IBEHS 3P04 DESIGN PROJECT: GONIOMETER **Veronica Marrocco**

Design Product: Wearable Anklet to Measure Angle of Ankle Joint

Wearable devices that measure the range of motion (ROM) of human joint complexes serve an important purpose in clinical rehabilitation applications. This design is for a wearable ankle bracelet that will continuously measure the orientation angle of the ankle joint (**fig. 1**) and display it on an external screen.

From a structural point of view, the anklet was designed to be as small as possible in order to minimize disruption and maximize comfort/ease of use. It has one rectangular housing on each side to hold the orientation sensor (**BNO055**) for angle data acquisition and microcontroller (**ESP32**) for subsequent data processing. The rectangular housings are specifically designed to fit the dimensions of the two chips. The controller measures 2.1” x 0.8” x 0.4”, while the sensor measures 1.05” x 0.8” with an undefined thickness. Although it is undefined, this thickness is visibly smaller than that of the controller, verifying that a depth of 0.4” is large enough to accommodate either chip. In application, both chips will be glued down to the base of their respective housings to prevent movement and/or breakage. In addition, to protect the integrity of the chips, two lids were designed that fit perfectly into the top of the rectangular housings, sealing them shut. Each lid has a length and width that match that of its corresponding housing, with a height of 0.2”. This height is accounted for in the housing containers themselves by extending their preliminary height by the same amount. Hence, the heights are 1.0” rather than 0.8” in order to accommodate both the 0.2” lid and the 0.8” chips, resulting in a smooth fit. The CAD parts and design are pictured in the appendices below (**figs. 2-3**). Unfortunately, the anklet was not selected for 3D printing since there was a lack of printer availability and another contributor’s design model (which took up significantly less material) was therefore selected as the optimal design for printing (**fig. 9**). However, a low fidelity prototype of the anklet was successfully constructed using a cardboard box, velcro, sponge and the sensor/controller system mounted atop a breadboard (hardwired) (**fig. 8**), which is shown attached to the area of interest in **fig. 10**.

Anatomically, the ankle joint performs **three** key movements that would perceptibly alter its orientation angle and hence, that this design solution would intercept: plantar- and dorsiflexion occurring in the sagittal plane; internal-external axial rotation occurring in the transverse plane and inversion-eversion occurring in the frontal plane (**fig. 1**) [1]. When the anklet is worn, the user/clinician must therefore ensure to secure the orientation sensor at the back of the ankle (posterior) and slightly lateral, against the bony surface of the tibia, since this is where all three ankle movements are best observed and most emphasized. Moreover, the bony surface of the tibia provides a stabilizing anchor, reducing the bracelet's wriggle room once fastened and hence lessening the signal noise.

From a software point of view, the **BNO055** sensor outputs angle readings of the form (roll, pitch, yaw) or (x, y, z), which represent the degree of inversion/eversion, plantar-/dorsiflexion and ab-/adduction, respectively. This angle reading is relative to the BNO055's calibration, which utilizes the ankle's resting position, i.e. 10° of plantar flexion **y**, and 0° of other movement **x**, **z** [1], as reference for (**0**, **0**, **0**). This is implemented as a 10° offset angle in the y-direction during calibration as seen in the program code (**figs. 5-6**) and flowchart, which served as an important, preliminary organizational tool before implementing the logic source code (**fig. 4**).

Following this calibration step, the computer program enters data acquisition mode, i.e. an infinite loop that processes and displays the orientation angle data from the BNO055 sensor in **200ms** increments, ensuring the program picks up on meaningful change. While simulated in **fig. 7** as hardwired connections for simplicity, in practice, the ESP32 program will obtain sensor data and display it to an external screen all via Bluetooth, which is a built-in module of the controller. Indeed, a wearable device must be wireless and should not be so bulky as to carry the weight of an interim breadboard, as in fig. 7.

