

# A Novel Joint Angle Measurement System to Monitor Hip Movement in Children with Hip Diseases.

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**Abstract.** Children's hip diseases are an umbrella term to define different conditions (e.g. Perthes' disease; hip dysplasia) that affect the hip bone during the first months or years after birth. Assessing the degree of hip stiffness is important in the management of the disease, but to date there is no system able to continuously monitor hip angle in children. We aimed to characterize a novel wearable joint angle monitoring system able to collect data during the day in everyday life to assess hip mobility in children with hip diseases. We developed a flexible sensor embedded in a microcontroller based device, including an external SD card to store data. Preliminary data collected by the sensor shows its feasibility into monitor hip flexion/extension (SEM of  $\pm 0.20$  degrees) during daily tasks. The preliminary results support moving forward with the prototype and improving its wearability, validating it in a wider study.

**Keywords:** optical flexible sensor · hip diseases · wearable technology · hip mobility

## 1 Introduction

Childhood hip diseases, including Perthes' disease and hip dysplasia, affect the femoral acetabular joint [1, 2] during the first months or years after birth with different grades of severity and symptoms. The two main characteristics of these hip conditions are pain and changes to normal range of motion (ROM) at the hip joint [1, 2]. The conditions induce stiffness of the hip joint, which causes difficulty in walking and affects normal daily life activities (e.g. climbing stairs or standing up from bed). Treatments for these conditions include surgery or conservative approaches, but common targets of the treatments are to manage the pain and to restore the normal hip mobility allowing a normal life in the affected children [1, 2].

The usual assessment of the impact of reduced mobility of daily life of these children is via quality of life questionnaires[3, 4], which indicates that hip stiffness reduces the ability to perform the daily tasks (i.e. limping and functional impairments during walking). However, there is no objective tool to measure functional joint mobility

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during daily living. In order to objectively assess the impact and extent of hip stiffness on the child's life a dynamic measurement instrument is required. This device could also be useful in monitoring disease progression and rehabilitation.

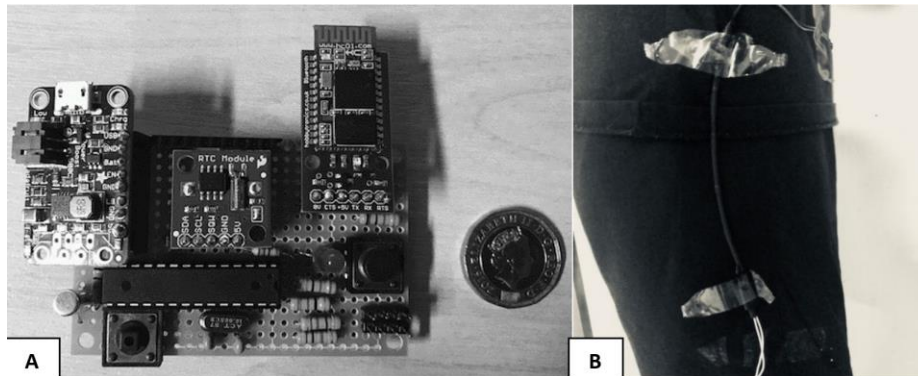
Nowadays, wearable technology is an emerging field in the health and medical sector (i.e. heart rate monitoring; body temperature measurement) [5, 6]. Despite this, no wearable instrumentation is available to monitor hip stiffness during daily life. Existing devices are only able to obtain hip ROM in a laboratory (i.e. electronic goniometers) or in clinical (i.e. manual goniometer) environment [7].

The aim of our study was to report the development of a wearable prototype for real-time wireless, continuous monitoring of hip ROM during everyday life, to be used as a monitoring tool in childhood hip diseases.

## 2 Developing of the Joint Angle Measurement Device

### 2.1 The Device

We developed a wireless device, with a core microcontroller (ATMEL ATMEGA328P), with 1 optical flexible sensor, to detect changes in hip motion (flexion/extension) (fig.1).



**Figure 1:** device prototype board (A) and optical flexible sensor attached over the clothes to the hip joint (B).

A Bluetooth interface (Tronixlabs HC-06) was implemented to send data for real time acquisition (Lab setting) to a computer. A local SD module (Hobby Components, HCARDU0008) for local data storage when the device is outside the laboratory environment; a real time clock microchip (Maxim Integrated, DS1307) for time and date recording; and a tilt ball rolling switch to detect changes in body position (person in standing or lying in down position), were also implemented.

