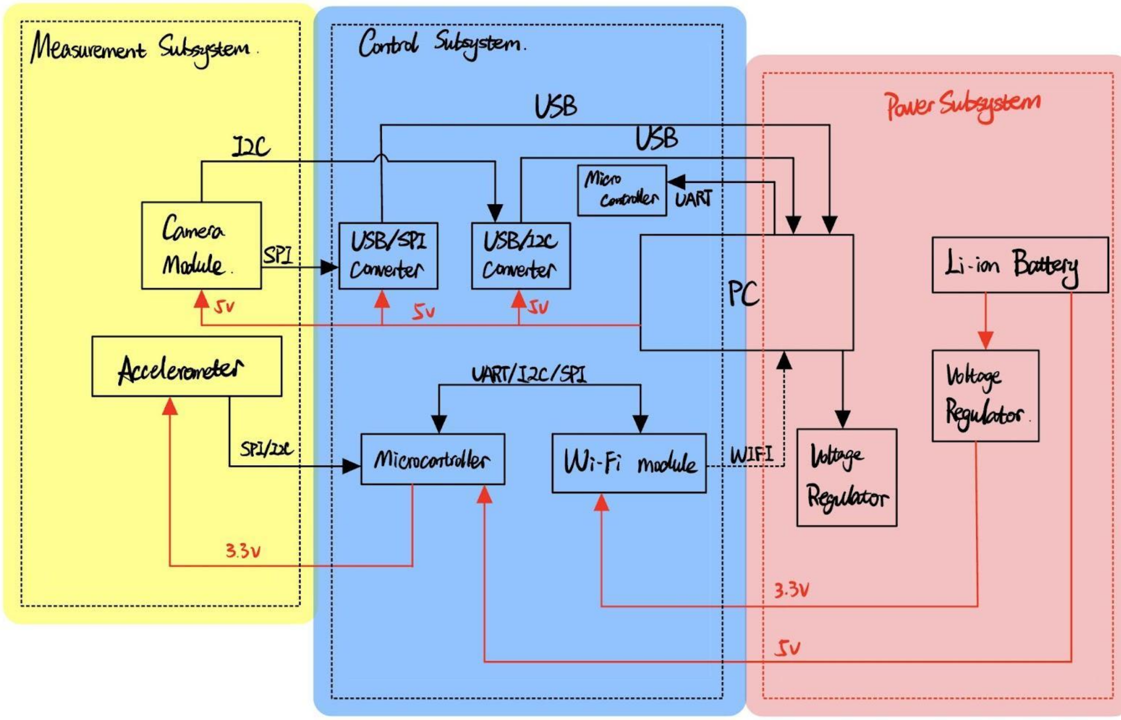


High-Level Requirements:
To consider this leg tracker a success, we have three main criteria:

1. The measured output of the leg is within 6 inches of absolute error of the actual position 80% of the time. This criteria exists so that our project is accurate in its function.
2. The minimum refresh rate of our output is 60 frames per second. This criteria is to ensure that our tracking is smooth and constant, as 60 fps is the current standard of most cameras.
3. The response time of the data will be within each refresh rate of the camera module, which is 30 fps, since we must provide output data with new camera input at every interval of camera input.

Design

Block Diagram:



Physical Design:

The physical design of our device mostly consists of the casing. The casing will be a 3D printed ring that houses our microcontroller and accelerometer. The casing will be large enough to fit the microcontroller, the accelerometer, the PCB that attaches them, the battery pack, and the wifi module. The hole in the center of the ring will be large enough to fit a full leg and clothing around. Since the plastic is very tough and not very comfortable on the skin, the casing must be able to fit around whatever pants the user is wearing. The weight of all the pieces inside the casing will be distributed in such a way that the ring is balanced and does not weigh down on one side significantly more than the other.

The rest of our physical design comes from connecting our camera module, PC, and device together. The camera module will simply sit on a table and connect to our PC on the same table with a USB connection. We will be using I2C/SPI to retrieve the camera data, as that will make interpreting the data significantly easier. The ring device and the PC will be connected using wifi, allowing us to not have any wires getting in the way of the user's leg. This connection also allows data to be transferred in a reliable manner, as attempting other forms of wireless communication can be inconsistent.

Subsystem Overview:

We have three subsystems, a measurement subsystem, a control subsystem, and a power subsystem. These three subsystems will communicate with each other to create our final product. These are all separate systems due to the complexity of each part and the different code needed between them.

Our measurement subsystem consists of the accelerometer and the camera module. Accelerometer will connect and communicate with the board, which is part of our control subsystem. Appropriate power will be provided from the board and the output of the accelerometer will be transferred through SPI/I2C for our accelerometer. Camera module will be connected to the converters which are part of the control subsystem as well and will be discussed in the control subsystem section. This subsystem will be powered by both PC and battery, which are part of the power subsystem.