Finally, a major limitation of this design would be its poor signal-to-noise ratio, since there are several other, more proximal, joints that equally affect the positioning and movement of the posterior ankle. For instance, flexion and extension of the knee joint may mimic plantar- and dorsiflexion, respectively, providing a false indication of ankle joint mobility. Additional measures would have to be implemented to account for this noise.

References

[1] Brockett, C. L., & Chapman, G. J. (2016). Biomechanics of the ankle. Orthopaedics and trauma, 30(3), 232–238. https://doi.org/10.1016/j.mporth.2016.04.015

Appendices

Fig. 1. Movements of the Ankle Joint

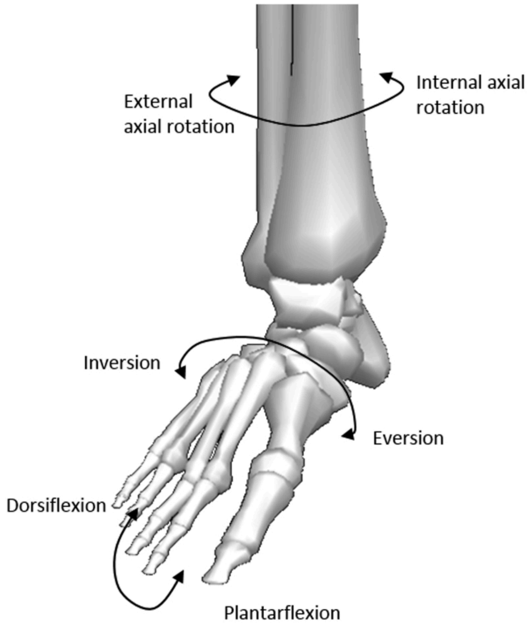

Fig. 2. CAD Design - Bracelet and Housing Model

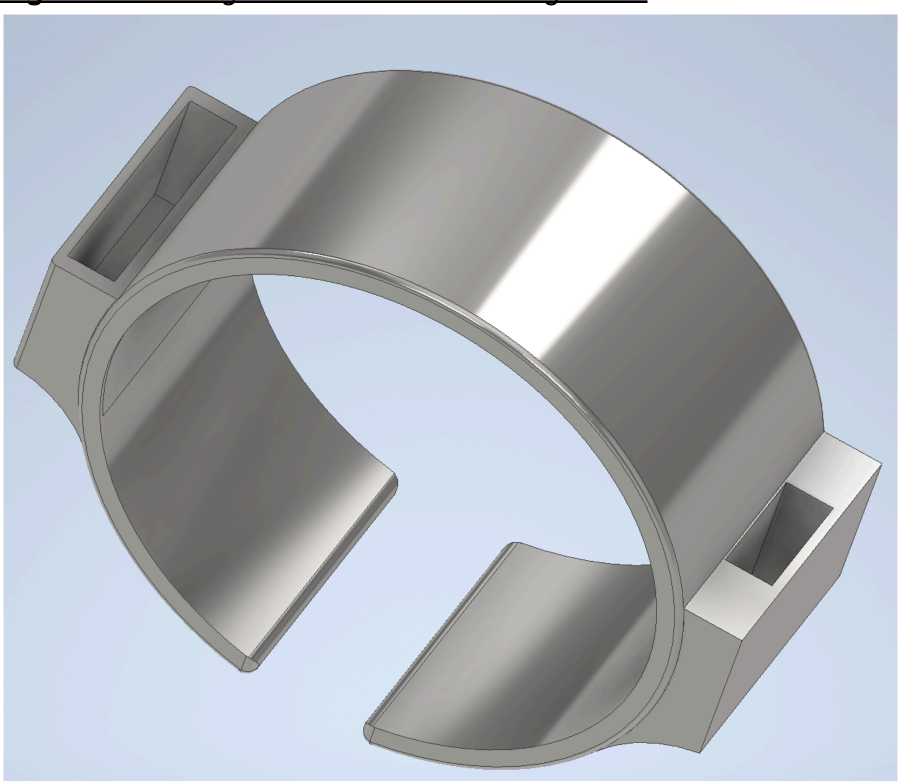

Fig. 3. BNO055 and ESP32 Lid Models

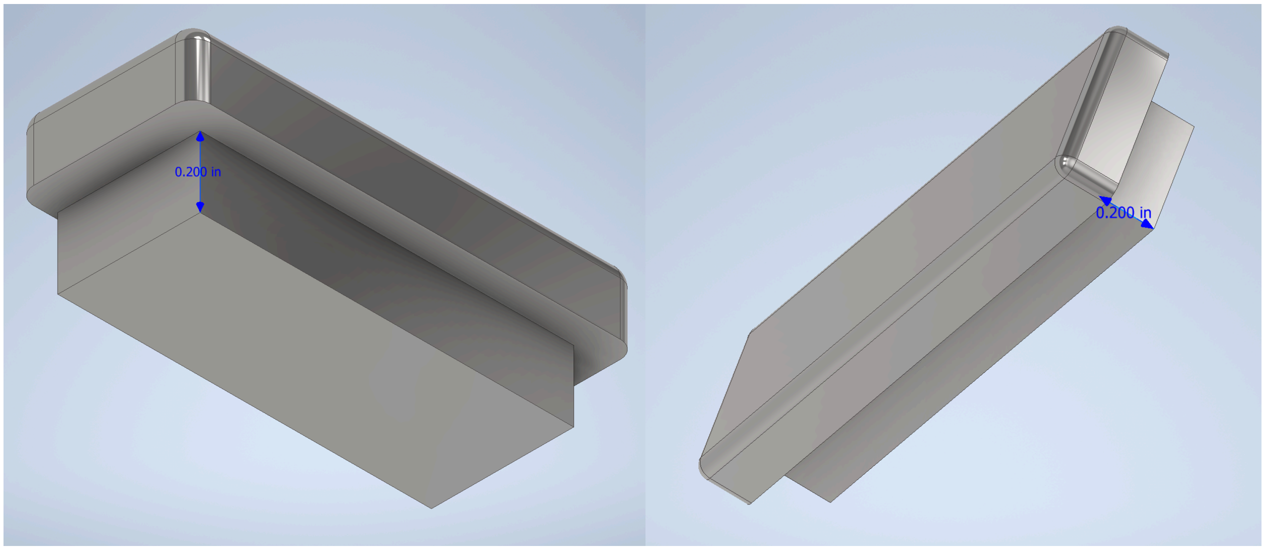

Fig. 4. Program Flowchart ***Stop** (power button) is external (hardware-dependent).

