FlexFix: Finger tracking and notification system for hypermobility and osteoarthritis

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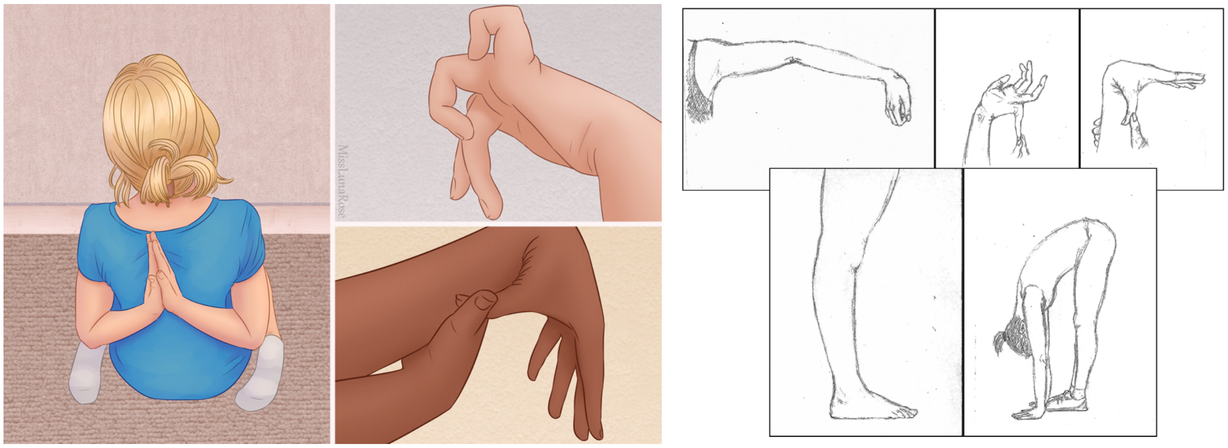
Abstract

Joint hypermobility syndrome refers to joints with ranges of motion beyond the normative. Hypermobility has no cure and symptoms are managed through pain relief medications and physical therapy involving strengthening of the muscles and joints. We hypothesize that an assistive monitoring device which provides visual feedback on finger flexion and force will enable individuals with hypermobility to better manage the use of their fingers to minimize symptoms such as fatigue, redness and locking of the joints. A functional prototype finger telemetry system was constructed, incorporating an angle measurement and a piezoresistive force sensor. A wrist-worn microcontroller processes the data and triggers a three stage visual indicator as a predictor of the individual's future joint pain. To determine if users will modify their behavior according to the monitoring device, a human subject study is proposed where participants will perform a repetitive task of polishing antique jewelry using a cloth. Subjects will be polled on their discomfort level with and without the telemetry device and if they altered their behavior during the task. If the hypothesis holds true, this research could inform how future consumer-oriented monitoring devices may be used to improve patient outcomes through self training and regulation.

I. INTRODUCTION

Osteoarthritis (OA) is the most common form of arthritis and affects over 32.5 million adults in the United States, particularly older adults and women [1], [2]. OA is caused by damage or breakdown of the protective cartilage that cushions the ends of bones. Joint hypermobility, which is where one's joints are more flexible than normative, has been recognized as a causal factor in OA due to the repetitive stress on the joints [3], [2]. Our project plans on addressing the issues faced by individuals who have hypermobile finger joints, namely the joint pain that comes from repetitive motions and excessive pressure on the joints. We hope that our device will encourage the user to modify their behavior when they are putting too much wear-and-tear on their joints, thereby slowing the onset of osteoarthritis.



(a) Examples of joint hypermobility by MissLunaRose12 is licensed under CC BY-SA 4.0

(b) Tests used in the Beighton scale by AstonMarti is licensed under CC BY-SA 4.0

A. Background

Joint hypermobility syndrome describes joints that can bend beyond the normal range of motion. Commonly referred to as double-jointed, it can apply to any number of joints in the body including shoulders, knees and fingers. Symptoms of hypermobility as it relates to the hand include joint swelling, joint instability, chronic pain and stiffness and locking of the fingers. [4]

Hypermobility has been found to be more common in children and women, especially women over the age of mid forties. [5]