Another subsystem we have is the control subsystem. This subsystem consists of our board, equipped with our microcontroller, which will receive the data from the accelerometer and relay the data to our Wifi module which will then wirelessly transmit the data to the PC. This subsystem also contains the USB/I2C converter and the USB/SPI converter which will communicate with the camera module through I2C and SPI interface, respectively, and transmit the data to PC through USB. Our PC will be receiving all the data and sending it to the second microcontroller which will then use the data to compute the finalized data. The control subsystem will be powered by the two power sources of the power subsystem.

Our last subsystem is the power subsystem. This subsystem consists of the PC and the battery, which will provide power to the other 2 subsystems. A voltage regulator will be included for both components of this subsystem so that they're capable of providing both 5V and 3.3V voltage supply. Our batter will be providing power to the microcontroller and the Wifi module while the rest are powered by the PC.

Subsystem Requirements:

Our measurement subsystem consists of an accelerometer and a camera module. The accelerometer we plan on using (PN: SEN-18020) is compatible for use in PCB design and it has SPI/I2C serial interface that allows us to enable this component to communicate with our board in control subsystem. This component requires a minimum of 1.7V and maximum of 3.6V supply voltage (Vdd) which means that a 3.3V supply of a board connected with a microcontroller can support it. This part allows us to receive data on the acceleration of the object attached with it, which will be the leg of the user in our case. As for our camera module, the part we're planning on using (DEV-18440) which is compatible for use in PCB design as well and has I/O ports that are compatible with both 5V and 3.3V. PC is capable of providing both of these voltage supplies which makes our measurement subsystem compatible with our power subsystem.. This part has a maximum image transfer rate range of 15~120 fps depending on the resolution of the image, which means that it suits our purpose of obtaining 30 fps images Our control subsystem consists of our board, which is equipped with a microcontroller. As previously discussed in the measurement subsystem, our board must be able to supply 3.3V at least for the accelerometer and it should also have an option to supply 5V just in case. This means that both 3.3V and 5V pins on our microcontroller should have a male or female pin connected to it so that both outputs are available for us to use. Once the data from our accelerometer is transferred to the microcontroller through either I2C or SPI interface, our microcontroller will relay the data to the Wifi module through one of its communication interfaces, UART, SPI and I2C. The Wifi module will then transmit the data to the PC through wireless communication. Our second board will contain the camera module and the converters, which will be connected through multiple SPI/I2C connectors, and it should also have a USB port on the board. Our camera module will communicate with the USB/SPI converter and the USB/I2C converter through their respective interface. The USB will then allow communication of data from the converters to the PC to be processed. Data from our measurement system will go through our control subsystem and will be transferred to the PC.

Lastly, the data from the PC will be transferred to our third board with the second microcontroller which will be receiving the data and computing the finalized data.

Our last subsystem is the power subsystem. This subsystem consists of 2 components, the battery and the PC. Our PC will be responsible for providing power for the parts that are physically connected to the PC while the battery will be responsible for powering the parts that will be attached on the user’s leg. Both parts will be connected with a regulator so that they’re capable of providing both 5V and 3.3V voltage supply since some of these components require a 5V voltage supply while some will malfunction with such a high voltage supply.

Subsystem Verification:

Requirements	**Verification**
1.All components must be connected to the appropriate power supply.	We can probe the pin that receives power for each component with a voltmeter and check that each component is receiving the

	appropriate voltage (5V or 3.3V).
2.The components of the accelerometer unit must not malfunction even if the user plugs in the battery backwards and corrects it afterwards.	The battery pack will make sure that power is not provided to the components of the accelerometer unit if the battery is in the wrong orientation. We can verify this functionality by having the battery placed in the wrong orientation while probing the power connections on the components with a power measurement tool such as a voltmeter. Power should not be provided.
3. Components of the accelerometer unit must not malfunction even if it's exposed to an environment that is hotter than room temperature since the components will be placed inside a case.	The accelerometer unit's functionality in a case can be tested individually by having it run for 10 minutes while checking the PC to make sure that the data from the accelerometer unit is being successfully communicated to the PC.
4. Our camera module should be capturing images at 30 fps and the data should be transferred to the PC and to the computational microcontroller for sensor fusion.	If everything works well, we should be receiving image data of a 30 fps camera. If it doesn't work, we can first check the connection between each component by probing the inputs and outputs to check that some sort of data is being transferred. If data is being transferred but the system is malfunctioning, we can check the data being received by the PC to see if it's either our SPI interface or I2C interface that's not working. If either isn't working properly, we can check the connection of the camera module, respective converter, and the USB to check where the problem occurs and address appropriately.
5. Wifi module must be able to communicate with the PC wirelessly throughout the entire duration of the demo.	We can check that the wireless connection is established and that data is being transferred through it by having the wifi module send data to a website with an arbitrary IP address and access the website with another device to check the data that's being transmitted.

