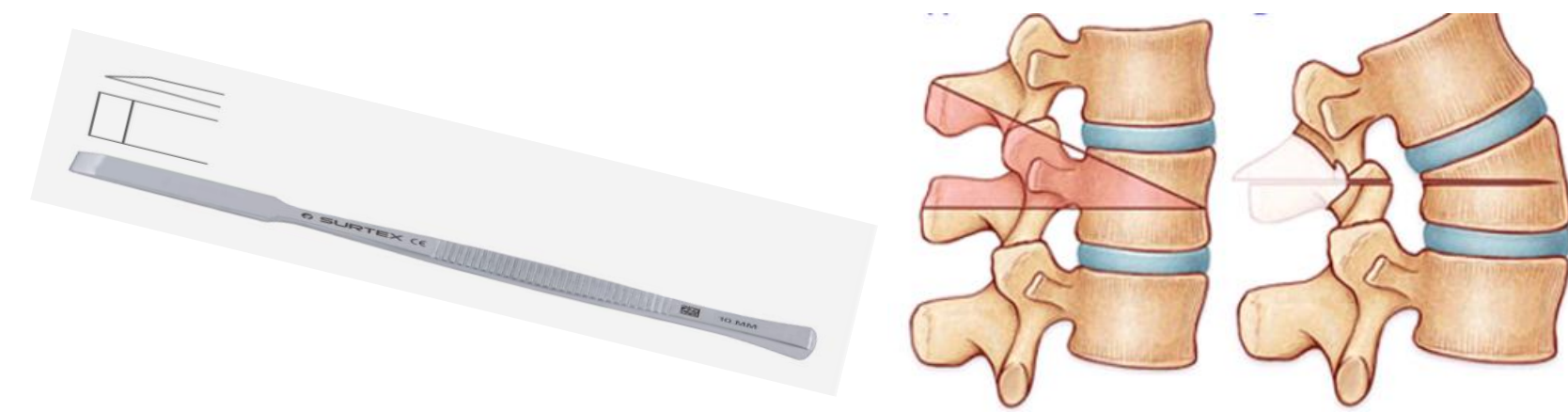


Background

Surgeons rely heavily on feel and experience when performing bone-cutting procedures. Up to half of the technical errors made by surgical trainees are related to the use of excessive force, wherein a large majority of those from junior surgeons.



Needs Statement

Develop a force sensing chisel that provides real time feedback during training, enabling surgeons to learn safe force application, reduce the risk of bone fractures, and improve patient outcomes, especially in fragile populations.



Experimental Setup

Housing Fabrication:

Initial designs of the bone chisel device and inclusion of the circuitry components were created in SolidWorks. The device casing was printed in PLA, and the chisel tip, strike cap, and strike rod were fabricated from 1018 cold-rolled carbon steel.

