Ski Jump Launch Trainer

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Biomedical Engineering 200/300

Section 303

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Function

Ski jumping is a highly technical and competitive sport that demands precise angular body positioning and timing to achieve optimal performance. 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 and compare it with reference data captured from more experienced jumpers. The system must capture key biomechanical data metrics including lower-body joint angles, torso stability, torso orientation, and vertical ground reaction forces. Data analysis must be performed on these measurements to identify differences between youth and experienced athletes. This analysis will provide youth ski jumpers and their coaches with quantifiable feedback to improve technique, optimize take-off timing, and ultimately enhance jump performance.

Client Requirements

Dr. Azam Ahmed and Dr. Walter Block outlined the following specifications for the ski jumping training system:

- The ski jump training system should be designed for youth athletes.
- The system must enable comparison between youth athletes and expert reference data.
- The ski jump training system must be usable at ski hills to capture realistic training conditions.
- A motion capture system that is capable of recording the 1-2 second in-phase to take-off transition of the jumping phase.
- Video and data analysis software that provide athletes and coaches with clear points of improvement based on input data.
- The project budget is up to $5,000, contingent on demonstrated progress, to acquire various sensors, IMU, force insoles, and other necessary materials.
- Resources provided by the University of Wisconsin Madison and recommended for use by the

client include CAE software, BME teaching labs, ECB built-in force plates, and ECB motion capture system.

- Human subject testing must follow consent procedures, especially for minors.

Design Requirements:

1. **Physical and Operational Characteristics:**
    a. **Performance Requirements:**
        i. The device must be capable of accurately calculating vertical ground reaction forces while withstanding a static load equal to 2.5 times the greater of 136 kg or the maximum specified user weight. The loading factor of 2.5 is based on intrinsic loading requirements for general consumer fitness recording equipment standards [1].
        ii. To optimize motion capture performance outdoors on ski hills, the system must utilize a minimum of three non-collinear markers per rigid body segment to track its six degrees of freedom (6-DOF) [2].
        iii. The data analysis and motion capture software GUI must be operated on devices with a minimum 800 MHz processor, 2 GB RAM, and 1 GB available hard disk space [3].
    b. **Safety:**
        i. All accessible areas of the training system must be free of burrs and sharp edges [1].
        ii. All corners of the training system must be radiused or chamfered [1].
        iii. Prior to testing the training system on youth athletes, parental permission and child assent must be obtained and comply with federal regulations (45 CFR 46 Subpart D) [4].

iv. IRB approval and oversight are required prior to human subject data collection from various ski jumping athletes: all investigators must complete certified human-subjects training [4].

v. Safety and injury prevention of participants must be prioritized by placing low risk simulated practice tasks before outdoor ski hill testing [4].

c. Accuracy and Reliability:

i. The sensors in the training system must meet an accuracy class of at least 0.5 following the International Vocabulary of Metrology (VIM) standard. This ensures that the combined effects of measurement uncertainty, linearity deviation, and temperature-related drift remain within plus or minus 0.5% of full scale per 10 °C under specified operating conditions [5].

ii. The motion capture of our training system must measure lower-limb and torso joint angles in the sagittal plane with a precision (repeatability) better than ±3° under ski hill conditions [6].

iii. Under ECB teaching lab conditions, the markerless motion capture system should demonstrate relative error ≤0.51% and absolute error ≤0.22° [6].

d. Life in Service

i. Based on ski jumping training system development guidelines, youth athletes aged 10–13 typically perform 1–2 dryland training sessions per week. The training system must be designed to withstand this frequency of use over its service life [7].

ii. In terms of annual usage of the training system U12 athletes on average perform 300 to 400 jumps which the system should be able to withstand at least half if the athlete wants to track their data over time [7].

e. Shelf Life:

i. The piezoelectric sensors integrated into the force plate system must demonstrate a shelf life of 15–20 years under normal storage conditions (15–25 °C), non-corrosive environment, no excessive shock or vibration) [8].

