A Non-Invasive Integrated Sensor For Monitoring Menorrhagia

INTRODUCTION

Menorrhagia (heavy menstrual bleeding) affects more than 10 million (one out of five) American women each year. Women who have menorrhagia usually bleed for more than 7 days and lose more than 80 milliliters of blood. This can lead to anemia which can cause fatigue, weakness, and other physical issues. Blood loss in menorrhagia is currently diagnosed based on a pictorial blood loss assessment chart which has a questionnaire for the number of pads changed, size of blood clots and the duration resulting in a scoring system. However, this method is highly inaccurate as each person has a different opinion of "heavy bleeding" and will record information not in the same manner. This lack of a standardized method often leads to wrong diagnosis and does not provide an easy solution to monitor changes following treatment. To overcome this issue, the goal of this project was to develop a novel method with real-time monitoring for accurate quantitation of blood loss in menorrhagia.

RESEARCH QUESTION

Force sensors are devices that convert an input mechanical load, weight, tension, compression or pressure into a measurable output signal whose value can be used to reflect the magnitude of the force.

My research question is, "Can I integrate a force sensor to accurately monitor menorrhagia using the weight changes on the sanitary pad?"

HYPOTHESIS

If I integrate force sensors with a sanitary pad, then I will be able to non-invasively monitor blood loss in menorrhagia by measuring the weight changes on the pad.

EXPERIMENTAL APPROACH

Goal 1: Develop the force sensor circuit for integration with Arduino for automated measurement of changes in weight.

Goal 2: Demonstrate the force sensor for measuring weight changes on the pad using the Arduino output.

Goal 3: Integrate the force sensor within the pad and demonstrate real-time non-invasive monitoring of blood loss using the weight changes based on the volume absorbed on the pad.