It is measured using **metrics** such as the Beighton scale which is composed of nine exercises. Individuals are asked to bend various joints including their fingers, elbows, knees and palm. A score of 0-3 is considered normal while a score of 4 or more out of 9 is classified as hypermobile. [6]

Types of therapy: There is no cure for hypermobility, but several treatments and techniques exist for management of symptoms including pain reliever medications and physical therapy to strengthen muscles and joints. [7]

Tangible impacts: Individuals with hypermobility may overexert grip forces in their fingers resulting in redness, fatigue and discomfort. The impacts can discourage individuals from partaking in recreational activities and hobbies. [8]

Primary osteoarthritis describes the reduction and degradation of cartilage between joints of the hands, knees and other joints. Like hypermobility, there is no cure. Treatments focus on pain relief, minimizing of swelling of the joints and preventing stiffness. Resting of the joints for a period of 10 to 30 minutes typically alleviates symptoms. [9] Because it is a condition associated with aging, studies estimate that 70-85 percent of those over the age of 55 have osteoarthritis. [10]

As both hypermobility and osteoarthritis have no cure and treatment focuses on pain management and reducing risk factors that worsen the condition, this paper seeks to assist individuals through external sensing and feedback to the user. The authors are not aware of any existing devices that provide live feedback to alter behavior to reduce pain caused by hypermobility or arthritis. As is in the case of osteoarthritis being relieved through rest, a primary exploration of this paper is how the constructed prototype might encourage such restful behavior before the onset of pain and more serious symptoms.

B. Overview

We hypothesize that providing visual feedback correlated to finger flexion and force will enable individuals with hypermobility to modify their behavior to reduce discomfort. **Section II** describes the needs for such a monitoring device as it relates to recreational activities and the discomfort that can result from overuse and fatigue of hypermobile joints.

To test our hypothesis we present a compact finger telemetry measurement system in **section III** which will collect and notify the user about their joint usage. A three stage visual indicator consisting of green, yellow and red lights worn at the wrist will inform the user about the intensity of their joint usage.

If the hypothesis holds true, this research could indicate how consumer grade monitoring devices could alter patient behaviors as discussed in **section IV**. In **section V** we explore the broader impacts of the system as a protective training and educational device.

II. PRELIMINARY RESULTS

In order to guide the design of a specific investigational device, we interviewed a woman in her late 60s with hypermobility and osteoarthritis who had a successful thumb reconstructive surgery a few years ago. She also stated that she will need thumb reconstruction on her other hand in the coming years. She enjoys working with her hands and doing fine manipulation activities such as restoring antique jewelry, so our project will be focused around these kinds of activities.

From our interview, we extracted a few key issues that the need-knower identified. The first is that sometimes she grips items too hard, especially when she is polishing and restoring antiques. This causes redness at her fingertips and causes her to feel fatigue and pain in her finger joints. This insight informed

Need	Priority
Fatigue from hypermobility	High
Gripping thin objects	Medium
Easily usable form factor	High
Joint locking	Low

TABLE I: Primary findings from the interview and priority for addressing them

our to-be-later-revealed pathway of telemetry informing the user that they may be gradually hurting themselves when doing strenuous tasks.

The need-knower also identified difficulty with sorting thin objects like papers. She described a previous solution that worked well for her, which was to use rubber fingertips. This illuminated the need for our solution to at the very least maintain if not improve the traction of the user's fingertips.

When discussing her working with hand tools such as screwdrivers, the need-knower expressed interest in compactness of design for a product that is as easy as possible to use in daily tasks. She identified large handles as helpful only to a certain extent as they can also occlude her workspace, so this sentiment was taken into account in our design as well.

The need-knower also mentioned that her finger joints can sometimes lock in place and she has to physically move them herself to release her fingers from that position. She mentioned that she had used finger splints in the past, so we looked into the different types she had used before (both metal and plastic) and these served as a starting point for our design.

The primary findings from our interview as well as our interest in addressing these needs in our solution are summarized in Table I.

