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Original Research

Design and Production of Intelligent Knee Brace (To Provide Feedback on Knee Flexion Angle for Injury Prevention Programs)

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ABSTRACT

Depending on the type of application, smart textiles have special capabilities such as controlling one's physical condition and health, as well as recording and sending vital signs of the body. In sports activities, smart clothing can monitor the amount and type of athlete's activity, speed of movement, and control and report joint movements. These smart textiles can improve athletic performance by correcting movements and thereby preventing or reducing sports injuries. In this regard, a smart knee brace can be a useful tool to assist in lower-risk performance and prevent the athlete from putting their knee joint at risk. In this project, the researcher intends to take the first step in making this knee brace. The first step is to build a knee brace that can receive feedback from the knee flexion angle. For this purpose, the smart knee brace is designed from three components: signal processor, length-sensitive textile, and information processing software. Analog data obtained from a non-wavelength sensitive signal processor is converted to digital data, connected to the router via wireless chip, and received via Wi-Fi. The TCP Telnet Terminal application installed on the mobile phone is also used to view the data. To check the numbers recorded by the knee, the smart fabric was first rested and stretched, and the numbers recorded. Then the speed of pulling and turning of the fabric was evaluated, and at the end, the knees were positioned at different angles, and the numbers were recorded.

Keywords: Intelligent Knee Brace, Smart textiles, Knee Flexion

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INTRODUCTION

Human activity recognition is becoming increasingly important. As contact with one herself and the environment accompanies almost all human activities, a Smart-Brace made of soft and stretchable textile pressure sensor matrix is proposed to sense human contact. Knee braces are designed for different purposes. Knee braces can be divided into several categories based on their use [1].

Injury Prevention Knee Braces:

This type of knee brace is designed to prevent Anterior Cruciate Ligament (ACL), Posterior Cruciate Ligament (PCL), and Lateral Collateral Ligament (LCL) injury. If a person has an injury, with the help of these types of knee braces, he can take care of his knee during training. Preventive knee braces aren't use during training because they restrict the movement of the knee joint, and this reduction in knee joint movement can reduce athletic performance [1, 2].

Functional Knee Braces:

This knee brace is used to strengthen and stabilize the knee joint during the recovery period after treatment. The choice of a functional knee brace depends on the level of injury. If the injury is mild, neoprene knee braces can be used with springs on both sides for extra support. If the injury is serious, knee braces with metal frames are used. Functional knee braces support the knee joint when jumping, running, and pivoting [1].

Rehabilitation Knee Braces:

People who have had surgery or are in rehabilitation can use this kind of knee brace. These knee braces severely restrict the movement of the knee joint and allow the joint to heal more appropriately. Rehabilitation knee braces are usually used in conjunction with physiotherapy. Generally, this type of knee brace is used between 6-8 weeks after surgery. The knee brace is made of foam and covers the thighs, knees, and legs. The stiffness of these knee braces is adjusted with adjustable rods on both sides of the knee brace [1].

Neoprene Knee Braces:

The neoprene knee brace provides the least support to the knee, thus, slightly limiting the range of motion of the knee joint. This knee brace is made of neoprene which is air permeable and antiperspirant. It also can retain heat in the knee area, which is very useful for people with inflammation and joint swelling [2].

Immobilized Knee Brace:

If a person has had knee ligaments surgery, this knee brace can keep the knee immobile. The immobilized knee brace extends from the leg to the thigh and firmly holds the plates on both sides and behind the knee [3].

Smart Knee Brace

In some sports, non-conscious knee braces are used during training to strengthen and stabilize the knee joint. Smart knee braces allow the athlete to be aware of the function of his knee joint at any time. We know that acute and chronic injuries to the knee joint occur when the joint is forced to move outside its normal range. If the sensitivity of the smart knee brace is regulated based on scientific theories of sports injuries to the knee joint, then it receives an alert when the athletes put their knee in a prone position [1, 4].

MATERIAL AND METHODS

Wearable strain sensors offer new integrated platforms for assessing athletes' biomechanical and physiological parameters [5]. Stretchable strain sensors can intimately couple with different body locations, resulting in highly localized tracking of sports activities. The present intelligent knee brace consists of four components:

Fabric Knee Brace

The knee brace should have a tensile strength commensurate with the increased tensile strength of the changed sensor[5, 6]. The force required to pull the sensor must be in the same range as the force required pulling the knee brace; this force must be a maximum of 2 Newton’s.