The device runs at 5V and it is supplied by a 3.7 V lithium battery 2000 mAh (Adafruit), connected to a power booster (Adafruit PowerBoost500) to reach the running voltage.

The optical flexible sensor was structured as a variable resistor embedded in a voltage divider design. The sensor implements a light-emitting diode (LED) to one side of a plastic optic fibre (POF), and a light-dependent resistor (LDR) to the other side. The POF was isolated by external light interferences through an external coating made of black shrinking tubes. When the optical flexible sensor is bent, the changes in angle reflection of the light from the LED through the POF changes the amount of light received by the LDR. This induce changes in resistance, read by the device, allowing conversion of the resistance value to a change in angle (degrees).

The bending of the optical flexible sensor induces macro-bending loss of the light that causes the change in the amount of light received by the LDR. Kim and colleagues[8] report that when the angle ( $\Theta$ ) of incidence light in a POF is greater than its critical angle ( $\Theta_c$ ), the light is transmitted to the end of the POF through the total internal reflection. The critical angle is the incidence angle ( $\Theta_i$ ) when the reflective angle ( $\Theta_r$ ) of the light is at  $90^\circ$  of bending.  $\Theta_i$  as showed in equation (2) can be directly obtained from equation (1):

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{\sin\theta_r}{\sin\theta_i} \quad (\theta_r = 90^\circ) \quad (1)$$

$$\theta_i = \sin^{-1} \left( \frac{n_2}{n_1} \right) = \theta_c \quad (2)$$

The light leak in the bent area when a POF is bended makes the angle  $\Theta$  smaller than the  $\Theta_c$ , inducing changes in light reflection through the POF and less light exposure to the LDR.

The changes in light exposure to the LDR (R1) increases its resistance, changing the output voltage ( $V_{out}$ ) of the voltage divider connected to the micro-controller (with R2 as fix resistor) which reads the different output and convert it in different joint angle degrees, following equation (3):

$$V_{out} = V_{in} \left( \frac{R_2}{R_1 + R_2} \right) \quad V_{in} = 5V \quad (3)$$

We set the value of R2 as a middle value between the minimum and the maximum value reached by R1 (in  $\Omega$ ).

In order to fit the subjective variation in hip mobility among subjects, the device self-calibrates itself in the first 15 seconds of recording. This is performed by the subject extending the joint in the  $0^\circ$  position (neutral hip flexion) and in the  $90^\circ$  flexion position.

## 2.2 Microcontroller's Code

Example pseudo code implementation of the voltage divider data acquisition from the microcontroller shown below (based on the example code made for flexible sensors implementations by Cates, Barton and Takahashi[9] ):

```
#define flexion_PIN = *Input pin of the flex
                                sensor*;

const float VCC = 4.98;
const float R_DIV = *R1 VALUE*;
const float STRAIGHT_RESISTANCE = *R1 resistance
                                when POF is straight*;
const float BEND_RESISTANCE = *R1 resistance when
                                POF is bended*;

int flexADC = analogRead(FLEX_PIN);
float flexV = flexADC * VCC / 1023.0;
float flexR = R_DIV * (VCC / flexV - 1.0);
```

## 3 Methods

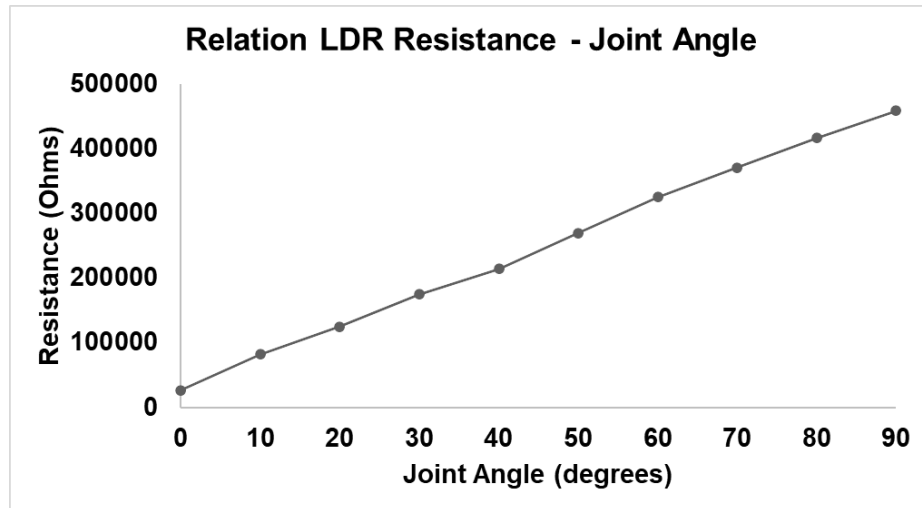
Data obtained by the device were compared with a manual goniometer examine the accuracy of the measurements. The device and the manual goniometer were positioned statically at 0°, 45° and 90° of flexion. Measurements from the optical flex sensor were taken at a sample rate of 1 millisecond, for a period of 10 seconds for each angulation and then averaged.

