(364)

Wearable Knee Health Rehabilitation Assessment using Acoustical Emissions

--Caitlin N. Teague[1], Sinan Hersek[1], Jordan Conant[1], Scott Gilliland[1], and Omer T. Inan[1], [1]School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, 30308

Each year, approximately 200,000 Americans endure anterior cruciate ligament (ACL) tears, and 100,000 reconstructive procedures are conducted to repair the injured knees (1). The injury itself, and the long rehabilitation process that follows, can majorly disrupt the quality of life for these Americans through missed workdays, reduction of overall physical activity, and increased risk of re-injury in future activities. Wearable technologies for quantifying the state of rehabilitation, and providing feedback to the user regarding which activities or intensities of activities are safe to perform at any given time, could potentially help accelerate the rehabilitation process as well as reduce the risk of re-injury.

Our lab has developed a novel, wearable sensing system based on miniature piezoelectric contact microphones for measuring the acoustical emissions from the knee during movements such as unloaded flexion / extension, sit-to-stand, and walking activities. The system consists of two Knowles BU-23173 contact microphones (Knowles, Itasca, IL) positioned on the medial and lateral sides of the patella, connected to custom, analog pre-amplifier circuits and a microcontroller for digitization and data storage on a secure digital (SD) card. In addition to the acoustical sensing, the system includes two integrated inertial measurement sensors including accelerometer and gyroscope modalities to enable joint angle calculations; these sensors, with digital outputs, are connected directly to the same microcontroller via serial peripheral interface (SPI). The system provides low noise, accurate joint acoustical emission and angle measurements in a wearable form factor, and has several hours of battery life.

We have also taken measurements from healthy subjects, and athletes following acute ACL tear, to determine initial features from these acoustical emissions that are associated with injured versus healthy joints. We have found that the main acoustic clicks during particular motions occurred at consistent joint angles for healthy subjects based on intraclass correlation coefficient analysis ($ICC(1,1) = 0.94$ and $ICC(1,k) = 0.99$) (2). For one subject with an ACL tear, we found that the consistency of the joint acoustical emissions was lower for the injured knee as compared to the healthy knee in the recording immediately following the injury (< 7 days), and improved following six months of rehabilitation. We envision using the wearable system we have recently completed to conduct further experiments with subjects following acute ACL tears, and tracking the progress of the rehabilitation while simultaneously measuring acoustical emissions in the context of particular movements. This data will then serve as a foundation for creating subject-specific algorithms for assessing rehabilitation and providing feedback to the users.

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