III. METHODS

Device concept: We developed a wearable device that captures relevant finger telemetry for evaluating our hypothesis including overall finger flexion and fingertip pressure. Ensuring minimization of overall packaging was critical for daily usability for precision tasks where this device would be most likely used. As shown in Fig. 2, the wearable device integrates a flexible angle measuring sensor with a pressure-sensitive piezoresistive sensor routed along the finger to a wrist mounted enclosure. Users wear this device while performing dexterous and straining tasks and the sensors will capture activity performed by the finger to then send to the wrist enclosure, which will shine different color LEDs depending on predicted risk of discomfort. This assistive device can be used by individuals with a range of finger related injuries and disabilities to reduce fatigue and prevent the onset of discomfort before it occurs.

Subsystem description / proof of function: The components of the design can be seen in Fig. 10 where there are a few notable subassemblies, including the fingertip, harness rings, knuckle guide, and wrist enclosure. The fingertip is constructed from a flexible resin material that provides a comfortable tacky interface material to assist with gripping. The design features a cutout which allows airflow, as well as the exposing the fingernail for related tasks. The fingertip integrates a piezoresistive pressure sensor and terminates the flex sensor to correctly capture the angle of the fingertip. Pressure applied by objects on the fingertip will be captured in a radial deformation of the piezoresistive sensor, which will change the resistivity of the affected zone, altering the overall resistance. The onboard microcontroller mounted to the wrist will then be able to measure this change in resistance with the assistance of a simple voltage divider.

Structural rings made from a similar flexible resin material provide a tacky, non-rotating functionality that keeps a harness in place. For different sized users, different ring diameters will need to be specified.

The harness itself is made up of two primary components: the electrical leads for the fingertip-mounted piezoresistive pressure sensor and a Bendlabs 1-axis soft flexible sensor. The output of this sensor is an angular value from the base of the sensor to the tip, regardless of the intermediate path travelled. This allows the device to capture the overall flexion of the finger.

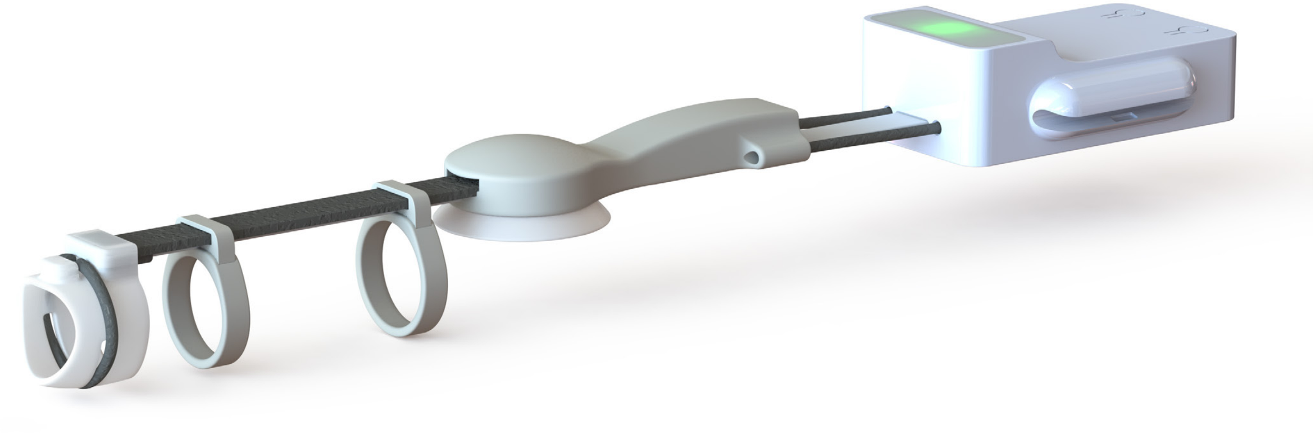


Fig. 2: 3d rendering of the proposed finger telemetry measuring device

The wrist enclosure holds an ESP32 microcontroller, vibration motor and Neopixel LED. The knuckle guide has silicone concave geometry that locates on the top of the finger's knuckle. Wire slack springs are found on both sides of the knuckle guide to the fingertip via the axial flexibility of the Bendlabs sensor and the repurposing of the piezoresistive flexible cordage to the wrist enclosure. The LED on the wrist enclosure will be informed via the algorithm uploaded to the microcontroller whether to shine green, yellow, or red based on recent finger activity.

