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Discrete internet Communicator -An ultra-low power, low cost network connected haptic feedback wearable device.

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# Abstract

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# Acknowledgements

Acknowledgements go here

# Introduction

## Background

This project was inspired by my housemate during my second year. She was experiencing some relationship issues with her partner at the time and after a long teary chat with her the primary cause of the issue was revealed – she felt that with her partner working long hours with his independent business and being out of contact with him for much of this time, that he would not think about her (it is worth noting that this is at time in history when most people have smart devices and are rarely unreachable).

This got me to thinking that a discreate device without the distraction abilities of a smartphone or computer could fill this void in the technological landscape while also being able to provide secondary useful functions to a user.

## Direction

Thinking on this subject further drew me to the concept of a simple low-cost device that can provide notification and potentially response to a user about an extremely limited number of matters without the user needing to actively seek out this information or be concerned with the devices upkeep or setup.

From this I noticed the ubiquitous appearance over the last decade or two of rubber wristbands worn by people to show support for various causes such as Cancer Research and Help for Heroes. These bands were inexpensive and did not require maintenance from the wearer as per other forms of jewelry.  
With this in mind, I wondered if my notification idea could be integrated into a band like this in such a way that the band maintains its key plus points – low cost, zero maintenance and robustness.   
I have an interest in mechanical watches and wondered if that kinetic (often described as ‘automatic’) mechanisms used to power many high-end watches such as those by Rolex, Omega and Patek Philippe could be adapted to provide power to the device allowing the user to never have to perform maintenance for the life of the device.

## Intended audience

* Youth (>18)
  + ‘best friends’
  + Boyfriend/Girlfriend
  + Parents summoning children
* Adults
  + Parents of the above
  + Healthcare workers (if embedded in rubber as charity wristbands hygiene should be simple)
  + Lovers
  + Those in need of discreate notification

## Objectives

* Low cost
* Low power requirements
* Short range communication with a more powerful device
* Haptic feedback

# Research

## Does it exist?

Seeing as the technologies required for this project all exist already (energy harvesting, short range radio, haptic feedback) I began research by seeing if similar products already exist on the market and if so, do they meet the objectives I have set out for the device? in short no, many devices exist that fulfill one or more of the objective but they fail to meet all in a reasonable manor.

I will outline some of these devices below –

Hey Bracelet

(House of Haptics, 2018) – ‘The revolutionary bracelet that sends touch over distance’

A picture containing spectacles

Description automatically generated

The Hey Bracelet consists of a pair of bracelets and a smartphone companion app. These items align with my first idea closely with their tag line of ‘The revolutionary bracelet that sends touch over distance' they seem to be aimed squarely at lovers with distance separating them. The bracelet consists of a motor that allows the band to tighten around the wearer’s wrist and a touch sensor on the outside to instigate this action in another user. However, these devices diverge from my idea in two key areas. Firstly cost, at $114.99 at the time of writing (18/11/18) it is difficult to consider these a low-cost item, and secondly power, they require charging via USB.

### Sony Wena

(SONY EUROPE LIMITED, 2018)- ‘The watch. Reborn.’

A picture containing sky

Description automatically generated

The Sony Wena is not a watch but in fact a strap that should fit many watch faces and is available in multiple sizes and designs, including several Sony made face designs. This device is positioned as a more all-round smart device with GPS (GPS, GLONASS, QZSS and SBAS compatible), Bluetooth 4.2 low energy, heartbeat and accelerations sensors, OLED display and NFC like (‘Wena pay’) hardware. Its features include receiving notifications from a smart phone, contactless payment and fitness tracking as well as being water resistant to enable to user to wear the device in the shower or humid conditions. The device has an expected battery life of approximately 1 week with a charging time of 1.5 hours. So, in many ways this device would cover the functions of my idea with two key differences, firstly it requires charging (albeit far less frequently than other described devices) and secondly its price tag. Starting at £349 the device is clearly aimed at the premium end of the market and can certainly not be considered disposable or suitable for a younger user.

### Generic low-cost smartwatch

There are many such devices on the market as of 2019 and it would be beyond the scope of this work to review all of them, so in this instance I will focus on a single model the ‘V8 Smartwatch’ this device is made by several companies and often sold under the label’s ‘GONOKER’ , ‘Leegoal’ and ‘DreaT’.



This device consists of the basic functionality of a feature phone in the form factor of a watch. It includes a MediaTek 6261s processor which is based around an ARM Cortex M4 or M7, this is assumed based on information from MediaTek’s website and a datasheet stating it uses the ARM7-E instruction set (Huang, 2012; MediaTek Inc, 2019) . This variant of the chip uses the J-S extensions to enable acceleration of Java based applications. It contains an inbuilt logic for Bluetooth 3.0, GSM/GPRS/EDGE, FM radio, AAC audio (with amplifier), I2C, SPI, UART, USB and SDIO and can be debugged using a JTAG interface. These are accompanied by 128MB or RAM, a 1.51” 240x240 display and a 0.3MP camera. This high amount of integration enables the device to run for a day or more on a single 280mAh battery.

