Ski Jump Launch Trainer

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Background and Motivation

Client Background

- The client, Dr. Ahmed, has a daughter who participates in recreational ski jumping at Blackhawk Ski Club.
- He has requested the construction of a ski-jump training system capable of analyzing multiple performance metrics in to order support her technique improvement through objective, data-driven feedback.

Figure 1: Professional Ski Jumper in Flight Phase [1]

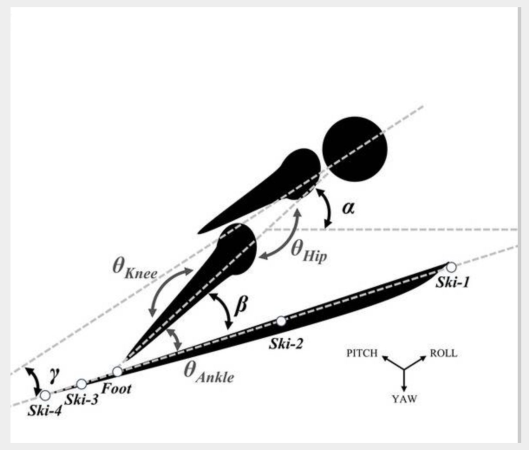

Figure 2: Biomechanical body angles important for ski jumping quantitative data [2]

Biomechanics of Ski Jumping

- The ski jumping phases of interest are in-run, takeoff, and early flight.
- In-run is where the jumper builds velocity and establishes their center-of-mass trajectory setting up how they enter flight [2].
- Takeoff is a brief explosive action transitioning the jumper from in-run to flight meaning small differences in timing and posture can yield significant differences in jump distance.
- Early-flight is the start of aerodynamic performance. The associated form directly influences lift, drag, distance, and ultimately overall performance [3].

Motivation

- Ski jumping is primarily a qualitative sport where feedback provided by coaches and judges is based on subjective perception of form and timing.
- The sport is highly dependent on form and approach, and is grounded in a unique and complex physics basis [4].
- Feedback should be rooted in quantitative data that demonstrates a high correlation with jump quality.
- There is a clear need for a quantitative-based learning system that tracks specific performance metrics and provides immediate feedback for areas of refinement.

Figure 3: Youth Ski Jumper at Blackhawk Ski Club during the In-Run Phase

- This system has the potential to not only provide coaches access to data driven feedback but also to enhance athlete safety by identifying poor takeoff mechanics and to establish increased training rigor to nourish development.

Problem Statement:

- To assist youth athletes in improving their skills, a ski jumping training system will collect biomechanical data during the in-run and take-off portions of the jump to allow coaches to provide feedback based on a quantitative objective basis.

Design Criteria

- The force plate device must be able to withstand the concentrated force of 2.5 the users specified weight [5].
- Must operate reliably in harsh winter conditions with 5th percentile temperatures and wind speeds reaching -23°C and 18 miles per hour respectively [6].
- The HTML user interface and MATLAB graph analysis must be user friendly.
- The microcontroller housing unit must stay firmly and securely attached to the ski boot during the full run of the jump.
- The size of the microcontroller housing unit should fit within traditional backpack size per DHS regulation. Specifically within 0.56m x 0.36m x 0.23m [7].

Final Design and Prototype

Figure 4: Force Insole Final Design

Force Insoles

Velostat
- Piezoresistive composite polymer
- Voltage divider resistor component
- Copper tape wiring
- Forefoot and heel force sensor locations

Insole
- 3D-printed PLA
- Client-specific size and shape
- Easily insertable and removable and replaces traditional insole