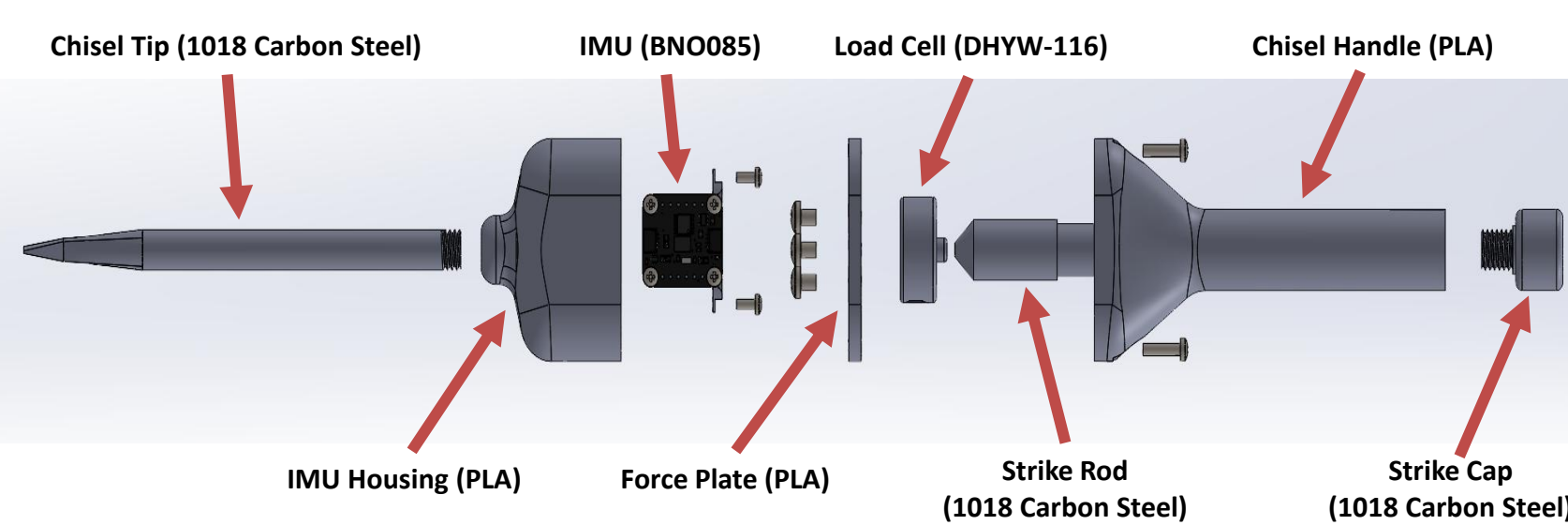
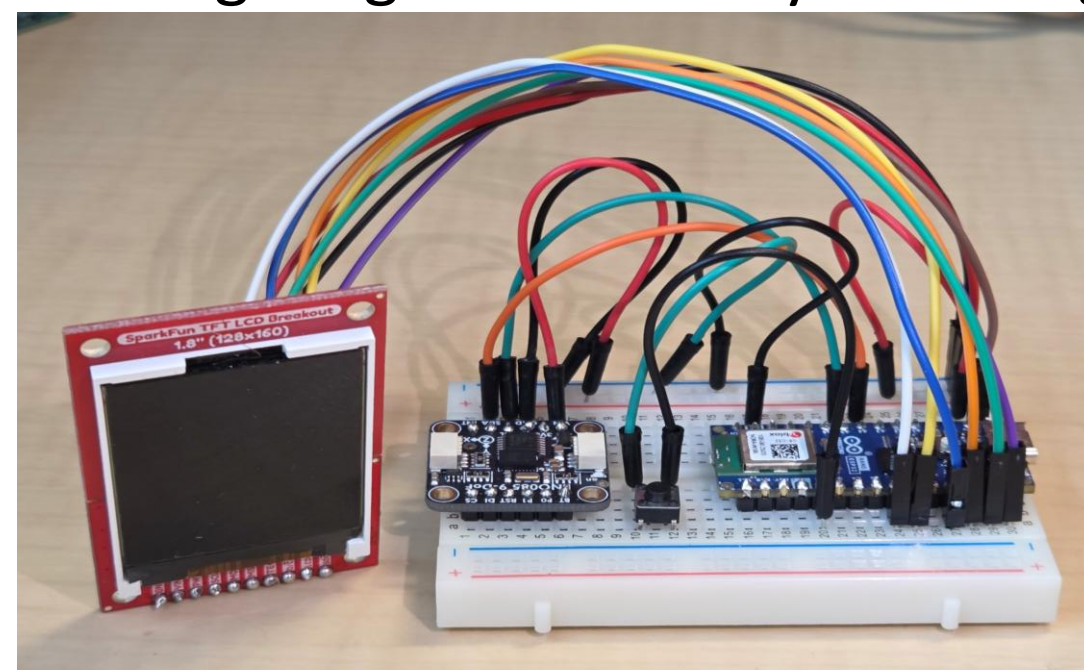


Figure 1. Complete digital design of the bone chisel feedback device. External circuitry components are attached to an external unit.

Software Development + Hardware Interfacing:

All device code was written in the Arduino IDE to capture both the angle/level of the bone chisel calculated by the BNO085 IMU and the force applied to the DHYW-116 Load Cell. This reading will send responses to the Sparkfun LCD Display and passive buzzer to alert the training surgeon that they are using too much force on the fragile bone.