Stretchable sensitive Textile

The present smart knee brace is made of a fabric with high stretch capability coated with conductive polymers. These coated electronics are manufactured on non-conductive fabric substrates to eliminate the use of metal components within fabrics by directly coating conductive polymers. An important achievement of using fabrics coated with conductive polymers as sensors is to achieve the natural essence of the materials and Maintain the comfort and flexibility of electronic textiles [5] (Figure 1).

Figure (1). Textile length change sensor

In an elongation sensor, by using an elongation, a noticeable change in conductivity occurs due to the formation and successive destruction of conductive networks during the increase of cyclic and repetitive lengths. Therefore, by coating textiles with conductive polymers, it is possible to produce flexible length changes that can increase this cyclic length without damaging the polymer coating and changing the coating properties, substrate properties, and mechanical properties of the substrate [5].

Signal Processor

ADC unit:

The ADC module unit has been used to convert the analog data to digital. The overall performance of the hardware is as soon as it is turned on, it starts applying software and hardware filters to read the nanosensor correctly (Figure 2).

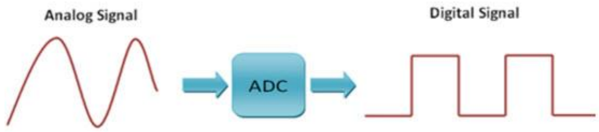

Figure (2). Signal processor

On ESP boards, the pins that can read analog signals are marked with them. Analog to digital converters have to many variations of microcontrollers. The converter on ESP is a 10-bit converter, meaning it can detect 1,024 types of analog signals. Some microcontrollers have 8-bit converters, and some have 16-bit converters.

ESP8266 module:

After converting analog to digital data and calibrating as defined, the processed data is ready to be sent over the Wi-Fi network. This section is done by the ESP8266 module (Figure 3).

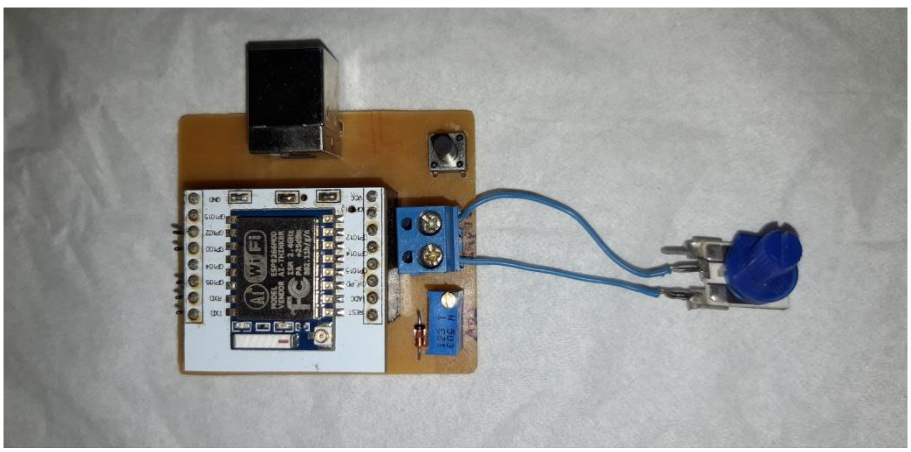

Figure (3). ESP8266 module

The core of the ESP8266 is a Wi-Fi wireless chip that can be easily connected to a router or access point and send or receive information over the Internet. You can also connect to this module via mobile phones that support Wi-Fi technology and send or receive commands. The ESP8266 chip has a 32-bit microcontroller with 4 to 32 MB flash memory and a speed of 80 MHz, is in the form of SOC and has an integrated TCP / IP protocol. This chip's other features include reprograming it like a microcontroller. The module can be configured in two modes: Station and Access Point. The chip has a serial communication protocol including UART, SPI, and I2C and, therefore, can communicate with all microcontrollers that support these protocols. Communication with the chip and its settings is possible through the AT commands.