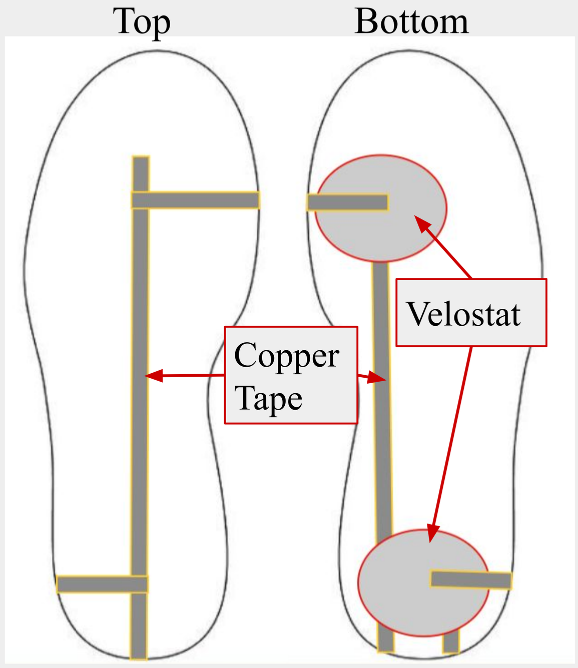

Figure 5: Left Footed Force Insole Diagram With Velostat and Copper Tape

Circuit Design

ESP32 Feather V2
- Continuous data collection
- Internal ADC conversion
- Access point Wifi server for user

Inertial Measurement Unit
- Accelerometer and Gyroscope
- 6 Degrees of Freedom, 3 linear velocity, 3 angular velocity
- SPI-based connection

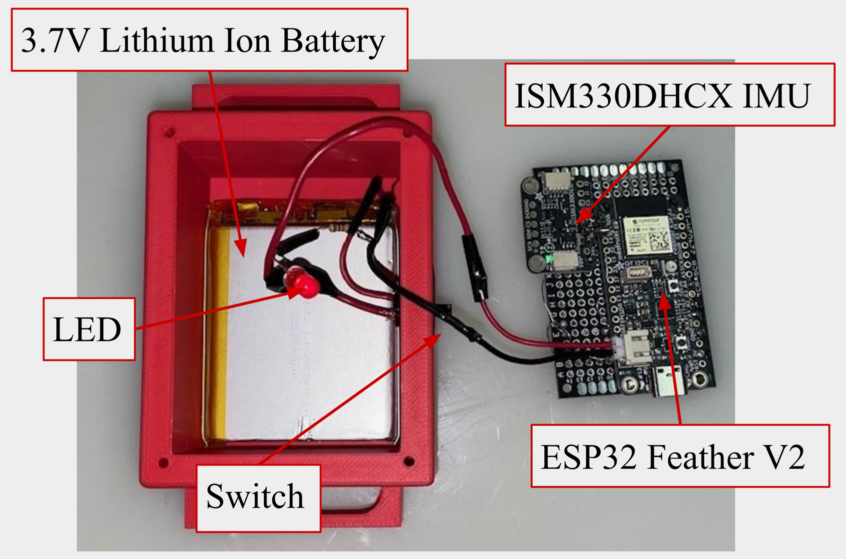

Figure 6: Full Housing Unit and Circuit including Microcontroller, IMU and LIPO Battery

Kinovea

- Open source biomechanical analysis software
- Facilitates precise measurement of relevant angular metrics
- Generates intuitive visualizations and analytical summaries of captured motion data

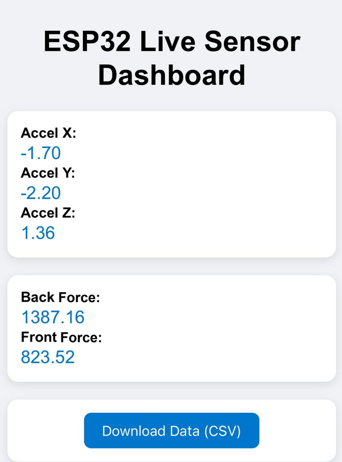

Figure 7: Online ESP32 Microcontroller WiFi HTML User Interface

User Interface

- ESP32 HTML WiFi Server
- Continuous data updating
- Newtonian force readings
- Weight distribution indication
- Linear velocity readings

Figure 8: Kinovea Knee and Ankle Angle Analysis of Youth Ski Jumper at Blackhawk Ski Club

Assembly and Fabrication

Housing Unit

- The microcontroller housing unit was 3D printed to fit the microcontroller complex on the back of the ski boot while allowing for proper organization of electrical wires.
- The housing unit was attached to the ski boot using velcro straps.