Experimental Test Plan and Results

Computational Testing

Simulated Compression Test that was performed on SolidWorks. Von Mises values were calculated in N/m². Each test had an applied downward force 300N on each axial face (Purple Arrow) with a fixed face located opposite of the axial face (Green Arrow).

Physical Testing

IMU Accuracy and Precision of Measurement test was performed via the IMU embedded into the device and against a protractor taken at angles 30° - 90° in 5° increments.

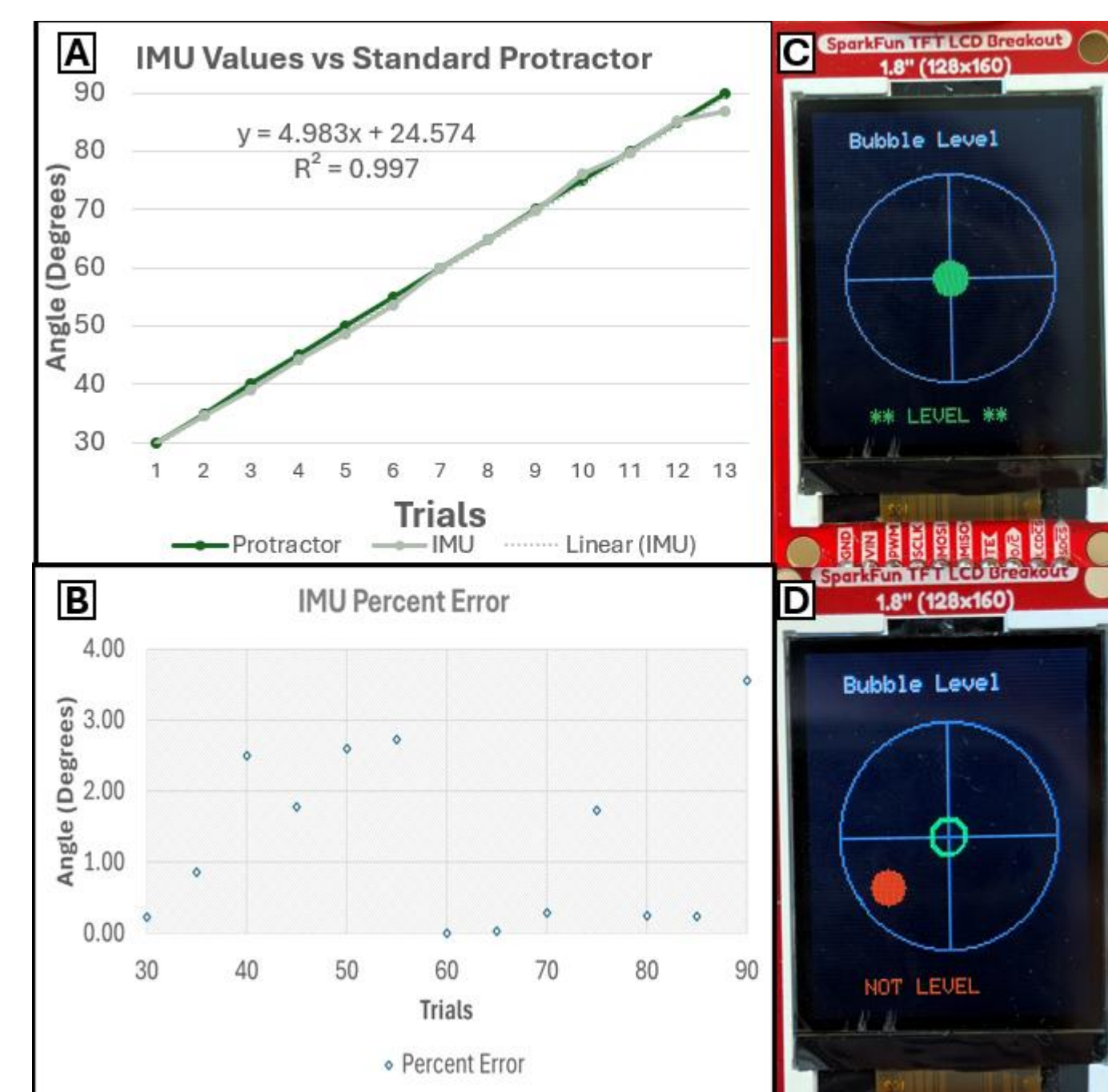


Figure 2. Von Mises Shear Stress test of the (a) bone chisel tip ($1.12e8$ N/m²), (b) strike cap ($1.43e7$ N/m²), and (c) strike rod ($1.52e5$ N/m²)