ii. Motion capture cameras involved in our training system are IR cameras with an average shelf life of 5.7 to 11.4 years [9].

f. Operating Environment:

i. The training system must operate reliably in laboratory conditions with average temperatures ranging from 20-25 °C and a relative humidity of 30-50% [10]. The lab environment should be free of corrosive gases, particulates, and other harmful substances that may damage the system [10].

ii. The training system must also operate reliably in outdoor conditions, which can vary significantly due to the year-round nature of ski jumping. Operation must remain stable across typical seasonal changes, with details of extreme weather tolerances provided in Section J.

g. Ergonomics:

i. Any software element of the system in which users will be interacting with should be user-friendly and should not require any prior knowledge or training.

ii. The comparison of relevant mechanics and metrics done by the system should be a streamlined process and suggested improvements should be easy to understand.

iii. The recording system should be low in component number and should follow an easy set up procedure for ease of use on the ski hill.

h. Size:

i. Components of the system must be transported up and down the ski hill as well as between the ski hill and campus and therefore should assume a relatively small size for easy transportation. Packed together, the overall system should not exceed a 0.56 m x 0.36 m x 0.23 m (22 in x 14 in x 9 in) volume in any dimension [11]. The components should be small enough to fit within these dimensions per traditional backpack size recommendations given by the DHS as this will allow easy transportation of the system.

i. Weight:

i. The weight of the system should be safe to lift and light enough to carry an extended distance by any individual regardless of strength. Components of the system will need to be transported up and down the ski jump hill and should therefore be easily transportable. The system should preferably weigh less than 20% of the transporter's personal body weight in order to avoid intense strain [12]. Further, the system should not exceed a weight of 23.1 kg if it were to be carried in a backpack per NIOSH and OSHA recommendation in order to prevent extensive damage to the bones and ligaments of the back [13].

j. Materials:

i. Durable and climate resistant materials are a necessity for the intense setting of ski jumping. The training system should consist of materials that can survive in the harsh winter conditions of Wisconsin. These conditions include 5th percentile temperatures of -23℃ (-10 ℉) [14] and 5th percentile wind speeds of 8 m/s (18 mph) [15], per the Wisconsin Climatology Office. Further, the system should be able to endure adequate levels of moisture and precipitation, including direct external contact with both rain and snow.

ii. Components of the design in direct contact with both human subjects and users must be made of non-irritative materials and must be absent from common allergens in order to prevent complication [16]. General biocompatibility in context with usage is required for any component utilized during human subject involvement and should therefore follow ISO standard 10993 for biological evaluation of medical devices [17].

iii. The fast-paced, dynamic nature of skiing also requires materials to be able to withstand intense force. Any component of the system worn or attached to the user must be able to withstand repeated extreme inertial, drag, and compressive forces [18].

k. **Aesthetics, Appearance, and Finish:**

   i. The finish of the analysis system should be clean and smooth. The system should be absent of sharp or harsh edges and all electrical wiring should be covered and separated from the outside environment [19]. The entire system should be as simple and organized as possible for ease of use, without sacrificing functionality. The system should also present a darker color to make identification of components easier in a potential white landscape of snow on the hill. The entire system should look cohesive and should carry a professional aesthetic.

2. Product Characteristics:

a. **Quantity:**

   i. Only one ski jump launch trainer will be designed and fabricated. The entire system will be reusable and shared amongst the users. Prototyping will be a consistent iteration of the same system and testing of the system will be done to ensure the final product has consistent output and performance.

b. **Target Product Cost:**

   i. With consideration of the various components required for the system already available at the university, and an evaluation of prices for motion capture based training systems, a target cost for the project is approximately $500 [20]. This figure is a summation that includes the $50 stipend given for the project by the department as well as further monetary support that will be provided by the client if and when required.