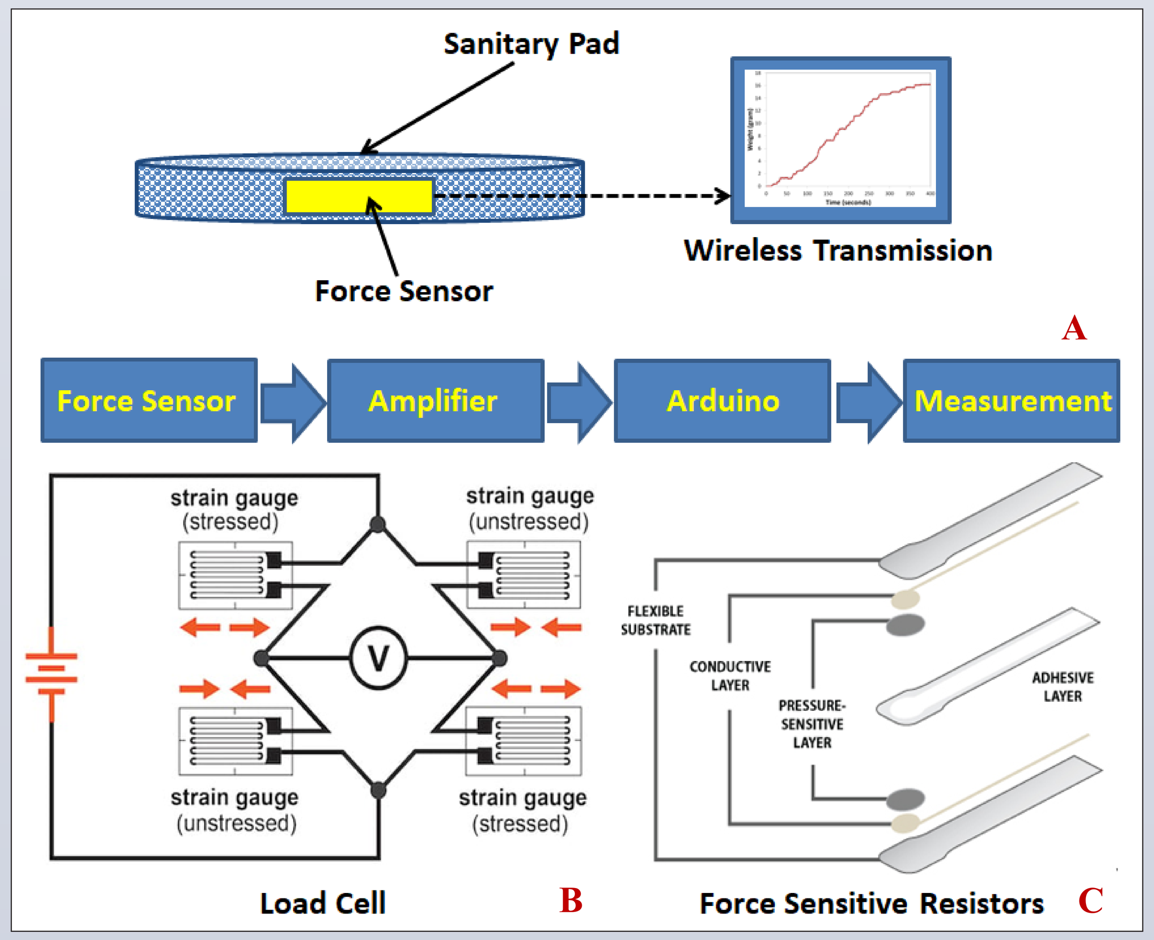


Figure 1. Concept of Sanitary Pad with Sensor for Monitoring Menorrhagia.
A. Force sensor measures the blood loss in real time and sends the data to a phone, tablet or computer. B. Schematic of load cell based on concept of strain gauge (https://www.allaboutcircuits.com). C. Schematic of force sensitive resistors based on pressure sensitive layers (https://www.tekscan.com).

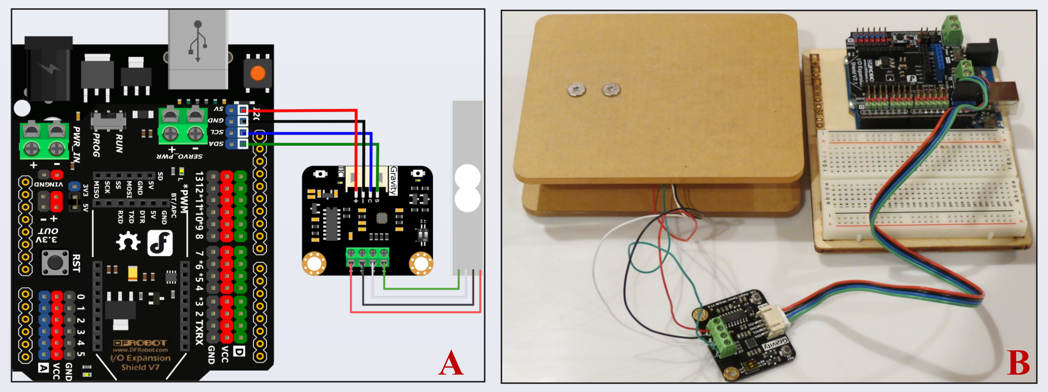
RESEARCH METHODS

Materials: Force sensors (load cell, force sensitive resistors), HX711 load cell amplifier, Arduino Uno board, sanitary pads, Monoprice Maker Select V2, PLA filament, water, sodium alginate, red food color dye, blender, weighing balance, beaker, pipettes, jumper wires, resistors, syringe, blunt needle.

Software: Solid Edge, Cura, Arduino Integrated Development Environment (IDE), Microsoft Excel

PROCEDURE

A. Development of Force Sensor: Initial experiments were conducted with the large load cell kit (Figure 2a). The electrical wires were connected from the load cell to the HX711 amplifier and the Arduino board (Figure 2b). The HX711 software library was uploaded to the Arduino IDE and customized. Next, the sensor was calibrated using known weights of 1, 2, 5, 10, 20, 50, and 100 grams. The calibrated sensor output was compared with the measurement from the weighing balance for accuracy (Figure 2c). Following calibration, a pad was placed on top of the load cell (Figure 2d) and water was dispensed using a syringe to measure the changes in the electrical signal which was converted to weight using the software code. This process was performed for pad sizes ranging from 1 to 5 and the measured weight values were plotted against time to test the sensitivity of the sensor.