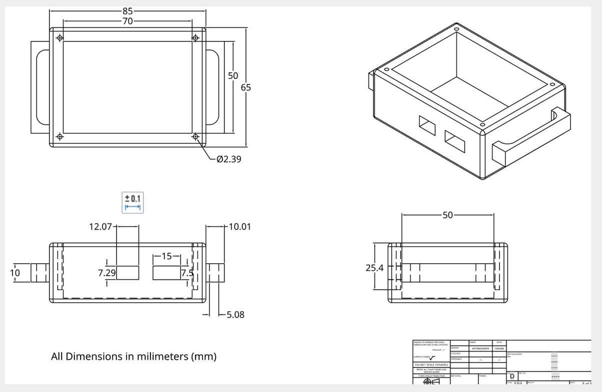

Figure 9: Onshape Technical Drawing of Microcontroller Housing Unit

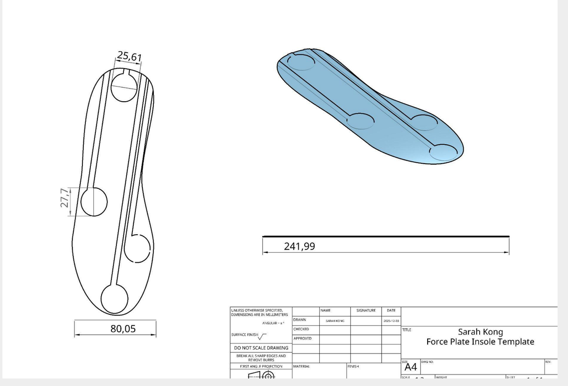

Figure 10: Onshape Technical Drawing of Force Plate Insole Template

Force Insoles

- The insoles were fabricated by 3D printing shoe insoles to the size of the subjects foot size.
- Copper tape and velostat were attached to the force plates and wrapped in electrical tape for insulation.

Testing and Results

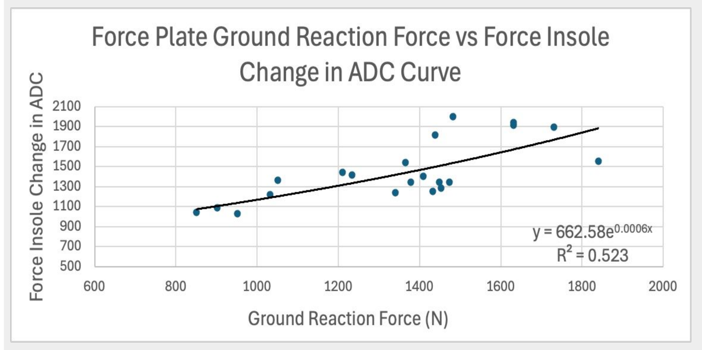

Figure 11: Force Plate Ground Reaction Force vs Force Insole Change in ADC: (R^2 = 0.523 & y = 662.58e^0.0006x)

Calibration Curve

- Experimentally determined quantitative relationship between microcontroller ADC reading and vertical ground reaction force found with Bertec Acquire force plate system.
- The regression shows a generally increasing relationship, demonstrating that the insole is load-responsive, though with moderate predictive accuracy ($R^2 = 0.523$).

Kinovea Data

- Angle data from a youth ski jumper was collected and examined across four separate runs.
- The athlete displayed stable and repeatable in-run positioning, with both angles remaining largely uniform during the approach phase.
- Greater variability began to appear as the athlete transitioned into the early flight phase.
- The most notable discrepancies in joint angles were identified comparing runs 28/30 to runs 36/40.