Information Processing Software

To view the data, it is enough to connect to designed hardware Wi-Fi network by mobile phone or laptop and view the sensor data online. In this design, the TCP telnet terminal program is used to receive data.TCP telnet terminal software is used to monitor serial ports and networks. Using this software, you can easily monitor the serial port and view the sent information. It can also communicate over the network or Wi-Fi with TCP or UDP protocols (Figure 4).

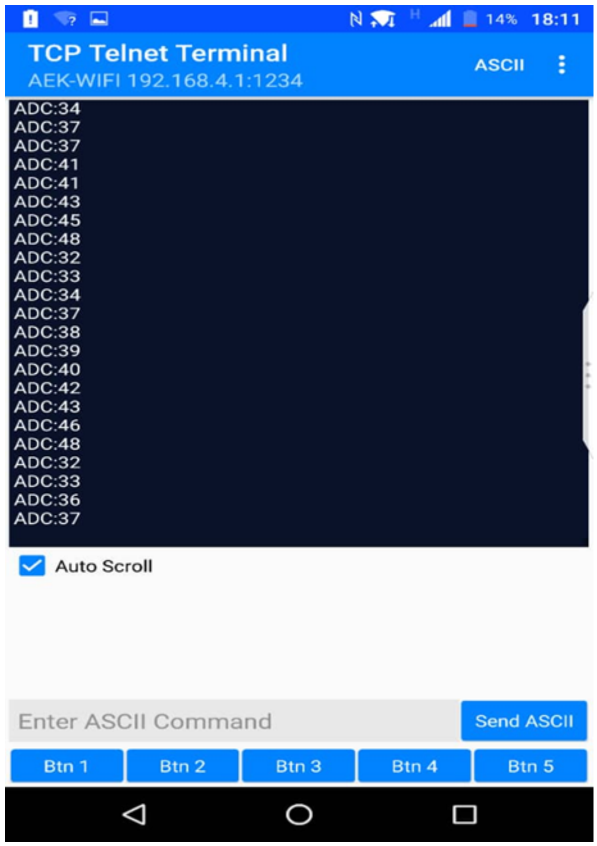

Figure (4). TCP telnet terminal

Knee Flexion Angle Measurement:

A 360-degree goniometer was used to measure the flexion angle of the knee [7]. In this purpose, the goniometer axis is placed on the outer bite of the tibia, one arm is placed on the leg along the outer ankle, and the other is in the direction of the femur (Figure 5).

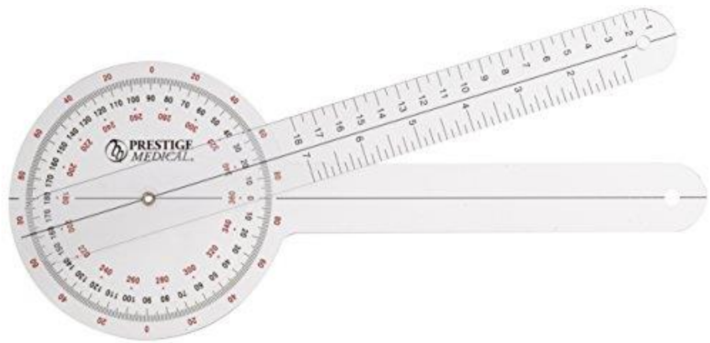

Figure (5). 360-degree goniometer

RESULTS

To check the numbers recorded by the intelligent knee brace. First, the smart fabric was placed in complete rest and stretch conditions, and the recorded numbers were checked. Then, the pulling and turning speed of the fabric was evaluated, and at the end, the knee was placed at different angles, and the recorded numbers were checked.

Range of Registered Numbers:

At this stage, the range of numbers shown in the rest position of the knee and the full stretch position was recorded. A knee brace is separated from the person's body and has not yet been covered. The range of numbers in the rest position of the knee was recorded between 32 and 48, with an average of 39. Full stretch is when the smart fabric is artificially stretched by hand to the end of its elastic phase. In this case, the range of numbers was between 272 and 281, with an average of 274. The figure below shows the maximum and minimum numbers that can be reported by the knee brace (Figure 6).