Weight (gram)	Weighing Balance (gram)	Load Cell (gram)	% Error
1	1.00	1	0
2	2.00	2	0
5	5.00	5	0
10	10.00	10	0
20	20.00	19.9	0.5
50	50.00	49.9	0.2
100	99.97	99.9	0.07

C

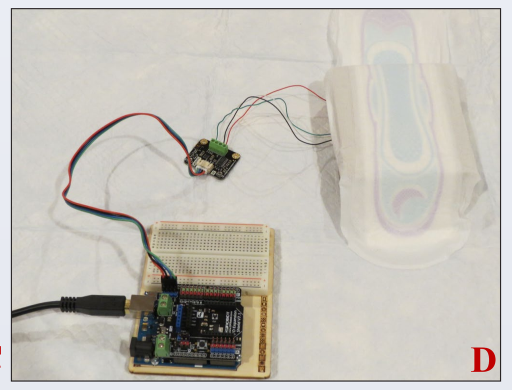


Figure 2. Load Cell Set Up and Testing. A. Schematic of load cell connected to HX711 amplifier and expansion board to connect to Arduino (https://wiki.dfrobot.com/). B. Image showing load cell connected with the HX711 amplifier and the Arduino. C. Accuracy testing of the load cell. D. Sample image of the load cell with the pad and measurement being taken following dispensing of water.

B. Force Sensor Based Measurement on Pad: Following proof of concept, plates and spacers to mount the load cell in a small footprint of the pad were designed in CAD and 3D printed (Figure 3a).The load cell was connected as before (Figure 3b) and the same process was repeated to monitor the changes in weight over the period of time. Simulated blood made by mixing red color food dye with 2% alginate solution in a blender was dispensed at different rates to mimic different patient conditions. Figure 3c shows drops of simulated blood solution being dispensed on the pads and Figure 3d shows magnified view of the pad.

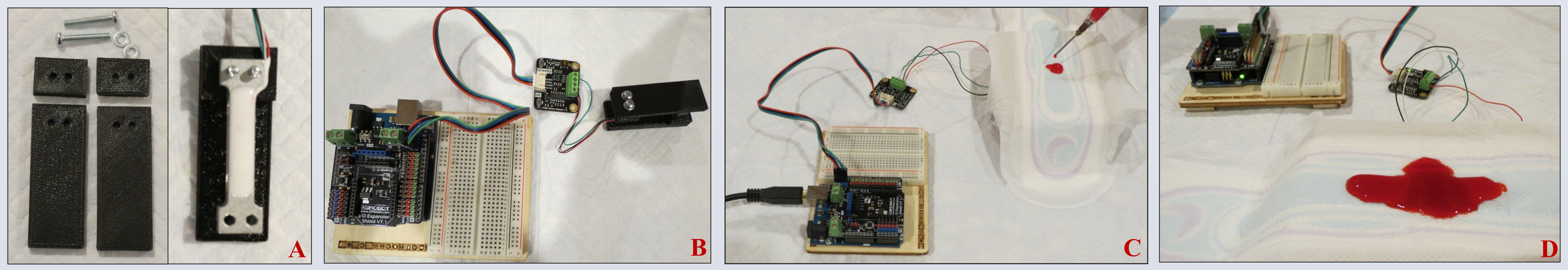


Figure 3. Load Cell Based Measurement. A. 3D printed mounts with load cell attached. B. Image showing load cell connected with the HX711 amplifier and the Arduino. C. Image of experiment in progress with simulated blood. D. Sample image of simulated blood on pad during experiments.

C. Non-Invasive Real-Time Monitoring: For truly integrated studies (Figure 4), a force sensor (8 mm diameter and 0.3 mm thick) was placed within the pad and the same process was repeated with simulated blood. In order to increase the area coverage, multiple sensors were joined together. As before, the experiments were repeated and the readings monitored over time.