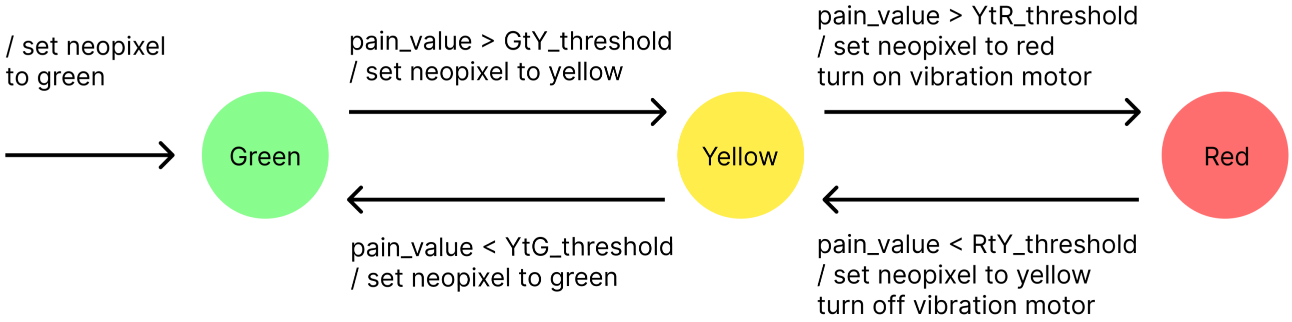


Fig. 3: State diagram showing logic for moving between green, yellow and red notification. GtY, YtR, YtG, and RtY stand for the color transitions (Green-to-Yellow, Yellow-to-Red, etc.) which all have different thresholds to prevent rapid fluctuation between states.

A proposed study:

We propose conducting a small scale human subject test involving older adults with hypermobility to investigate the role of providing users with activity-based visual feedback. The study will consist of 14 volunteers with similar high Beighton test scores to indicate their extent of hypermobility. Volunteers will be recruited from an older adult population who especially are engaged in dexterous tasks in their day to day activity. The study will ask subjects to perform a repetitive task of polishing metal using a cloth. In the first phase of the study, subjects will not wear the device and be polled periodically (every 5 minutes) to rate their discomfort on a scale of 1-10. In the second phase of the study, subjects will wear the device, but no visual feedback will be given. The data will be collected while asking the users to rate their discomfort periodically. Adequate rest time will be enforced between tests. In the third and final phase of the study, the visual indicator on the device will be enabled. Subjects will be observed based on how they do or do not change their behavior according to the provided visual feedback.

Discussion of procedure /expected outcomes: Participants will be asked to polish a piece of copper stock with a provided cloth and polishing solution. Participants will be asked to polish until the stock has changed color matching a control piece. We intend for our device to provide data that can provide information about the correlation between finger activity, namely the flexion/extension behavior of the finger and the pressure applied at the fingertip, and eventual discomfort. When an appropriate function that predicts pain has been calibrated for an individual's unique condition and pain tolerance, we hope that the feedback mechanisms are effective in alerting the user to their elevated risk of eventual discomfort and encourages them to modify their current behavior to reduce pain.

IV. INTELLECTUAL MERIT

The development of the proposed device and study can create a data set which can help future researchers correlate and design solutions to a range of dexterous and joint conditions. This study has the potential to demonstrate how to some degree, patients can modify their own behavior through a simplified visual and haptic feedback mechanism. Future studies could investigate different mechanisms for giving feedback to users, such as through notifications on a connected personal device. Such studies could also investigate the timing of delivery of the feedback, such as immediate vs delayed and whether to provide it to the patient or a caretaker or medical team instead. Shortcomings of the proposed device include telemetry capture along only a single finger. A modular approach allowing multiple fingers to be tracked and plugged into the same wrist worn device could be one mitigation strategy. Questions that may be beyond the scope of the proposed study include the long term effectiveness in retaining any modified user behavior as a result of time spent training with the proposed assistive device.

V. BROADER IMPACT

This research indicates the potential for a compact telemetry system to help individuals self-train and manage discomfort associated with hypermobility. Such a system could be introduced at early onset and diagnosis in younger age patients, serving as a training tool which may help individuals prevent over usage of their fingers before reaching levels of fatigue and discomfort. The system could thereby provide protective and preventive training if introduced and utilized early on.