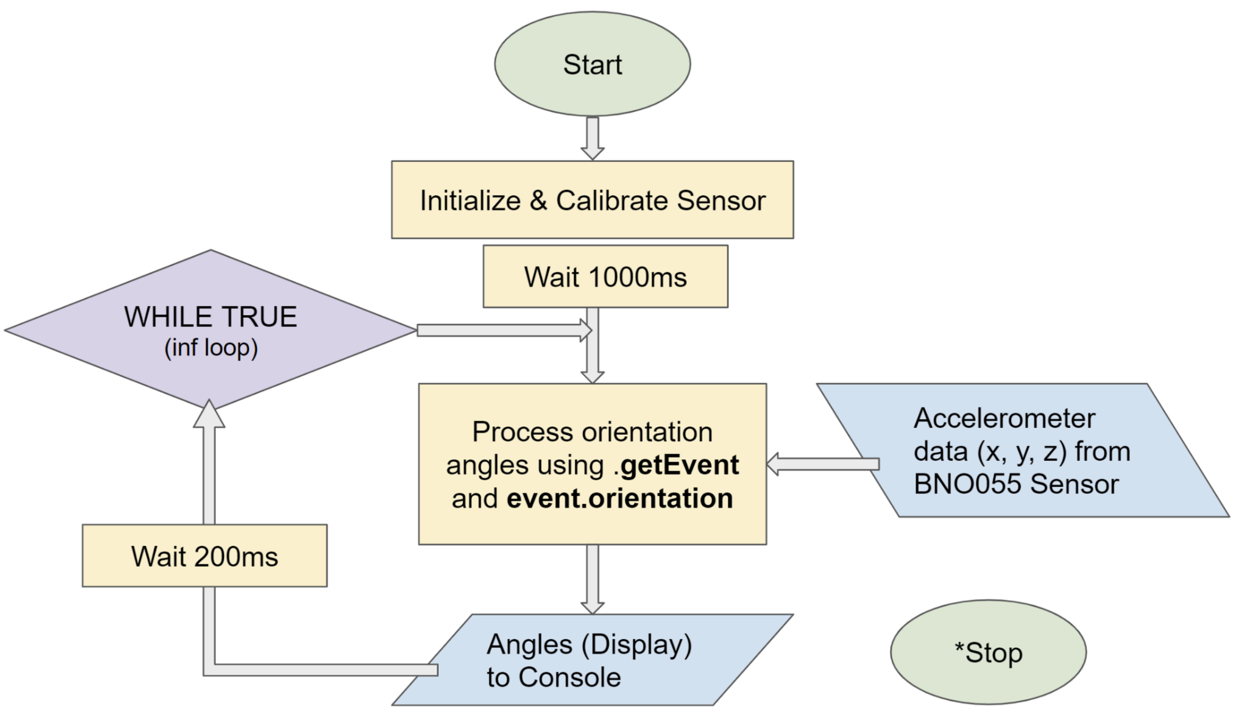

Fig. 5. Program Code

```
Adafruit_BNO055 bno = Adafruit_BNO055(55,0x28);

void setup(void)
{
  Serial.begin(9600);
  Serial.println("Orientation Sensor Test"); Serial.println("");

  /* Initialise the sensor */
  if(!bno.begin())
  {
    /* There was a problem detecting the BNO055; check connections */
    Serial.print("Ooops, no BNO055 detected");
    while(1);
  }

  delay(1000);

  bno.setExtCrystalUse(true);
}

void loop(void)
{
  /* Get a new sensor event */
  sensors_event_t event;
  bno.getEvent(&event);

  /* Display the floating point data */
  Serial.print("Inversion/Eversion: ");
  Serial.print(event.orientation.x, 2);
  Serial.print("\tPlantar-/Dorsiflexion: ");
  Serial.print(event.orientation.y - 10, 2);
  Serial.print("\tAb-/Adduction: ");
  Serial.print(event.orientation.z, 2);
  Serial.println("");

  delay(200);
}
```

Fig. 6. Initial Calibration Settings (after reset)

```
Inversion/Eversion: 0.0000      Plantar-/Dorsiflexion: 10.0000   Ab-/Adduction: 0.0000
Inversion/Eversion: 0.0000      Plantar-/Dorsiflexion: 10.0000   Ab-/Adduction: 0.0000
Inversion/Eversion: 0.0000      Plantar-/Dorsiflexion: 10.0000   Ab-/Adduction: 0.0000
```