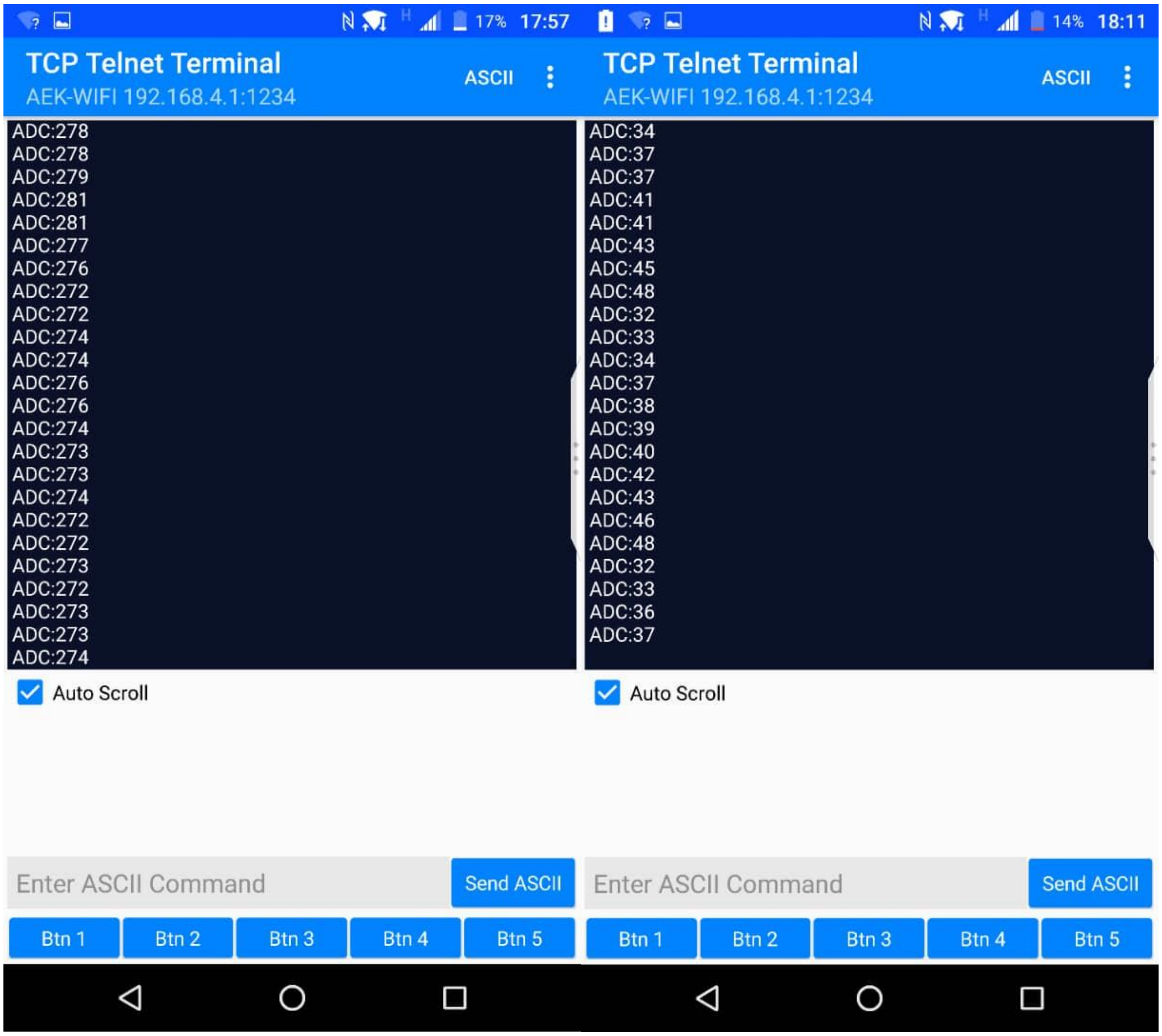

Figure (6). Maximum and minimum numbers

Table 1. Average, maximum, and minimum numbers recorded at rest and full stretch of the fabric

STRETCH	REST	
274	39	**MEAN**
281	48	**MAX**
272	32	**MIN**

Stretching Speed:

One of the most important issues examined was the speed of receiving and processing information when changing the amount of traction of the smart fabric of the knee brace. For this purpose, the knee brace is first artificially slightly stretched so that the numbers are in the anatomical position of the knee, that is, about 52. Then, quickly pull the knee brace to reach the maximum range. As seen in the figure below, the change in numbers from the anatomical position to the full tension position was recorded with a distance number of 99, which indicates the high speed of receiving and processing knee brace information (Figure 7).