Beyond the proposed use as applied to hypermobility, the modular design of the system could allow at home telemetry collection for any number of hand and finger related conditions. The aggregation and combined analysis of such data amongst many users may enable predictions and long term studies for a wide range of conditions. Sharing of the code, schematics and plans with the open source community may further accelerate possible uses and learnings from such a telemetry system.

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APPENDIX B
INVESTIGATIONAL DEVICE DETAILS

The electronics are mostly stored in the case that is strapped to the user's wrist. The ESP32 microcontroller is connected to 4 components: the Bendlabs sensor, the pressure sensor, the Neopixel, and the vibration motor. The microcontroller utilizes the I2C protocol to poll the Bendlabs sensor for the angle information. The conductive cord is connected to the microcontroller as part of a voltage divider. When the microcontroller reads the analog input from the voltage divider, a higher signal indicates more pressure has been applied to the conductive cord.

To calculate a measure of potential pain, we devised a function that takes in the current angle position, the previous angle position, and the current value from the pressure sensor voltage divider. This "pain function" can be changed from person to person depending on their unique condition, but the one we implemented was of the form

$$pain = (a \times pressure + b)(c \times \cos(currentangle) + d) + (f \times abs(currentangle - previousangle) + g)$$

where a, b, c, d, f, g are tunable constants. We designed this function to take into account both the torque being applied to the finger and the speed at which the finger is bending. The first term is similar to the equation for torque where applying a pressure with a straight finger will produce more "pain" than applying the same pressure with a bent finger. The second term utilizes a scaled estimation of the angular speed of the finger. We implemented these two terms because we believe that both of them can contribute to joint and finger pain, but the "pain function" can and should be calibrated for each individual user.

The "pain" value is calculated every time the sensor values are updated. These "pain" values are put into a ring buffer, the length of which can also be tuned to change the amount of time that the values are saved for. Summing up these values in the ring buffer gives a measure over the amount of "pain" the user has accumulated over a certain amount of time, and this sum is what determines what state the LED should indicate. The other constants that need to be tuned per user are the state transition thresholds. If the sum of potential pain exceeds the threshold for the next elevated pain state, the state will transition up one level, and when the sum comes back down after a period of less aggravating activity and falls below the threshold for the next lower state, the state will transition down one level. We chose state transition thresholds such that the decreasing state thresholds were less than the increasing state thresholds to prevent jittering of the states and also to build in extra time for the user to rest before being informed that they have sufficiently decreased their potential pain.

