# TAILOR: Wrist Strain Monitoring Sleeve

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## Abstract
TAILOR is a sensor-equipped wearable sleeve that aims to improve the incidence of repetitive strain injuries and carpal tunnel syndrome. With the significant increase of people working in offices over the last few decades and the growing proportion of computer use, injuries around the wrist and the elbow are becoming more prevalent. TAILOR aims to deliver a relatively unobtrusive solution for monitoring the strain on the wrists and elbows, and provide a more proactive way of preventing these injuries. To achieve this the system targets a just-in-time intervention approach using a visual, real-time feedback.

## Author Keywords
Posture; Human Computer Interaction; Repetitive Strain Injury;

## CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** *Haptic devices;* User studies; Please use the 2012 Classifiers and see this link to embed them in the text: https://dl.acm.org/ccs/ccs_flat.cfm

## Introduction
In the last two to three decades the prevalence of typing work both at home and in the offices has increased drastically [8]. The availability of personal computers and their

use in daily activities has resulted in tripled incidence of associated repetitive strain injuries over the course of just four years [11]; a trend which is only expected to grow as more and more services are becoming digitised.

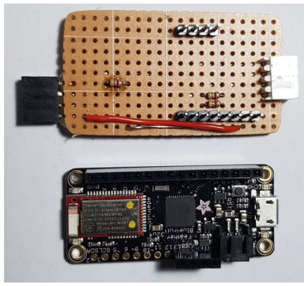

**Figure 1:** Adafruit Feather BlueFruit LE with custom flex sensor hat.

**Figure 2:** Schematic drawing of a resistive flex sensor held with 3D printed slots.

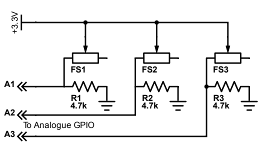


**Figure 3:** Schematic of the sensor hat PCB

With rapidly growing industries such as *E-sports* where the participants often exhibit systems of these injuries, the need for a way to reduce and prevent these risks is greater than ever [3].

One of the main injuries associated with typing work is Repetitive Strain Injury (RSI) [2]. Individuals whose occupation involves repetitive activities such as typing, bar-code scanning or other assembly line work frequently develop RSI due to prolonged cumulative trauma to the same areas of their body [4]. This causes damage to the muscles, tendons and nerves and can often lead to loss of sensitivity, pain and and inability to work amongst other problems [15].

Carpal Tunnel Syndrome (CTS) is yet another widespread problem faced by the global population that stems from repeated strain [1]. Similarly to RSI, CTS can also be frequently caused by cumulative trauma and likewise, the range of associated symptoms can include both pain and weakness but also shock and uncontrollable sudden movements. CTS is considered to be a serious condition requiring significant medical treatment and or surgery [17].

Both RSI and CTS stem from incorrect posture during performed work and can be frequently prevented simply by correcting that posture. Despite this, the two conditions are still extremely prevalent as they are frequently only noticeable once they are fully developed. As such, the preventive approach is one viable strategy of reducing the risk of acquiring RSI or CTS [15].

Our solution - TAILOR - is an easy to use, just-in-time (JIT) intervention in a form of a sensor-equipped sleeve. It aims to monitor the stress exerted on the user's wrists and elbows as they perform repetitive activities and provide real-time visual feedback. Based on the provided biofeedback, the user can then adapt their posture and prevent the injury before its symptoms become apparent.

## Related Work

The paper by Leung et al. (2012)[10] proposed Limber - a system comprising of a wearable and a game-like desktop application. It allowed its users to correct their posture based on visual feedback and evaluated it over two development cycles. The device used a single stretch sensor applied to just one finger. In their paper from 2015, Peppoloni et al. [14], demonstrated a wearable system for the arm that monitored the posture via EMG and IMU sensors and assessed the risk for work-related musculo-skeletal disorders, including the CTS. The EMG sensors were however not suitable for a standalone wearable device as they needed to be attached directly onto the skin. The proposed solution focused on a passive monitoring and did not provide any biofeedback. Several other software alternatives exist, focusing on taking frequent breaks, such as those described by Morries et al. (2008)[13] and Kemp et al. (2002)[9].

BITAIKA was developed as a posture correction system aimed at enabling users to adjust their own posture [6]. It combined the use of piezo-electric pressure sensors and a camera to provide visual feedback which enabled the users to self-correct bad posture. The system provided the user with a side view of themselves and allowed for the observation of the pressure applied to the chair. By gauging the persons' centre of gravity and position, the system was able to inform the user of their bad posture via notifications. The system has proven to be effective in the preliminary tests

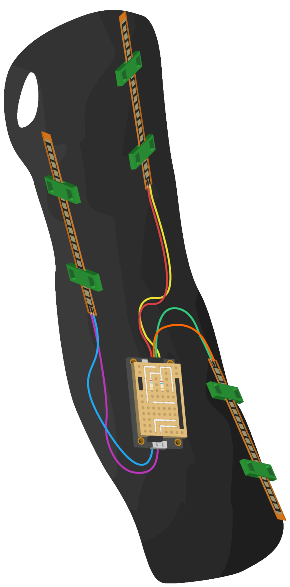

**Figure 4:** Schematic of the sleeve with electronics directly mounted on top.

and has been shown to reduce the time spent in strain-exerting positions in its users.

