Project Title: Real-time Exercise Coaching and Range of Motion Tracking using RTOS

"BarBuddy"

I. Introduction

- **Problem Statement:** The absence of real-time feedback regarding range of motion and speed during exercise can contribute to incorrect form, diminished results, and the potential for injury. Lifters often either don't reach close enough to technical failure to achieve optimal results or overshoot technical failure, leading to "junk volume" (Nippard, n.d.; Schoenfeld et al., 2021).
- **Proposed Solution:** The development of a wearable, FreeRTOS-based device that utilizes IMU sensors and Bluetooth technology to monitor range of motion and lifting speed, offering instantaneous feedback to enhance exercise form. Providing this feedback to the user will enable more optimal training, coaching lifters to stay in the desired range of motion, and to stop their set when technical failure is reached.

II. Project Objectives

- **Accuracy:** Attain suitable positional tracking accuracy for ranges extending up to 5 feet* during brief exercise sets.
- **Real-time Feedback:** Deliver audio cues upon detection of divergences from the intended range of motion or repetition tempo limits.
- **Usability:** Construct an intuitive, unobtrusive, and readily attachable sensor system.
- **Data visualization (optional):** Produce a simple companion app to display exercise data and patterns.

III. Methodology

- **Hardware:**
    - Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout (BNO055)
    - ESP32 Microcontroller
    - RealDigital BooleanBoard FPGA with MicroBlaze processor
- **Software:**
    - FreeRTOS on the MicroBlaze processor
    - Sensor fusion algorithms for position estimation
    - Range of motion and speed threshold detection logic
    - Feedback generation mechanisms
    - Bluetooth communication protocol
- **Description of product:**

    Due to time constraints, this will be a prototype "product," demonstrating the functionality of such a device, while not being the ideal end product. The Adafruit BNO055 has the benefit of a processing unit which does a fusion calculation on the sensor's data inputs. This makes the BNO055 an "all in one" AHRS sensor, which will provide accurate data with no processing needed. This will help take some of the load off of our FPGA. We ran a fusion package on the FPGA in a previous project, but it required a lot of stack space and we had several overflow errors. By moving the fusion processing to the sensor, we can take a lot of the load off of the FPGA.

The sensor will be attached to a small breadboard, along with an ESP332 microcontroller. This small breadboard will then be affixed to a fabric strap, which will have a velcro fastening mechanism. This strap can then be put on a barbell, or a limb for example. The ESP32 will send the positioning data from the BNO055 to the BooleanBoard, which has a built-in BLE module. Ideally, this strap would be a manufactured product with the sensor and transmitter built into a single small board; this prototype will demonstrate the idea. It is obviously not ideal to have a breadboard in the gym, but at least it's wireless!

The BooleanBoard will take the positioning data and process it to give the user feedback. The BooleanBoard will be responsible for recording the warm up set, determining the ROM, and notifying the lifter if they deviate from the ROM. In this way, the BooleanBoard doesn't have to be wired up to the user in any way, as that would be a large hindrance to the exercise.

As it stands, the current plan is to have the BooleanBoard plugged into a laptop, which will allow the lifter to interact with the board. This will allow us to provide a menu task and an interactive system through the terminal. Ideally, we would also involve an android app to interact with the board, that way we could eliminate the laptop. However, as a team of 2 this isn't feasible with the time constraints. This is another prototype situation, it's not perfect to carry a laptop around the gym.

The program running on the BooleanBoard will provide a menu for the user to enter the lift they are performing though a serial terminal, then start the warmup recording phase. During this phase the program will record the position data and define the boundaries for the range of motion. The user will then start the working set phase via the serial terminal, and start their set. If the user deviates from the ROM boundaries, the FPGA will display a message on the terminal indicating it, and logs the deviation.

We would like to implement a better feedback system for the lifter, such as an audio queue, but with the time and personnel limitations on this project, that will not be implemented. For now, the app will be designed with a 2 person workout team in mind, one person to use the application while the other lifts.

Once the user has finished the set, they can view data about their deviations on the terminal, or start a new lift.