Fig. 4: Functional 3D printed prototype

Fig. 5: Green and red visual indicator examples

Fig. 6: Assembled functional prototype

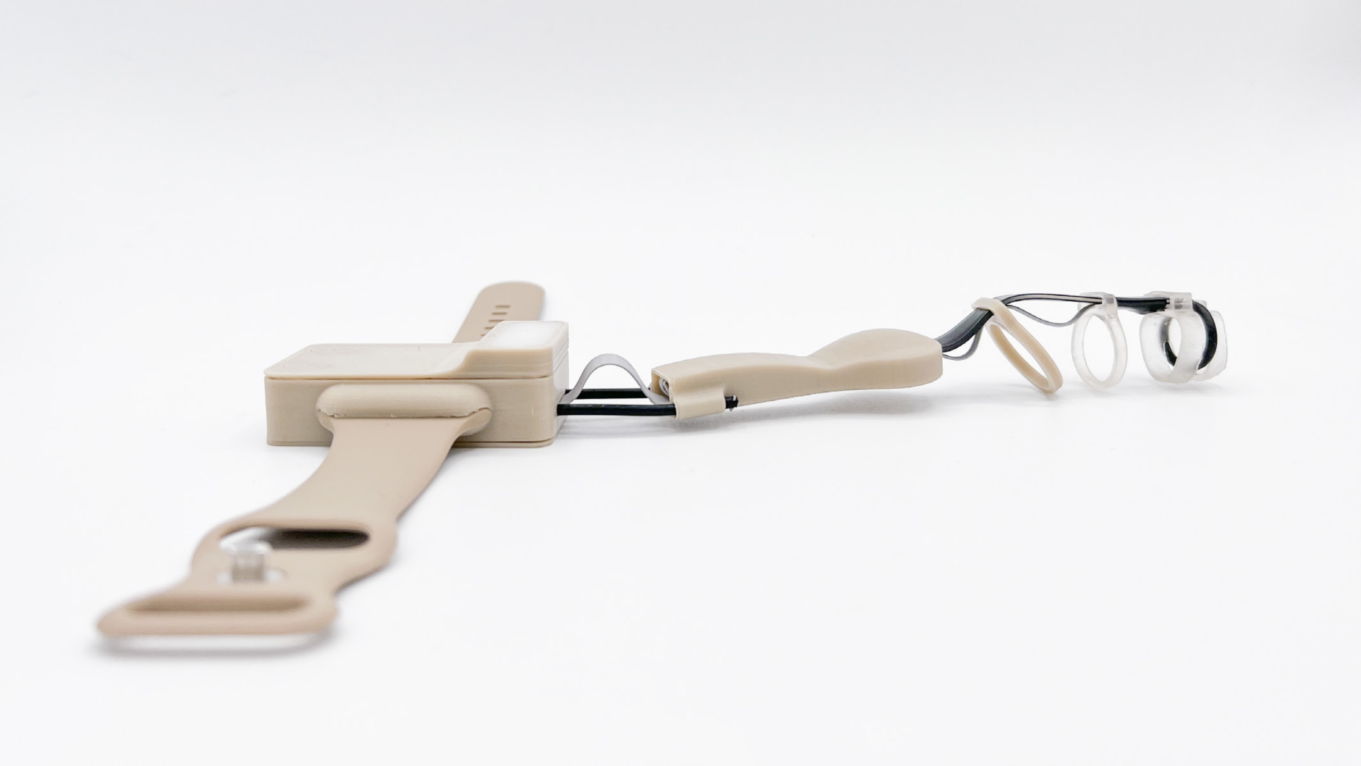

Fig. 7: Assembled functional prototype

Fig. 8: Side view of 3D model of the proposed finger telemetry measuring device