3. Miscellaneous:

a. **Standards and Specifications**

i. The ASTM F3109-22 standard states how to verify, test, or calibrate multi-axis force platforms like force plates used in balance. It has methods to quantify error in output signals across the working surface and force ranges, and included parameters like Center of Pressure. The ski jump simulator falls under this standard as we will have to run multiple tests of the force plates to determine the data of the amateur skier and compare it to the data of the expert [21].

ii. The ISO/IEC 19774-2:2019 standard covers motion capture and motion data animation for humanoid models. It specifies how to represent motion capture data in a structured way, particularly for the use of animation of articulated characters. It ensures compatibility and reproducibility of motion data between systems. The ski jump simulator falls under this standard because it will use the motion capture of humanoid models to obtain data related to the biomechanics of ski jumping. For example, data is sampled per frame and this standard defines the frame count, frame time (time per frame) and how the total duration is computed [22].

b. **Customer:**

i. The users of this device will be youth amateur ski jumpers with the average age from 8 to 12 years old. They will want the data collected to be reliable and accurately compared to an expert's data so they know what aspects of their jump they must change to improve it and more closely mimic the expert.

Patient-Related Concerns:

a. For human subject research, the participants must fully understand what data is being collected from their ski jump, what the motion capture set up involves, and how the data will be used, stored, or shared. Since we will be working with young amateur athletes, getting the parents informed consent is also needed [23].

b. Participants may also be concerned about risk of harm depending on the use of the motion capture. If it gets in the way of the ski jump, it could cause injuries. We must ensure the motion capture equipment does not get in the way with safety gear or impact the jumpers mobility in any way [23].

c. Privacy and confidentiality is crucial for the motion capture data because it could potentially personally identify the jumper by video footage or biometric signatures. To ensure privacy, we should first clearly inform the participants how long the data will be kept and who can access it as well as try to de-identify the motion capture data related to each jumper who participates [23].

d. Since there is a trainer involved who may have the Blackhawk ski club use our motion capture system for their ski jump, it is important to make sure all participants know their participation is voluntary and that just because their club may be using our system, they aren't required to have their jump data measured and collected [23].

Competition:

Automated Motion Evaluation System from Wearable Sensor Devices for Ski Jumping

i. Researchers developed a machine learning-based system using inertial sensors to automatically evaluate ski jumping performance, capturing full-body motion data from junior athletes and comparing it to style scores from expert judges to train and test the model [24].

ii. The system segments jumps into key phases, analyzes kinematic features, and detects style faults in accordance with official scoring rules, showing strong alignment with human judging and offering potential for more objective, mobile performance evaluation in jury-based sports [24].

iii. A multi-step data processing pipeline was developed to extract accurate kinematic motion data from inertial sensors, including sensor-bone alignment, orientation estimation, magnetic disturbance compensation, and joint position calculation, enabling reliable segmentation of ski jumps into key phases like flight and landing [24].

iv. Key motion features—both technical (e.g., ski angles, joint positions) and aesthetic (e.g., stability, leg extension)—were extracted and used in a machine learning pipeline with Dynamic Time Warping to compare jumps against reference patterns, achieving high precision and recall (70–85%) in detecting style errors relative to human judge scores [24].

Theia Markerless Motion Capture Device

v. Uses 10 SONY RX02 cameras to collect data sets of ski jumping movements in a ski jumping stadium [25].

vi. Uses data collected from cameras to offer insight into performances, technique, and aerodynamics [25].

vii. Analyzes the joint angles of the hip, knee and trunk movement across the take-off phase, aerodynamic profiles in airflow and lift/drag during flight phase, and real-world technique to give performance insights [25].

viii. User-friendly “ANALYZE” function after calibration to accelerate data processing [25].

Foot Pressure Sensors

ix. Insoles composed of 16 pressure sensors, 3 accelerometers, and 3 angular rate sensors per side [26].

x. Great for tracking volume and distribution of force during a specific action [26].

xi. Uses many internal sensors that are hooked up to a chip that communicates to its online interface through Bluetooth [26].

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