A similar device has been built by KATAWARE [7] and was presented in their technical report. KATAWARE's device aimed to achieve gesture recognition with a glove using a combination of resistive flex sensors and accelerometers. The gesture glove implemented partial gesture detection using the on-board microprocessor and then sent the readings to a computer wirelessly via ZIGBEE modules. Gesture detection was realised with a simple bit table with combined data from each of the sensors, where the sensor's analogue data on the glove was first thresholded to produce a 1-bit output. The microprocessor then sent out the bit table to a computer for further recognition. Software on the computer implemented the remaining gesture recognition by matching on the values of the bit table. The gesture detection scheme has been found to be effective at recognising simple gestures and the overall system design using off the shelf wireless modules was robust enough for the real time data collection.

In their paper titled "Effect of a Wrist Motion Storage Biofeedback System (WMSBS) on Wrist Motion during Keyboard Typing Work", Won-gyu Yoo set out to show the effect of WMSBS during keyboard typing work, with a wider goal of assessing its use for wrist posture re-education (correction). To do so, they proposed a novel solution in a form of an ultrasonic movement analysis system used in conjunction with markers used to assess the kinematic wrist data. That setup was enhanced with the WMSBS consisting of an accelerometer, storage program and a biofeedback in the form of on-screen pop-ups.

Demmans et al. (2007) [5] presented their Work-in-Progress paper in which they attempted to prevent RSI in laptop users by correcting their neck posture. The system integrated both a user-worn device and a feedback interface. The proposed device measured multiple movements and through three flex sensors, which are placed at specific areas around the user's neck. A scale of the user's posture ranging from good to extremely painful was then displayed on the interface represented by an emoticon and a colour.

## Design

Our device was designed to be used with a standalone desktop application. As such it identifies several layers, including the physical device, connection protocols and feedback application. This section outlines the design steps and methodology in which the system was constructed.

*Hardware*

To help gauge the amount of stress on the users' critical points of stress, off-the-shelf flex sensors were chosen for this purpose, due to their wide available and easy of use [16]. The flex sensors are resistive sensors; as such they provide enough granularity to gauge users motion and translate it into the degrees of movement.

In order to collect the data and turn the voltage readings from the sensors into useful information, the Adafruit Feather BlueFruit LE (Figure 1) was the chosen as the development board. This board has a Microchip ATMega32u4 microcontroller [12] as well as an Nordic nRF51822 Bluetooth Low Energy radio, which were a vital part of our solution as they served as main platform for the raw data capture and transmission.

The chosen development board also hosts a Lithium Polymer battery connector with an built-in charging circuit for the batteries. This allows the device to be powered by battery and operate without being tethered to a computer or other device and was one of the main reasons for using the board in our system.

To construct the TAILOR sleeve, a ready-made sports sleeve was acquired and used as a base. It serves as a platform accommodating all of the other components. For secure placement, the sensors are mounted via 3D printed slots (Figure 2) rather than sewn. This enabled us to position the flex sensors appropriately on the highly-elastic fabric without it tearing or bending the sensors in the restful state. The end result is illustrated in Figure 4.

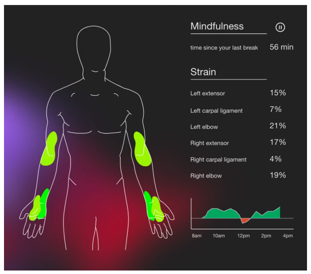


**Figure 5:** Example of Desktop App GUI

*Software*

To enable the display of the measurements, a desktop monitoring software that connects via Bluetooth Low Energy (BLE) to the device has been written. As the hardware only provides raw sensor data transmitted in real-time, the software is responsible for data collection, visualisation, and persistence for future reference. In order to communicate the feedback to the user effectively, the graphical user interface (GUI) has been designed with simplicity and legibility in mind. The fundamental part of the interface focused on displaying the overview of the body and highlighting the strain in wrists and elbows using varying colour scale. To display the detailed information on each of the body parts (as linked to the sensors), interface enabled on-hover interaction with each of the measured zones - providing zone-specific data as needed. In addition to that, the GUI also provided an option to display raw sensor data built-in calibration functions. The GUI was realised in JavaFX, a rich internet application (RIA) framework that provides support for variety of graphics features. The design of the application is shown in Figure 5.

For the BLE communication, a simple serial UART protocol has been used to transmit tagged floating point data between the sleeve and the desktop software in plain ASCII. The desktop software simply reads and parses the UART input and stores it in a map-like structure for the later access.