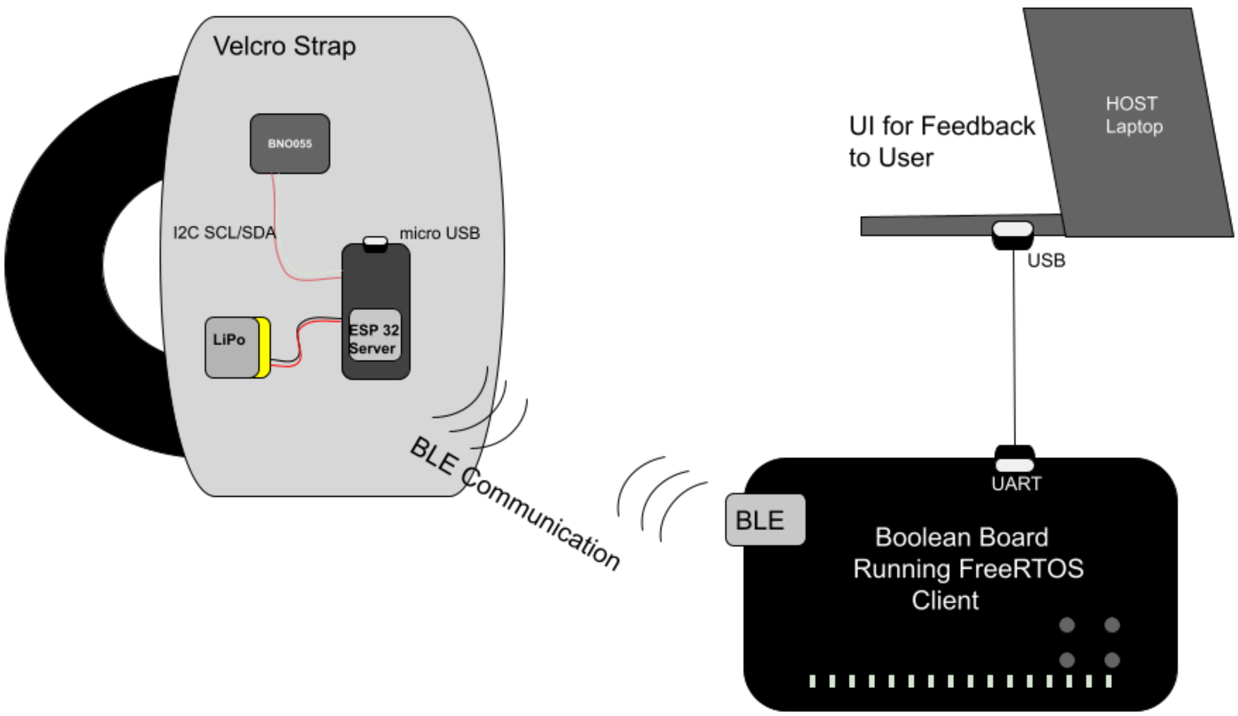

Fig. 1 Block Diagram

IV. Project Milestones

- [ ] Create IP with multiple UART drivers, one for the USB UART and one for the BLE UART.
- [ ] Test the UART functionality of both the BLE and USB UARTs
- [x] ~~Develop an app in Arduino IDE for the ESP32~~
    - [x] ~~ESP32 will be a client server which will automatically connect to the BooleanBoard over BLE~~

    (ESP32 will autoconnect but having issues with the BLE UART)

- [ ] Test the bluetooth serial connection between the ESP32 and the FPGA
- [ ] Test the BNO055 sensor for positioning data
- [ ] Create a breadboard with ESP32 and BNO055.
- [ ] Mount breadboard on strap.

- [ ] Develop application with feedback algorithm and user interface
- [ ] Test application
- [ ] Test product

Stretch goals:

- Add functionality to display the tolerance amount on the SSEG display
- Add functionality to display rep status on RGB LEDs (red = bad, green = good)
- Add functionality to adjust the ROM tolerance with the buttons

V. Budget

- Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout (BNO055) - $29.95 (from Adafruit Industries)
- ESP32 Microcontroller – HUZZAH32 (4MB Flash, WiFI+BT) - $19.95 (from Adafruit Industries)

VI. Team

- **Robert Wilcox**
- **Ibrahim Binmahfood**

VII. Potential Impact

- **Personal Fitness:** Assist users in accomplishing fitness objectives with greater efficiency and safety.
- **Injury Prevention:** Mitigate the likelihood of injuries arising from improper form.
- **Data-Driven Training:** Furnish quantifiable metrics to monitor progress.

VIII. Conclusion

- The current majority consensus among hypertrophy training studies is that training close to failure is essential for optimal growth, but that going beyond technical failure introduces greater injury risk and is not as growth promoting. The feedback provided by the *Barbuddy* will help lifters train closer to technical failure while not going beyond, improving the SFR of the exercise.

  This project provides an excellent demonstration of technology that can greatly enhance training, and serves as a prototype for potential future improvements. The next improvements would be developing a better way to house the sensor and ESP32, or possibly making a custom IC which would perform the necessary functions. This would be a lot smaller and less invasive to the user. The development of an app would also be a great next step, as it would allow the FPGA to be disconnected from the computer and just interact with the user wirelessly. Theoretically, a housing with an android device as a screen could be made for the FPGA, turning it into an all-in-one unit for this application.

These are obviously “pie-in-the-sky” type goals, but I think that this project does highlight an area of fitness that hasn’t really been touched. Though we are developing a very basic prototype version, I hope the value in demonstrating the possibilities of this tech are considered.

References

- Nippard, J. (n.d.). Junk volume: Why you must avoid it for max muscle growth. jeffnippard.com. Retrieved March 7, 2024, from https://jeffnippard.com/blogs/news/junk-volume-why-you-must-avoid-it-for-max-muscle
- Renaissance Periodization (n.d.). Training volume landmarks for muscle growth. RP Strength. Retrieved March 7, 2024, from https://rpstrength.com/blogs/articles/training-volume-landmarks-muscle-growth
- Team Full ROM. (n.d.). Hypertrophy training periodization. teamfullrom.com. Retrieved March 7, 2024, from https://teamfullrom.com/blogs/news/hypertrophy-training-periodization
- Schoenfeld, B. J., Grgic, J., Van Every, D. W., & Plotkin, D. L. (2021). Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. Sports, 9(2), 32. https://doi.org/10.3390/sports9020032