Figure 3. IMU angle measurement test against a protractor. (a) IMU angle measurements compared to the protractor. (b) Percentage error of the IMU among each angle measurement. Showcasing of the LCD Display when it is level (c) and not level (d) with the original tare.

Design Evaluation:

Element	Validation	Potential Sources of Error
HX711 and Load Cell	Validate both the HX711 and Load cell by using known weights logging the accuracy of the force applied with repeated trials	- Poor wiring (input and output reading error) - Sampling rate limitations of 10 – 80 Hz - HX711 (missed rapid force changes and delayed response) - Voltage fluctuations from ESP32 and USB-C power source (noisy readings)
BNO085 IMU	Validate the IMU using a goniometer and test accuracy using a linear regression model	- Loose wiring and poor soldering/resoldering (faulty connections on prototype + poor readings) - BNO085's are known to have fusion lags that will cause latency

Specifications and Constraints

Req ID#	Function	Description	Type	Specification	Metric
FR-01	Force Measurement	Measure strike force during use.	Objective	Detect force, range 20–300 N with ±2–5% accuracy.	Force (N), Accuracy (%)
FR-02	Angle Detection	Detect angular orientation.	Objective	IMU reads angle, especially pitch & yaw , within ±2–5% after calibration.	Angle (°), Accuracy (%)
FR-03	Accuracy Validation	Ensure reliable test readings.	Objective	Force and angle results stay within ±2–5% of validation tests.	Error (%)
FR-04	Calibration	Zero sensors before testing.	Objective	Include tare/calibration for stable baseline readings.	Baseline stability
PR-01	Cutting Efficiency / Sharpness	Cut synthetic bone effectively.	Constraint	Bevel angle 15°–30° ; blade width 3–25 mm .	Angle (°), Width (mm)
PR-02	Mechanical Strength, Durability, Reusability	Withstand repeated use and remain reusable.	Constraint	Withstand 300 N load and 500 mallet strikes at 2 J/strike ; FOS > 4.	Force (N), Cycles, Energy (J), Pass/Fail
PR-03	Drop Resistance	Remain functional after drops.		Survive a 1 m drop test without loss of structural or electrical function.	Drop height (m)
PR-04	Ergonomics for Control, Geometry & Dimensions	Be comfortable and properly sized.	Objective	Handle diameter < 35 mm ; shaft length 13–25 cm .	Diameter (mm), Length (cm)
PR-05	Cost	The prototype should remain affordable.	Constraint	Total cost per unit should remain under \$500 .	Cost (\$)

Standards

- ☐ ISO 14971 – risk management
- ☐ ISO 13485 – quality management practices
- ☐ IEC 62304 – software validation and reliability
- ☐ IEC 60601-1 – electrical safety considerations
- ☐ Human factors guidance for usability and safe feedback design.

Conclusions

- Our chosen design shows a high probability of success and fulfilling its main goal, where the LCD screen shows the angle and force of the circuitry elements

Lessons Learned

- Different coding cases must be incorporated for differing bones strikes, where cervical, thoracic, and lumbar vertebra, and other bones have different properties
- There is a trade off with ergonomics and component capabilities
- Intimate knowledge of circuitry and coding

Future Considerations, Iterations, and Plans

- Incorporate a larger LCD screen for Trainees
- More sensitive force sensors and harder steel material for the strike rod, cap, and chisel tip

References

- [1] Centers for Disease Control and Prevention. (2021). *Osteoporosis or low bone mass among adults aged 50 and over: United States, 2017–2018*. NCHS Data Brief, No. 405. <https://www.cdc.gov/nchs/products/databriefs/db405.htm>
- [2] Bone Health & Osteoporosis Foundation. (2023). *About osteoporosis*. <https://www.bonehealthandosteoporosis.org>

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