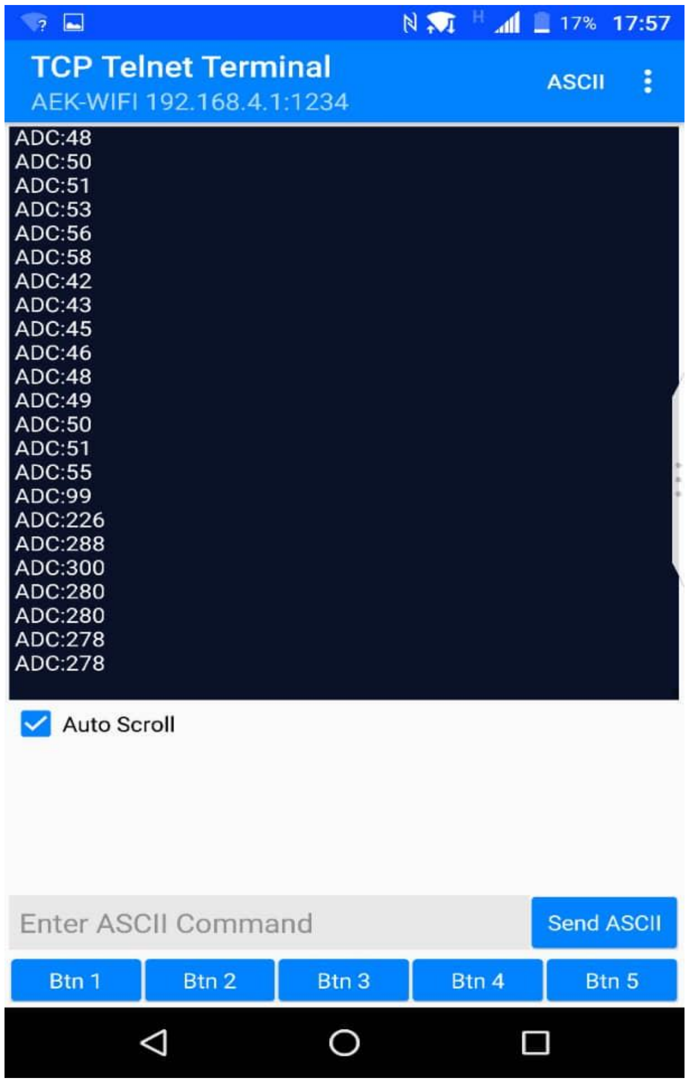

Figure (7). Change in numbers from the anatomical position of the knee to the position of full tension

Speed Back:

Another issue that needed to be investigated was how the knee brace returned to its full anatomical position. For this purpose, the knee brace is artificially stretched completely, so the range of numbers indicating full tension is about 274. Then, quickly release the knee brace to reach a range that indicates the knee's anatomical position around the number 52. As seen in the figure below, the change in numbers from the full stretch position to the anatomical position of the knee is recorded without any distance, indicating the high speed of receiving and processing knee brace information (Figure 8).

Figure (8). Change in numbers from the full stretch position to the anatomical position of the knee

DISCUSSION AND CONCLUSION:

The knee brace was examined in the following positions:

1 – The most important positions that the knee joint experiences while performing sports skills is the position in which the foot is on the ground, the ankle moves around the frontal axis, and is in the dorsiflexion position, and the knee moves around the frontal axis [8], and is in the flexion position. An example of a sport for this situation is the position of the foot in the performance of shooting skills in football [9], (Figure 9)

Figure (9). Ankle in dorsiflexion position and knee in 70 ° flexion position

The knee brace was tested when the ankle was in a dorsiflexion position and the knee was bent at a 70-degree angle, as shown in the figure below. The range of numbers recorded was 108 to 229, with an average of 155 when the knee was in 70-degree flexions. Note that the angle of the legs and thighs in the full (anatomical) extension position is assumed to be zero degrees (Figure 10).