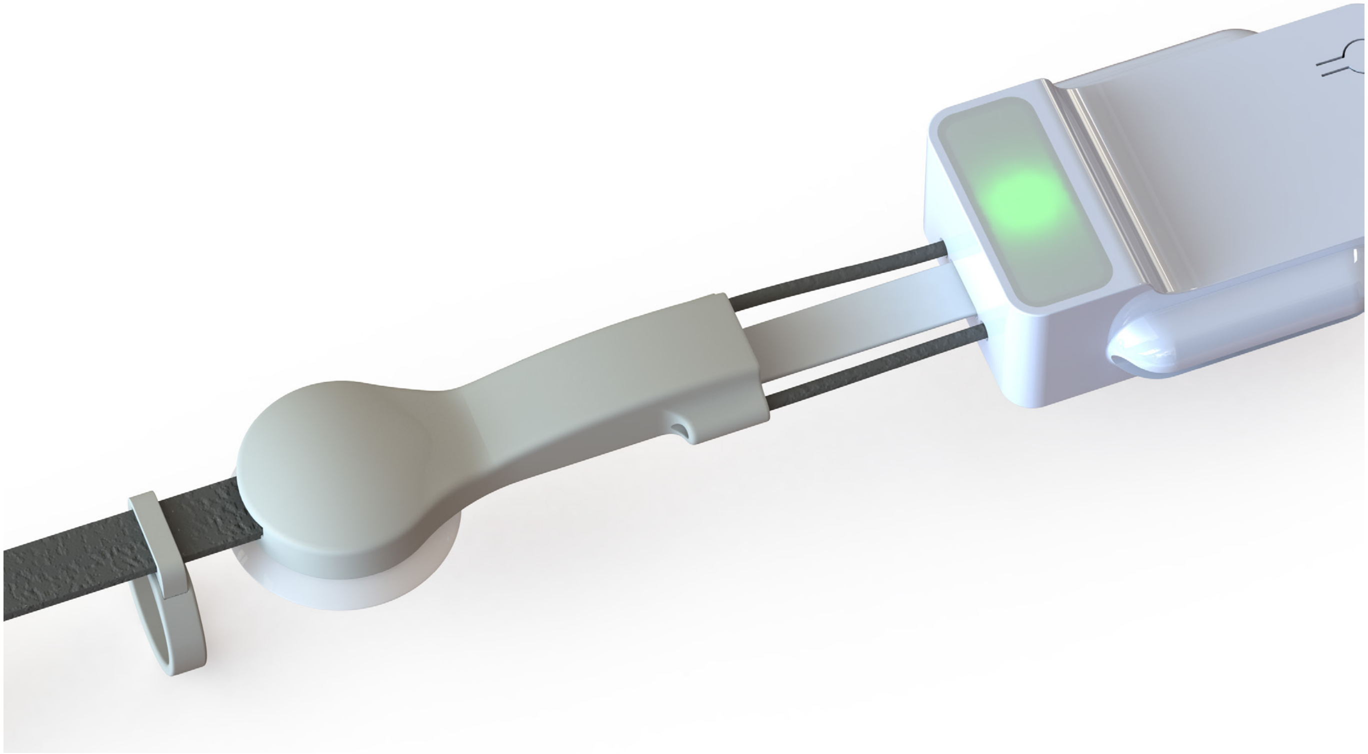

Fig. 9: Detail view of 3D model of the knuckle holder and wrist worn electronics enclosure

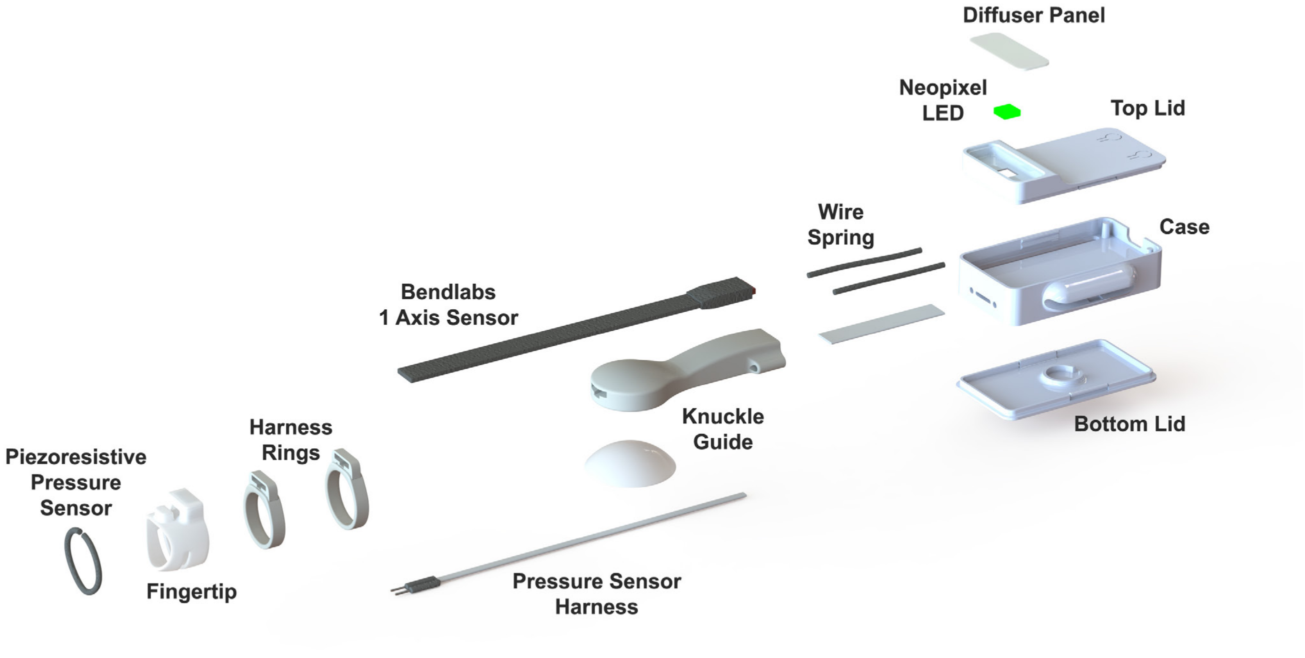

Fig. 10: Exploded view of components and subassemblies