Tolerance Analysis:

One aspect of our design that could pose a risk to successful completion of the project would be the voltage regulator causing the hardware components to not receive enough voltage. If our Vin-Vout value is less than that of the dropout voltage of a voltage regulator, our system may end up functioning as if there isn't enough voltage being supplied to it. This can be solved by having high enough Vin relative to the required Vout of the system. Our minimum Vout is 3.3V since both of our components in our measurement subsystem, which are the accelerometer and our camera module, are compatible with 3.3V voltage supply. Our Vin value can be up to 5V since our board will be equipped with a microcontroller which makes our maximum dropout voltage of the voltage regulator 5-3.3=1.7V. This is enough for voltage regulators that regulate voltage to an output of 3.3V so this design should be feasible.

Power consumption of the external components which will be powered by the battery is an important factor as well since it would determine how long our system can run. The maximum power consumption for each external component is (0.55mA+ 4.3mA) * 3.3V = 16.005 mW for the accelerometer, (266mA+22mA) * 3.3V = 950.4 mW for the Wifi module, and 160mA * 5V = 800mW for the microcontroller. 16.005mW + 950.4mW + 800mW = 1766.405mW = 1.766405W. A common AA battery has around 3~4 Wh of lifetime so placing multiple of these batteries would make the lifetime of our system last hours. Using a triple battery holder for example, our system's lifetime would be approximately 6 hours which is long enough to track leg motions for time consuming activities.

Heat in external components is also a factor to be considered. The operating temperature for all 3 parts in the external casing is -40°C to 85°C. Since the demo and operation of the system would normally be under room temperature which is around 20°C, our microcontroller would have to become extremely hot for it to pass the operating temperature. Since we're only using 2 connections, we wouldn't be generating heat anywhere near the maximum heat capacity and we can also make sure that we remain within this temperature range by adding some holes in the casing to allow heat dissipation.

Another aspect of our design that could pose a risk to successful completion of the project would be the framerate of the camera module and the process of transferring the data from the camera module to the PC. According to the datasheet of the camera module, the maximum image transfer rate of the module is 30 fps when using 1080p (1920x1080). This means that each image taken by the camera module contains 2,073,600 pixels which translates to a file size of 49.77 Mbits. This means that we'll have to transfer data at the rate of 1493.1 (30 * 49.77) Mbits per second since we're capturing 30 images per second. A SPI interface in common MCUs, such as a STM32 MCUs, transfers data at the rate of around 30 Mbits/s which is nowhere near what we need. In order to solve this problem, we can use a USB/SPI converter and a USB/I2C converter to receive data from the camera module which can increase our data transfer rate to fit our needs.

Ethics and Safety

Following the IEEE code of Ethics and the OSHA standards, we promise to keep the following code of Ethics and safety.

- Safety First
  - Safety is our top priority and we are committed to creating and maintaining a safe and healthy environment during the development process. Wearable components like our accelerometer would be covered with insulation tape and cloth to avoid accidental electric shock.

    - This is in accordance with IEEE Code of Ethics 1.
        - Code 1 states that all members must always prioritize and protect the safety of the public and the environment.
    - This is in accordance with OSHA standard 1910.137.
        - 1910.137 describes design requirements for protective electrical insulation equipment which is the insulation tape and cloth in our case.
- Compliance with safety regulations
    - We strictly adhere to the lab safety regulations and report any safety incidents or hazards.
    - This is in accordance with IEEE Code of Ethics 1 and 4.
        - Code 1 states that all members must always prioritize and protect the safety of the public and the environment.
        - Code 4 states that all members must refrain from participating in any activities that disobey the laws and regulations which include safety regulations.
    - This is in accordance with OSHA standard 1910 Subpart H.
        - Subpart H discusses hazardous materials and the safety procedures and equipment necessary for protection against different hazards.
- Privacy
    - We protect the privacy of sensitive information and data entrusted to us. We will only collect the minimum amount of data from the accelerometer and camera that are necessary for our project.
    - This is in accordance with IEEE Code of Ethics 4.
        - Code 4 states that all members must refrain from participating in any activities that disobeys the laws and regulations which include privacy regulations.
- Avoid Misuse
    - We will try our best to avoid accidental or intentional misuse of our project. For accidental misuse, we would compose a manual for the user to let them know how to use the product properly. In the case of intentional misuse, one possible scenario is to attach the sensor and camera to others without their acknowledgement. To avoid this situation, we would make the accelerometer part bright and obvious.
    - This is in accordance with IEEE Code of Ethics 1, 2, and 3.
        - Code 1 states that all members must always prioritize and protect the safety of the public and the environment.
        - Code 2 states that all members must work towards educating the public about new technologies.

        - Code 3 states that any professional project must refrain from creating and participating in a situation with conflicting interests and that the members must alert anyone who's affected by these situations if it occurs.
- Upholding the Code
    - We will always uphold these codes throughout the project regardless of the situation. We will report any and all cases of violation of these codes without the fear of retaliation.
    - This is in accordance with IEEE Code of Ethics 10.
        - Code 10 states that all members must keep each other accountable to follow these codes and that retaliation towards members who report violation of these codes should not happen.

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