Figure (10). Ankle was in a dorsiflexion position, and the knee was bent at a 70-degree angle

2 – Another position is where the foot is on the ground, and the knee is bent, such as squats. In this position [10, 11], the ankle is in an anatomical position (the ankle in the anatomical position has a 90-degree angle between the leg and the foot), and the leg is almost motionless, but the thigh moves backward and puts the knee in a flexed position, (Figure 11)

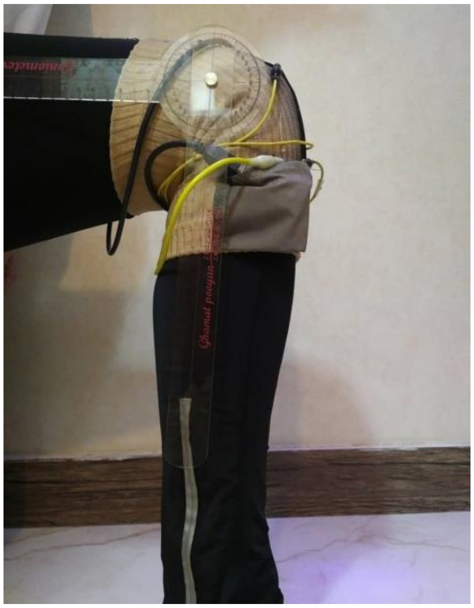

Figure (11). Ankle in neutral position and knee in 90-degree flexion position

The knee brace was tested when the ankle was in an anatomical position and the knee was bent at a 90-degree angle, and the results showed in the figure below. Here, the angle of the legs and thighs in the anatomical position of full extension is also assumed to be zero degrees. The range of recorded numbers was between 58 and 70, with an average of 63 when the knee is in 90-degree flexion (Figure 12).

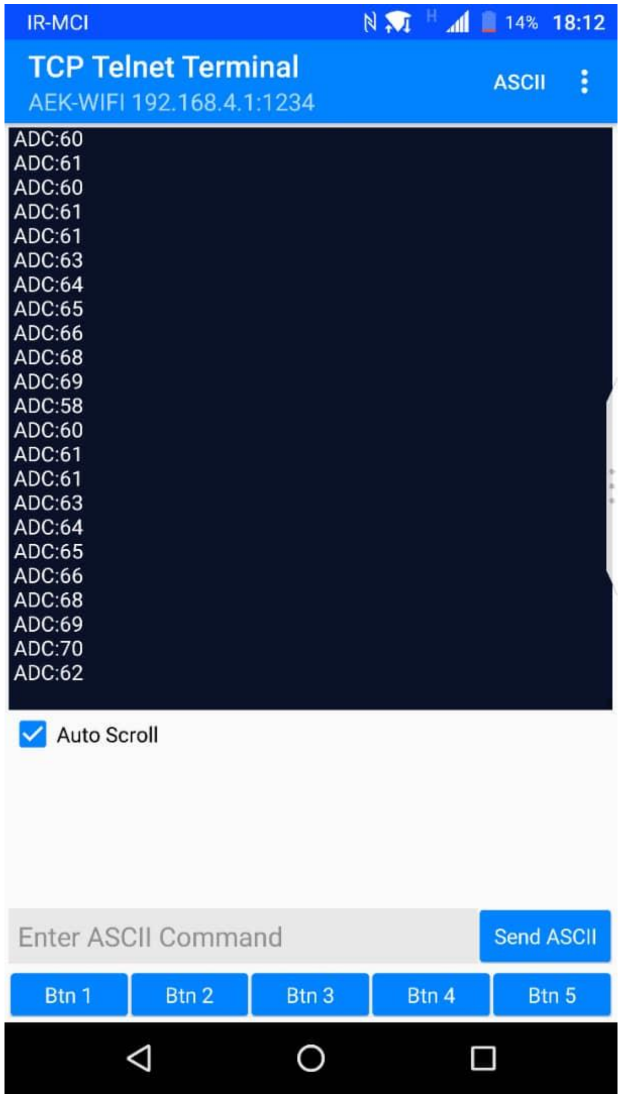

Figure (12). The ankle was in an anatomical position, and the knee was bent at a 90-degree angle

3- The third position in which the foot is on the ground and the knee is bent is landing [12]. In many sports, such as jumping, performing a skill, and landing, the ankle is in the plantar flexion position when landing, and the knee is flexed (Figure 13).