*System Design*

The device consisted of three resistive flex sensors (see Figure 2), two of which were attached to the wrist and one to the elbow. These areas were selected due to their frequent strain, as reported by typists. All of these sensors were connected to the General Purpose Input-Output (GPIO) pins on the development board. The firmware written on the board was used to read the analog values for the voltage on the GPIO pins and convert it into an angle of bending of the sensor. A custom 'hat' was used to connect the flex sensors to the Adafruit board (see Figure 1 and Figure 3). Using a prototyping board has allowed the controller and the sensors to form a single package which streamlined its use once the system was assembled together.

This development board advertises itself as a Bluetooth peripheral and when connected to a device it will send the angle data from the sensors to the paired device. This information is then interpreted and graphed by the desktop software written to provide the end user direct feedback as to how their typing position affects the points of pressure. The whole device is encased within 2 layers of a sports arm sleeve in order to contain all of the above hardware in a more usable and portable form.

## Setup

The device has been developed as a proof of concept; as such its usage has to follow a given procedure to maximise the effects. The participant begins but putting on the inner arm sleeve which holds all the resistive sensors and the controller/communication device. Once in place, the sensors have to be slotted into the 3D printed slots and controller has to be attached on top of the sleeve. The outer sleeve should then be worn on top to hold everything tightly in position. The device can be turned on and paired with the feedback system over Bluetooth. The device is shown in Figure 6

Once paired, the desktop application has to be started. In conjunction with the help of the demonstrator, it will allow for the calibration of the sensors in the correct posture..

## Evaluation

*Device testing*

A small test campaign has been conducted with a qualitative measure in a questionnaire to gauge user responses to using the device. The test campaign was carried out in the University of Bristol Faculty of Engineering SCEEM building and consisted of several participant who attended the demonstration. A varied group of people tested the device by wearing it, calibrating it to their posture and typing sample text to on the computer keyboard (see Figure6). Upon finishing the users were presented with the questionnaire to evaluate the design.

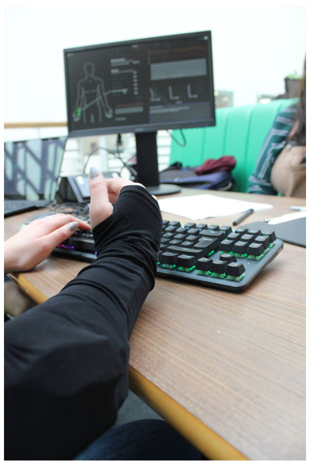

**Figure 6:** A complete device worn on participant's right arm.

*Results*

The questionnaire provided used the Likert Scale, allowing users to indicate how much they agree/disagree with the eight statements, with a section for additional feedback. Each answer on the scale was related to a score between 1 and 5, strongly disagree and strongly agree, respectively. This allowed for an average percentage of how much the statement was true to be calculated. In total, 17 participants filled out the questionnaire.

The survey aimed to first analyse the participants typing habits, with an average of 94% agreeing that they type a lot (approximately 20 hours per week) and 72% believing they have a bad posture whilst doing so, reaching the correct target audience.

The questionnaire showed promising results, with a 96% agreement that this device would be useful for someone who has RSI and 91% agreeing that they would use this device themselves.

Aforementioned users also had the option to write additional feedback which in most cases they did. The overall consensus was that participants liked the device and found it to be very comfortable and that wearing it felt natural whilst typing. The majority of the additional comments were reacting positively to the user interface.

It was stated by one user that they would prefer the device if it were slightly smaller, possibly just a wristband rather than a full sleeve. On top of this, a couple of participants would like an additional instant feedback, such as vibration, if the user was typing incorrectly for a specific period of time. There was also interest in this device, from a few participants, about whether it could be used for other activities such as playing a musical instrument.

## Conclusion

Although with more qualitative evaluation we find that this system is desirable for most of the users showing 91% of people would use this device again. Since our system aims to help those who are most likely to be affected by RSI and similar wrist injuries from prolonged typing activity and straining of the wrists, it is clear although with a small sample size, users feel that this type of system would benefit them. Although still lacking in features and data collection, this initial study encourages further research into such a device as well as refinements to improve the usability as well as expand the range of users to not be only limited to offices and typists but possibly musicians.

## Future Work

There are many possible future parts to amend in order to provide more research into the effectiveness of such a device. Considering the lack of quantitative data one possible avenue is to run a more scientific and robust test collecting raw data, wrist movement and perhaps even correlation with biological data to observe the actual effect of movement on the strain exhibited by users.

In the future we would like to be able to add more sensors to the device. This would allow us to monitor more parts of the arm and more muscle groups and nerve sections which are commonly affected as well as providing more comprehensive data. In addition to this it would be advantageous to design a more easily wearable sleeve and have a more custom hardware solution that is less obtrusive in order to provide users a more comfortable and seamless experience.

To improve the user experience the user interface and application can also undergo some additions to help users see more clearly when they are not in a *good* posture. A pop up notification upon longer periods spent in a bad posture could also be a more proactive form of informing the user and helping them change their habits.

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