Electronic Knee Wrap for Injury Prediction

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ABSTRACT

Anterior Cruciate Ligament (ACL) injuries are among the most common injuries in sports. While significant research has been conducted for identifying the factors responsible, there is a need to quantitatively determine an athlete's risk of suffering the injury in real time. To this end, we explore the opportunity to mount a high performance, small area circuit on a knee wrap. We integrate a set of factors such as knee acceleration, knee orientation and valgus forces for computing the risk percentage of an athlete in real time. In addition, this knee wrap will also be multi-purpose, allowing both doctors to predict injuries and athletes prevent injuries on the field.

The design incorporates microcontrollers, inertial measurement units and wireless module mounted on the knee wrap. In order for the therapists and physicians to interact with the data, we have implemented a server and are using a website to display the data. We are able to show that the sensors measure accurate data at (TODO Hz) frequency, successfully transmit to the server and display the data.

Keywords

Anterior Cruciate Ligament (ACL), Knee Flexion angle, Deceleration, Knee Injury Risk Index (KIRI)

1. INTRODUCTION

ACL ruptures are one of the most common injuries in sport and very expensive to treat.There are approximately 175, 000 primary ACL reconstruction surgeries performed annually in the USA with an estimated cost of over $2 billion US [13]. This is followed by a lengthy rehabilitation period. Even then, over a quarter of patients reinjure their ACL [12]. These injuries also cause early-onset of osteoarthritis for numerous people between the ages of 30 and 50, and related injuries such as ACL tear in the other leg. (TODO cite Lohmander et al)

An ACL injury can have an immense impact on an athelete's career and quality of life. Because of this, preventing ACL injuries is exceptionally valuable and important. We propose the use of an electronic knee wrap (eKwip), to predict and prevent ACL injuries in both healthy athletes and injured patients. By monitoring the angles, orientation and movements of the knee of the wearer, eKwip is able to predict when an injury is imminent. We propose to create a prevention mechanism to cushion knee and prevent the knee from bending at angles that may cause an ACL rupture. This mechanism will be triggered in case of imminent danger. To encourage adoption of such a knee wrap, eKwip is designed to be unobtrusive and flexible, unlike the current mechanical braces on the market.

eKwip allows the wearer to monitor his or her knee performance and risk of injury throughout the day to decrease the chance of future injury. It also allows physical therapist to easily observe and assess the performance of injured patients remotely. With eKwip, the aim is to reduce the rate of ACL injuries in both healthy athletes and injured patients.

eKwip utilizes various factors that have been demonstrated to cause the injury such as accelerations and angles. It integrates these factors with machine learning algorithm to accurately calculate the risk by adapting to the athlete's physical characteristics such as flexiblity and normal range of knee movement. Currently, the microcontroller (Mbed) receive knee acceleration and orientation angles from the sensors. Using a wireless module, this data is quickly transmitted to the server, which calibrates the angles and acceleration, and displays them on the website in a user friendly format.

Sec.2 reviews knee anatomy, including the major causes of ACL injuries and the performance requirement of eKwip. Then, we review the prior work in ACL detection and the common rehabilation procedures used in the industry for measuring the strength of the ACL in Sec.3. Sec.4 illustrates the basic idea of eKwip with the model diagram. Sec.5 describes the technical implementation of eKwip in detail. As real-time analysis is a necessary component, Sec.6 describes the performance of the system with respect to requirements and how we improved the system over time. Sec.7 details our remaining work that involves implementation of KIRI algorithm, machine learning implementation, and testing and validating the system. Throughout the paper, we focus on latency and unobtrusiveness of the wrap.

2. BACKGROUND

As the paper includes interdisciplinary content, we pro-

*Advisor: LeAnn Dourte (dourte@seas.upenn.edu), Insup Lee (lee@cis.upenn.edu) vide information in this section about the mechanical properties of the knee used throughout the paper. The knee joint is the largest joint in the human body that connects the femur and tibia. ACL is one of the four major ligaments in the knee. It originates from deep within the lower extremity of the femur and attaches in front of the spine of tibia. The figure below is representative of the knee anatomy and the location of ACL. (TODO Add knee figure. Figure 3 from http://www.aclsolutions.com/anatomy.php. Edit figure to locate femur top and tibia bottom).

ACL is responsible for resisting anterior translation and medial rotation of the tibia, in relation to the femur. This resistance is crucial for controlling the forward movement and twisting of the knee. Major cause of ACL injury is small knee flexion angle along with medial rotation. The knee flexion angle is the angle between the femur and the tibia. The medial rotation is the internal rotation of the knee towards the midline axis of the human body. As a result, these angles are an important indicator for the injury.

Another common reason for the ACL injury is due to asymmetric distributed forces acting on the joint. As these forces are not equally distributed, the resultant force direction does not pass through the vertical axis at the center of the leg. This resultant force causes anterior translation and medial rotation. Once the forces exceed the resistance offered by the ACL, the ACL ruptures due to excessive strain (TODO cite GRIFFIN et al). Now, these forces are caused due to sudden movements such as changing directions or landing from a jump, which are most common in sports (TODO cite GRIFFIN et al). These decelerations generally happen as fast as 50ms (TODO cite some paper), and therefore, ekwip needs to be able to measure the deceleration as fast as 10s of milliseconds. The decelerations can then be related to the forces to provide a more complete analysis for risk calculations.

3. RELATED WORK

Related work for this project is divided among three fields: algorithms for ACL injury detection (Section 2.1), knee brace effectiveness/performance hindrance (Section 2.2), and Knee Mechanical Properties (Section 2.3).