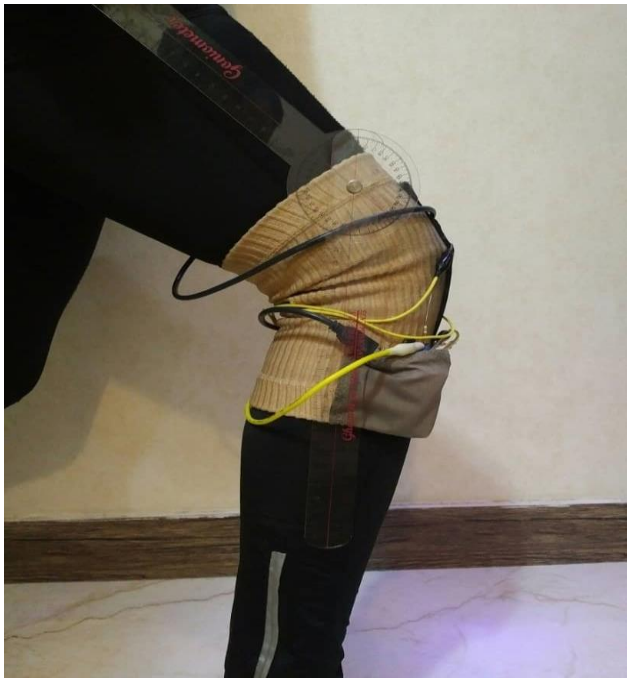

Figure (13). Ankle in plantar flexion position and knee in 130 ° flexion position

The knee brace was tested when the ankle was in the plantar flexion position and the knee was bent at a 130-degree angle and the results showed in the figure below (Figure 14). Here, too, the angle of the legs and thighs in the anatomical position of full extension is assumed to be zero degrees . The range of recorded numbers was between 44 and 60, with an average of 52 when the knee is in 130-degree flexions.

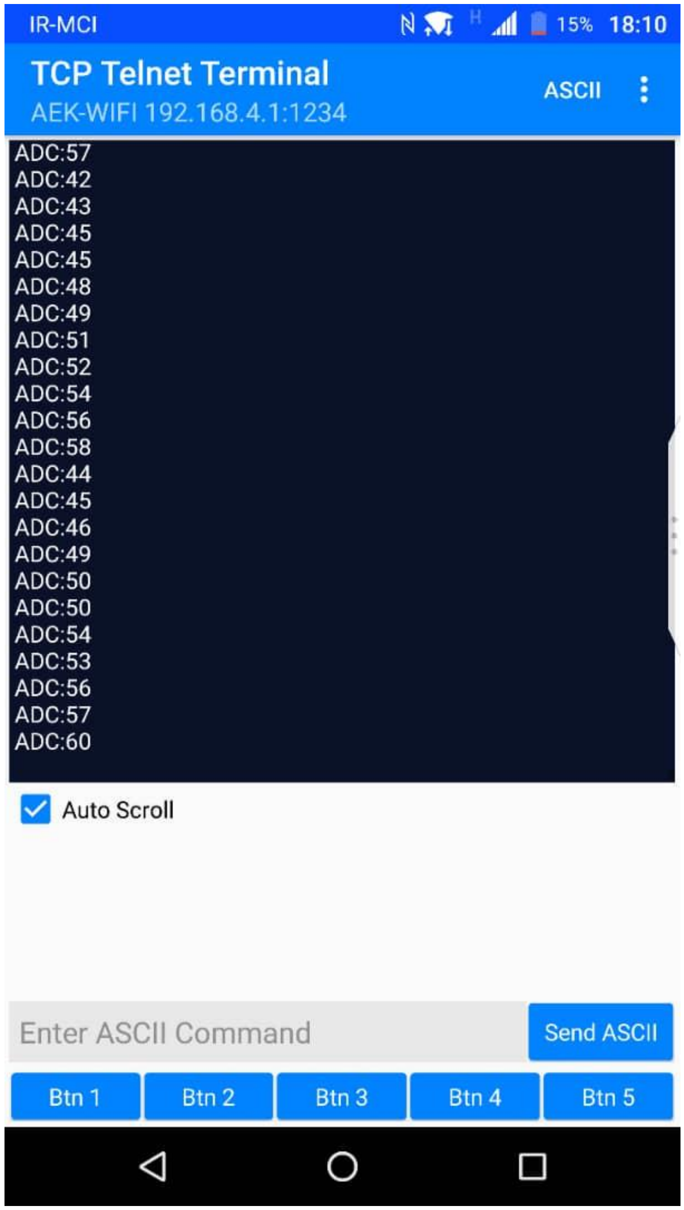

Figure (14). The ankle was in the plantar flexion position and the knee was bent at a 130 degree angle