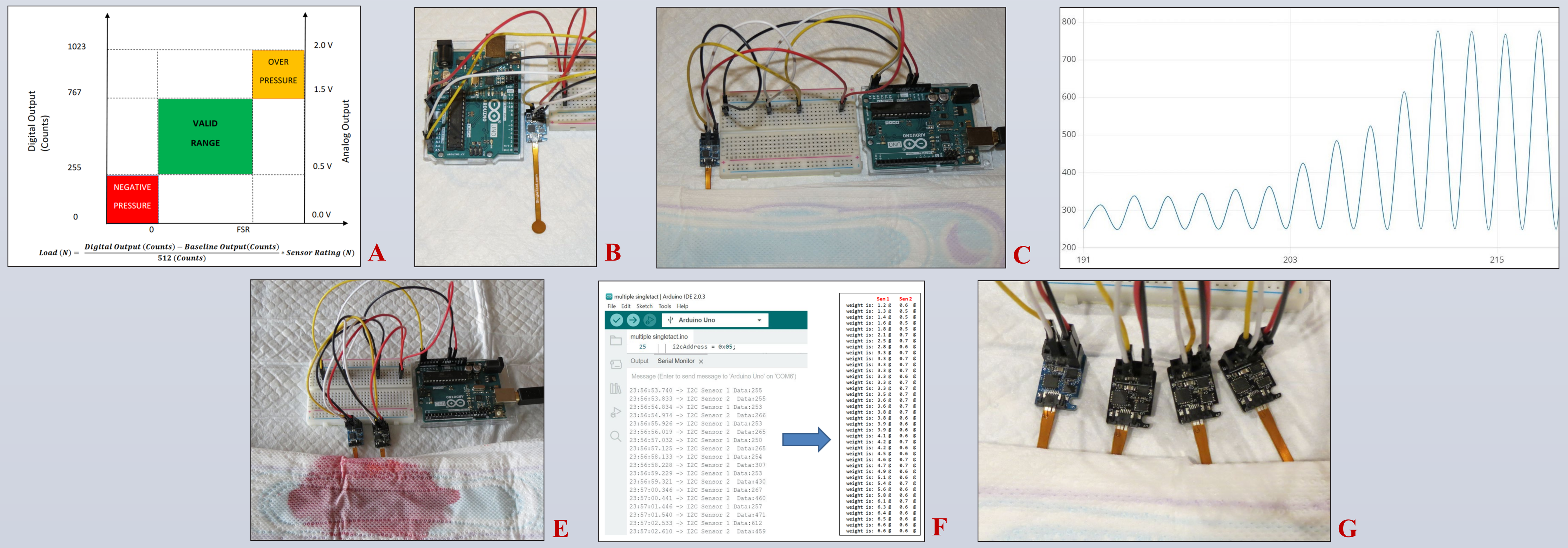


Figure 4. Interfacing of Force Sensitive Sensors with the Pad. A. Working principle (https://www.singletact.com). B. Sensor integrated with Arduino. C. Single sensor based measurement. D. Raw signal from sensor. E. Dual sensor integration. F. Conversion of raw signal to weight. G. Four sensor integration.

DATA AND OBSERVATIONS

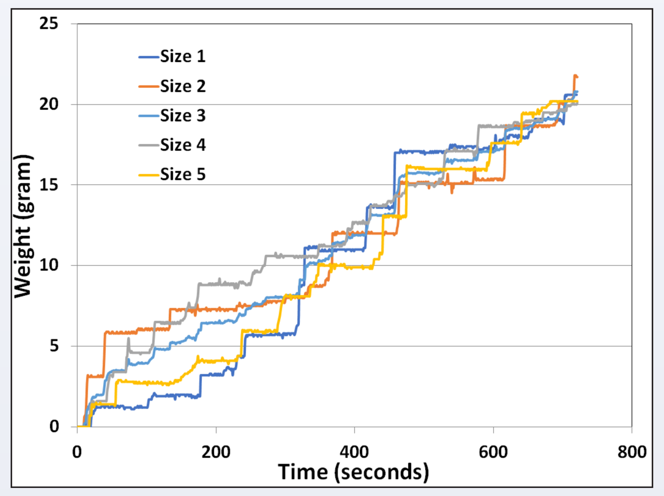


Figure 5. Monitoring of Weight Changes on Sanitary Pads. Size 1 represents pad for low flow and size 5 represents pad for heavy flow. The sensor was able to monitor changes in all of the pads.