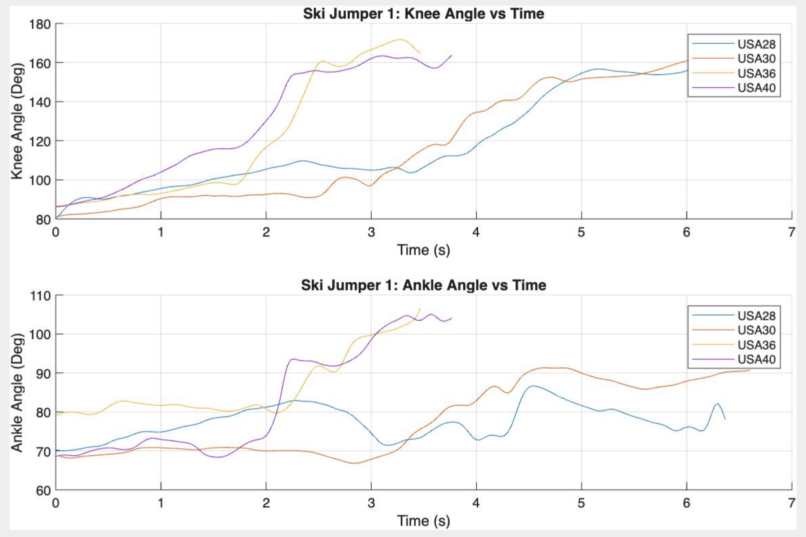

Figure 12: Kinovea Motion Capture Analysis of Time Versus Knee and Ankle Angle for Youth Ski Jumper

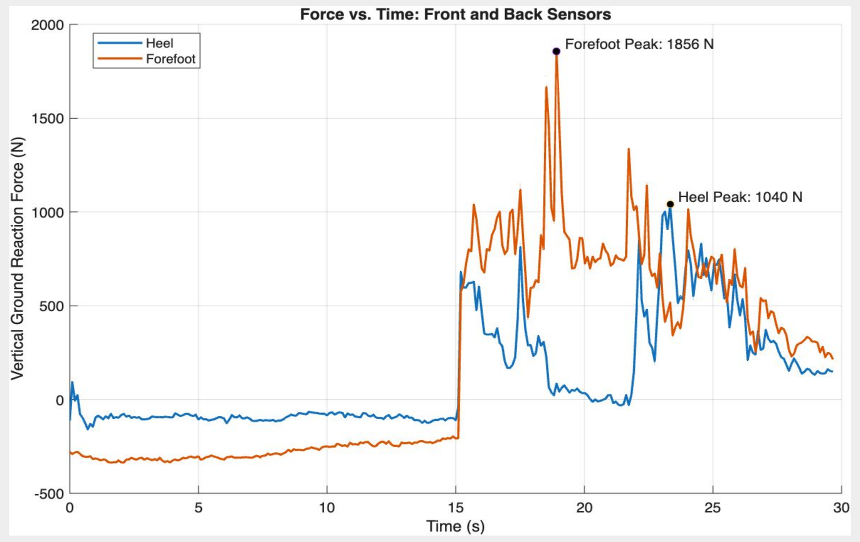

Figure 13: Force Insole Vertical Ground Reaction Force for Forefoot and Heel Sensors

Insole Testing

- Force over time curve for three simulated jump on force insoles.
- Peak vertical ground reaction force (forefoot): 1856 N
- Peak vertical ground reaction force (heel): 1040 N
- Higher forefoot loading reflects the athlete's forefoot-dominant takeoff strategy, consistent with expected ski-jump mechanics

Future Work

- Test force plates on ski jumpers at the Blackhawk Ski Club for both general performance and system performance under incremental conditions.
- Collect a large pool of data to identify strong correlational relationships between jump performance and the metrics being assessed.
- Work alongside coaches to analyze athlete specific data and curate personalized feedback to align with user-specific goals.

Acknowledgements

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References

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