Table 2. Average, maximum and minimum numbers recorded at different angles of the knee

130 DEGREE	90 DEGREE	70 DEGREE	
52	63	155	**MEAN**
60	80	229	**MAX**
44	57	108	**MIN**

Dynamic deceleration movements, such as the one performed in the present study, are known to increase ACL loading and have been identified as a mechanism of ACL rupture [13]. It has been suggested that teaching athletes to flex their knees more at landing may reduce their risk of ACL injury. However, increasing the knee flexion of skilled athletes experienced at such an abrupt horizontal movement is "challenging" due to their ingrained motor patterns. Therefore, interventions that can increase knee flexion during such a task, particularly with experienced athletes whose movement patterns are relatively "ingrained", are keenly sorted for ACL injury prevention initiatives.

As the results of the present study about the effects of immediate feedback on increasing knee flexion during dynamic movement tasks are inconclusive, further research is recommended to answer the following questions:

a) Can the use of the IKB within a landing training program change the knee flexion angle displayed by a larger and more constrained subject sample during landing movements [14]?

b) If the knee flexion angle can be modified, what is the optimal knee flexion angle that
Should it be obtained during landing?

c) Can change in knee flexion angle made in the gymnasium or laboratory be transferred To the field?

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Institutional Review Board Statement: The study protocol was approved by the Department of Biomechanics and Physical Education of the University of Guilan, Rasht, Iran

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available at request.

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طراحی و ساخت زانو بند هوشمند(دریافت بازخورد از زاویه فلکشن زانو جهت جلوگیری از آسیب)

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چکیده

منسوجات هوشمند بسته به نوع کاربرد، دارای قابلیت های ویژه ای نظیر کنترل وضعیت جسمانی و سلامتی فرد، همچنین ثبت و ضبط و ارسال علائم حیاتی بدن می باشند. در فعالیتهای ورزشی، البسه هوشمند قابلیت نظارت بر میزان و نوع فعالیت ورزشکار، سرعت حرکت و همچنین کنترل و گزارش حرکات مفاصل را دارند. استفاده از این منسوجات هوشمند می تواند به بهبود اجراهای ورزشی از طریق اصلاح حرکات و به دنبال آن پیشگیری و یا کاهش آسیب های ورزشی بیانجامد. در این راستا، استفاده از زانو بند هوشمند می تواند به عنوان یک ابزار مفید و کمکی به اجرایی با ریسک کمتر منجر شده و به ورزشکار اجازه ندهد تا مفصل زانوی خود را در شرایط پر خطر قرار دهد. در این طرح ، محقق در نظر دارد تا اولین گام را برای ساخت این زانو بند بردارد. اولین مرحله، ساخت زانو بندی است که بتواند بازخورد از زاویه فلکشن زانو را دریافت نماید. بدین منظور زانوبندی هوشمند که از سه جزء پردازشگر سیگنال، منسوج حساس به تغییر طول و نرم افزار پردازش اطلاعات طراحی شد. داده های آنالوگ حاصل از منسوج حساس به تغییر طول توسط پردازشگر سیگنال تبدیل به داده های دیجیتال شده و این داده ها توسط تراشه از طریق بیسیم به روتر وصل شده و این اطلاعات از طریق WiFi دریافت گردید. جهت مشاهده داده ها نیز از برنامه TCP Telnet Terminal که بر روی گوشی تلفن همراه نصب شده است استفاده شده است. به منظور بررسی اعداد ثبت شده توسط زانوبند، ابتدا پارچه هوشمند در شرایط استراحت و کشش کامل قرار گرفته و اعداد ثبت شده بررسی گردید. سپس سرعت کشیده شدن و برگشت پارچه ارزیابی شد و در پایان، زانو در زوایای مختلف قرار گرفته و اعداد ثبت شده بررسی گردید.

واژ های کلیدی: زانوبند هوشمند، منسوج هوشمند، فلکشن زانو