3.1 ACL Injury Detection

This section covers research in minimizing the testing required to detect whether an athlete is at risk of suffering an ACL injury. Prior research in ACL Injury Detection has shown that techniques exist that accurately capture and analyze various measures relating to the knee to determine the probability of ACL injuries [10]. Using such metrics as knee flexion angles, medial rotation, and body mass, researchers were able to come up with a way to determine knee abduction moments (KAM), which are used to identify whether or not an athlete is at high risk for an ACL injury, with a sensitivity of 77% and specificity of 71% [10][2].

3.2 Knee Brace Effectiveness/ Performance Hindrance

This section deals mainly with studies of the extent to which a Functional Knee Brace and a Prophylactic Knee Brace interacts with an athlete's ability to perform on the field. Prior research in using Functional or Prophylactic knee braces out in the field has shown that it potentially hinders an athlete's movement by restricting the anterior translation. In addition, the studies on the usefulness of these kinds of braces in preventing the injury are inconclusive [8]. Knee braces, especially Functional Knee Braces (FKB), which are more mechanical in nature and thus more obtrusive, are shown to provide ̈20-30% greater knee ligament protection.̈ This suggests that while FKBs have an impact in reducing the severity of knee injuries, there is an opportunity to come up with a new brace to evaluate the risk index and thereby provide proof for the capability of existing braces. Another important factor of the effectiveness of knee braces is in rehabilitation, where a combination of exercises and brace use can speed up recovery [5]. eKwip can also provide evidence for establishing the usefulness of these exercises.

3.3 Knee Mechanical Properties

Research has proved that the relative angle and forces between the femur and tibia are a major risk indicator to ACL injury. The paper S̈hin, et al. 2006?p̈rovides the numerical data, which we will use to calculate the risk index for the athlete. From the graphs below, we can see that the authors of the paper created a model to track the knee flexion angle and the forces over time and found correlation with the experimental model of the injury. (TODO cite the paper Shin et al) (TODO add the 2 graphs of angles and forces over time)

4. SYSTEM MODEL

Talk briefly in high level about the model. Include the flow chart that we made. talk about how stuff interacts avoid lot of technical implementation in this section as the next section talks about the implementation in detail

5. SYSTEM IMPLEMENTATION

In general, talk about why, how we implemented, and how they work. these are general guidelines, not exclusive

Subsection (Mbed) - Why mbed, what does it do

Subsection (Sensor) - why these imu, found the bug in library, updated the library and at the end wrote our own custom library for faster performance

Subsection (Wireless Module) - why this? how we made it work

Subsection (Server) - I have no idea what Alex has done here

Subsection (Website) - Could be included in server section (your choice)

6. SYSTEM PERFORMANCE

Include the graph about the latency

Describe the graph in detail.

relate back to the idea, why this performance is good enough

something more.

7. REMAINING WORK

At its current point, eKwip is in the prototype stage. While the current implementation is able to collect data on the wearer's knee movements as well as transmit that data to the server, there is no conclusive metric being calculated for the prototype. As such, the first step moving forward is to come up with an algorithm to calculate the Knee Injury Risk Index (KIRI). In order to do this, certain factors, such as the calculated Q-angle or knee adduction moment during movement, after being calculated, will be given certain weights and a final KIRI value will be returned for the wearer. The Q-angle is formed from a line drawn from the Anteriro Superior Iliac Spine (the front of the pelvic bone at the hip level) to the center of the kneecap, and from the center of the kneecap to the Tibial Tubercle (a bump about 5 centimeter below the kneecap on the front of the Tibia (TODO Add a citation for this). The knee adduction moment determines how force is distributed at the knees (TODO Add citation). A higher Q-angle means that the wearer has an increased risk of ACL injuries, while the knee adduction moment of a person in movement will affect how certain loads are applies to their knees and ACL.

Another important issue that needs to be addressed is the variability of gaits, resting positions, and Q-angles from person-to-person. Designing a wrap that fits everyone will not generate accurate results as we move between athletes. Our solution to this issue is to produce a basic machine learning algorithm that will cause eKwip to adapt to wearer. The algorithm will likely collect data on the wearer initially. Then, using this information, eKwip will adjust its collection formulas to fit with how the wearer normally rests or moves. This aspect of the project will likely be the most difficult; therefore, we will be spending a major portion of the remaing time on creating and validation the implementation.

Testing and validation of all data collection and the system itself will be carried out along with the implementation of the previously mentioned features. Validation is critical for the system and will make-or-break whether or eKwip is actually useful as an aid for physical therapists or coaches. Fortunately, access to equipment at the Penn Sports Medicine Center will allow us to test eKwip against what is currently being used. Because of the nature and focus of our project, certain data will be very risky or even dangerous to collect on an actual person. Fortunately, knee models at the Penn Sports Medicine Center will allow us to collect this information as well as give us methods to gather data on the knee in various positions or stances. Moving forward, testing and validation will be continually done, with majors tests performed when major milestones are completed on the project.

Based on how fast these features can be implemented and how much time remains, we may pursue the reach goal: to implement a prevention measure for eKwip that will be an extension of the prediction. However, this largely depends on how fast we can perform reads and calculations on the system itself as well as how quickly we can ensure the accuracy of the values. Prevention also requires major research into potential materials to use, as eKwip would need a method to brace the sudden movement of the wearer to lessen or prevent the injury. In addition, a Prevention implementation will modify the rate and method of data collection and calculation. It is likely we may not reach this stage of the project, but, as stated, this is all highly dependent on the time constraints.

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