Additional data were recorded using the device during dynamic movements that simulated daily activities such as sitting. The device was attached to the hip of the participant though medical tape (see Figure 1B) while the participant performed sit to stand maneuvers on a chair.

## 4 Results and Discussion

### 4.1 Optical flexible sensor response

The optical flex sensor demonstrates linear relationship between the changes in LDR resistance made by the POF bending and the changes in angle detected by the device (Figure 2).



**Figure 2:** Linear relationship between changes in LDR resistance and device angle detection.

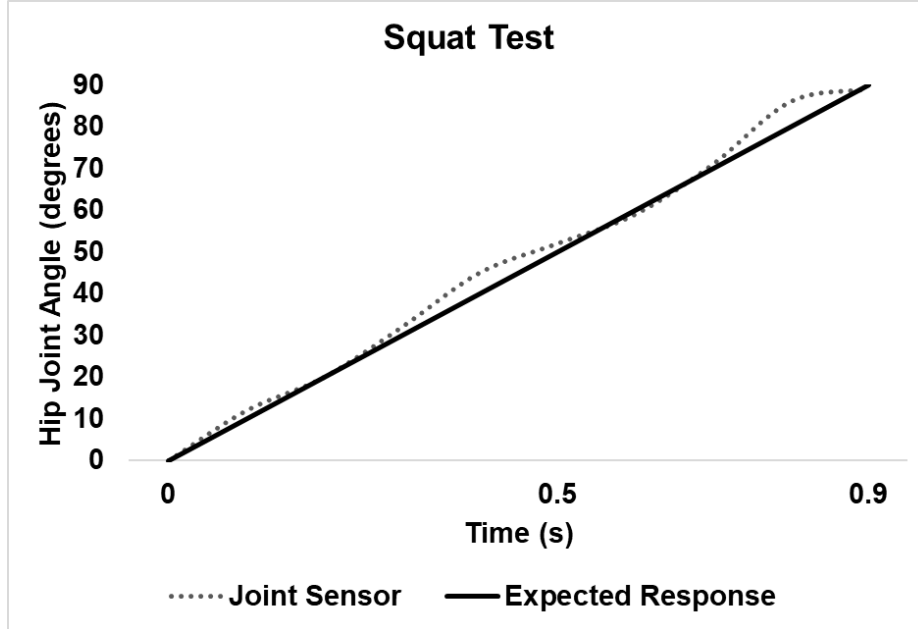
During the measurements taken in static position, the optical flex sensor shown good agreement with the manual goniometer at 0°, 45° and 90° of flexion (Table 1).

**Table 1:** Agreement in measurement in both devices at 0°, 45° and 90°.

Manual Goniometer Angle	Optical Flexible Sensor Angle Mean (±SEM)
0°	1° (±0.20°)
45°	44° (±0.20°)
90°	89° (±0.20°)

## 4.2 Example Tests Results

During 5 repeated trials the device was able to detect the expected hip flexion response while performing sit to stand maneuvers (Figure 3).



**Figure 3:** Changes in hip joint angle during body weight squat.

Taken together, this preliminary data show the device's ability to detect the changes in angle of the hip joint which reflect flexion and extension (relating to sitting and standing). The data were successfully transmitted to a computer/laptop (through the Bluetooth interface) or were stored on the SD card included in the device.

## 5 Conclusion

The aim of our study was to report the development of a wearable prototype for real-time, wireless, continuous monitoring of hip ROM during everyday life.

Our device has shown good preliminary results in the simulated daily activity tests performed, showing fast and accurate reading of the changes in the POF bending angle during flexion/extension of the hip joint. The preliminary data have shown the concept is feasible. In order to make the sensor suitable for implementation in clinical practice, further miniaturization and testing in ambulatory environments are required. Further modification will seek to improve the current prototype, improving its features and its wearability to fit the population of interest. Additional tests of reliability will be performed which include longer durations of data collection (i.e. 24 h/7 day period) using a larger sample size and including children.

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