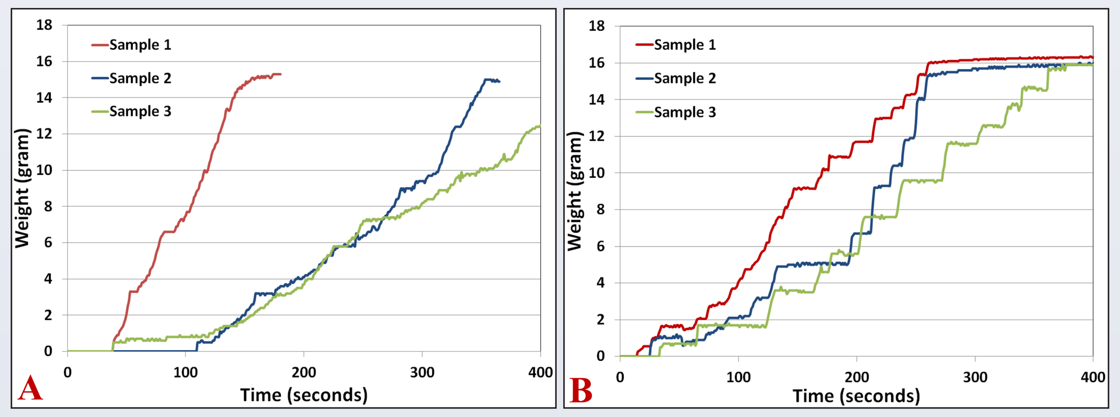


Figure 6. Monitoring of Weight Changes with Load Cell Integrated with Pad. A. Measurement of weight changes with water as fluid. B. Measurement of weight changes by simulated blood mimicking blood loss.

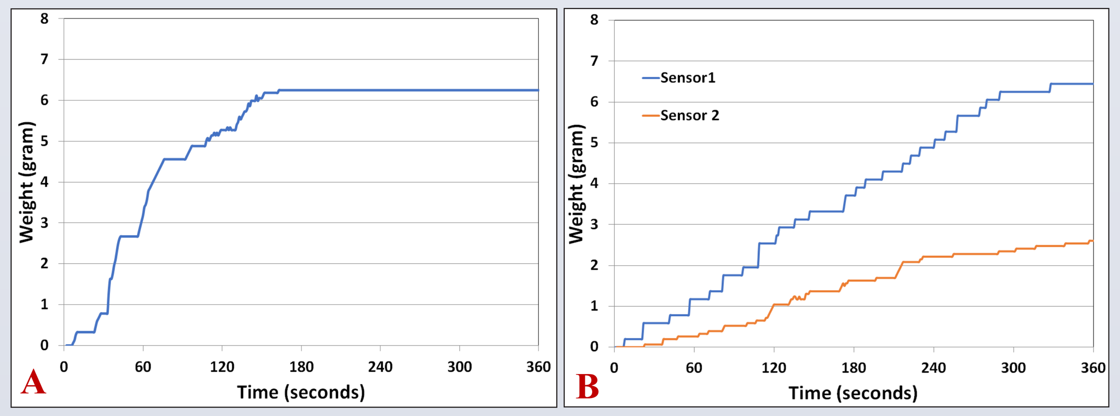


Figure 7. Monitoring of Weight Changes with Force Sensitive Sensors Integrated with Pad. A. Single sensor measurement showing saturation of sensor. B. Dual sensor measurement with continuous monitoring.

CONCLUSION

- Results showed that my hypothesis was correct. Sensors connected to an Arduino allowed non-invasive monitoring of weight changes on the pad accounting for blood loss in menorrhagia.
- The sensors had less than 1% error in calculating the weight based on the water and simulated blood experiments. 3D printed load cell based sensor could not be completely integrated with the pad. However, force sensitive sensors were easily integrated with the pad.
- Multiple sensors increased sensing area leading to increased sensitivity while demonstrating real-time non-invasive monitoring of blood loss.
- This new method of integrated sensors has great potential for diagnosing and treating menorrhagia, bringing relief to millions of women.

FUTURE DIRECTION

- Fabricate and integrate an array of sensors to cover the entire pad.
- Develop an interface for wireless transmission from the sensor.
- Work with clinicians for refinement of the data for clinical decision.
- Integrate a biodegradable sensor within a biodegradable pad for an environmentally friendly solution.
- Develop cell phone based image analysis to provide comprehensive results on the clot size and blood loss during menorrhagia.
- Integrate sensors for diagnosing diseases such as diabetes and cancer.

All schematics and images were made and taken by Nikita Prabhakar unless otherwise stated