Fig. 7. Preliminary Sketches

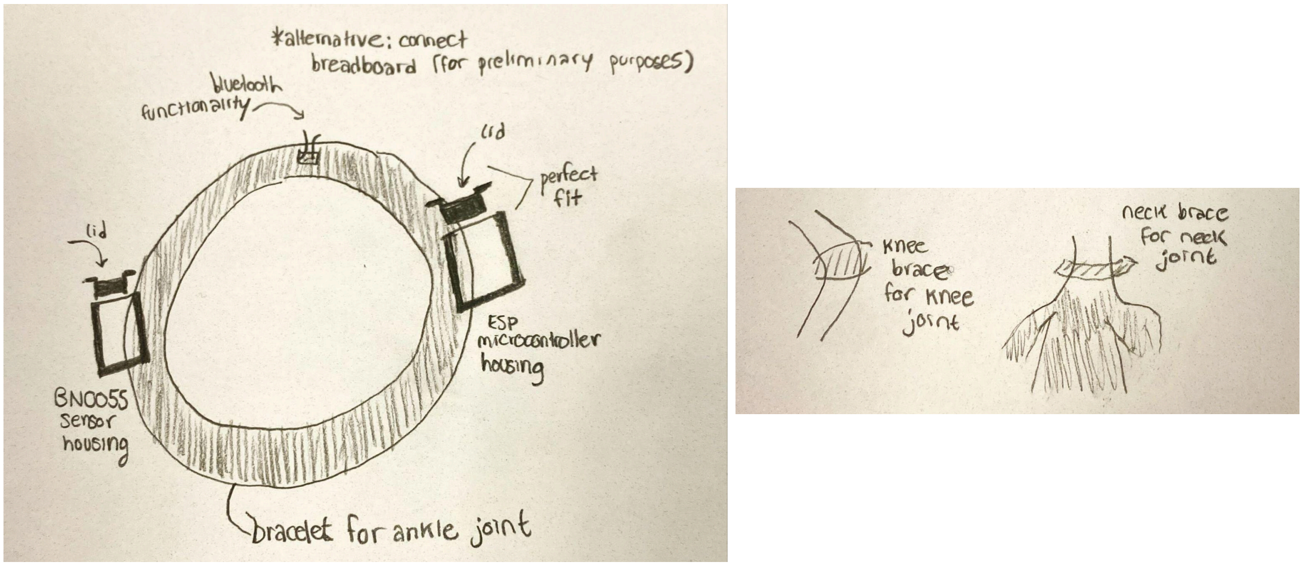

Fig. 8. Electrical Connections via Breadboard

*This was a preliminary design method. The Design solution would ultimately resort to Bluetooth (wireless) connection between sensor, microcontroller and external monitoring screen.

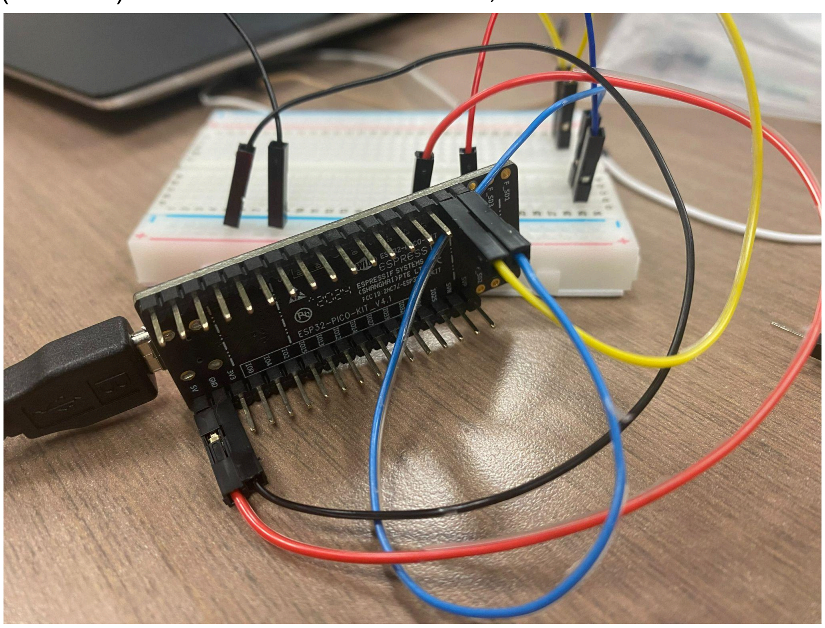

Fig. 9. Group's Low-Fidelity Housing Prototype (3D Printed)

Fig. 10. Low Fidelity Prototype of Anklet (Preliminary)