The device can be set to take notifications from an accompanying Bluetooth enabled smart phone using its provided Android or IOS app and has a price of under £10 meaning that it is likely the closest to meeting the goals of our project.

### Comparison

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Product | Notification | Battery life | Additional features | Cost |
| Hey Bracelet | (Single notification based on proprietary app) | 1 week | Waterproof | £86.82 ($115 USD 7/03/2019) |
| Sony Wena | (Multiple based on a proprietary app) | 1 week | Waterproof, OLED display, Wena Pay | Starting at £349 |
| Generic Smartwatch | (Multiple based on a proprietary app) | 1-3 days | Phone features, Apps, Camera, SD card, Colour LCD display | > £10 |

## Energy harvesting

A potential solution to power a device such as is being created in this project would be energy harvesting. This is the process of using some of the energy the human body naturally expends during its normal function and converting/storing this for use by a device, this is often transparent to the end user.

Methods for doing this have existing in many forms for hundreds of years but have only recently become viable to power wearable electronics. This is due to efficiency improvements in both the harvesting methods and in the devices they are intended to power. Below I will outline the details of several of these methods and their suitability for our purposes.

### Mechanical harvesting and automatic watches

This is likely the oldest form of energy harvesting done by humanity with origins known to be dating back at least as far as Daniel Schwenter (1585-1636) and his idea to use respiration to wind a mechanical watch (Richard Watkins, 2016) however this approach is not known to have been used practically.

Commonly this method involves a weight connected to a shaft in such a manner that when attached to the human body this weight will cause the shaft to partially rotate due to the common movement of the person. This shaft would then be used with a ratcheting mechanism to wind a spiral torsion spring storing the collected energy for slow and constant release via a lever escapement (WF&CO, 2019).

The amount of energy stored by mechanisms as described above can power a mechanical watch for upwards of 50 days from a full charge (Hublot, 2019) however at a cost of £262,000 a mechanical device like this is far beyond the funding and scope of this project. Research has been completed into the efficiency of these mechanisms and this is thought to be approximately 45%.(Longhan Xie, Carmen G. Menet, Ho Ching, Ruxu Du, 2009) This however does not give us power in a form that can be used to drive electronics.

This problem has to a certain extent been solved by companies starting with Seiko with their ‘Kinetic’ range beginning in 1988 (Seiko, 2018) followed by various other companies including Citizen and Swatch. These watches contain a mechanical harvesting system as described earlier but instead of transferring energy to the escapement of a watch, they power small generators and in turn a battery or capacitor used to run a quartz clock movement. As these technologies are proprietary the actual power values are not disclosed to the public however upon research some have theorized the production to be within an order of magnitude of 1 joule every 2 days or 0.000277778 Watt hours (Wardell, 2016). At the 1.8v minimum we are likely to need for our microcontrollers this can be converted to 0.15432 mAh using the formulae

Or in our case

Or 154.32 Microamps. This is likely enough for our electronics but is unlikely to be enough to drive a haptic feedback device like a vibration motor.

### Piezoelectric

This method works on the concept that many materials (often crystalline) generate small quantities of electricity when put under mechanical stress, this may be from compression or deformation (flexing) this is often used in industry to detect vibration or sound. In order to use this energy circuitry is required to normalize the energy produced.

When put under stress the piezo element will output a voltage in a range based on the amount of mechanical stress inputted. This can typically range from 20/30 V + down to zero hence the requirement of a buck regulator or similar to keep the output voltage at a level that is safe to use without burning out energy storage components or the microcontroller itself.

Piezoelectric energy is a reversable process so care must be taken that the energy harvested cannot be conducted back into the piezo element as this would result in deformation of the element and in turn loss of the potential energy.

The amount of energy created with this method is quite low with high voltage outputs and low current (ampere) output. It is not uncommon for elements to put out voltages in a range up to 100 volts or more if under extreme load (such as being hit by a hammer) but the ampere output is usually less than 100 microamps (Elhalwagy. et al, 2017; Hickman, 2017). With outputs like this, losses involved in rectifying and converting the energy output may result in very low efficiency.

### Seebeck/Peltier

The Seebeck/Peltier effect is the effect that when a temperature gradient is applied to a conductor the energy will excite negatively charged particles (electrons) at the hot end of the conductor and cause them to move towards the cold side producing a tiny voltage. Due to the tiny amount of energy produced connecting these in series as would be done with a battery results in the series connections losing the energy generated via resistance and the effects of the temperature gradient. To counter this a second material is used to provide the reverse connection, they are doped in such a way that positively charged particles move from the hot side to the cold thus continuing the flow, these are the same concepts as in semiconductors and are called p-type and n-type conductors.

The output of a thermoelectric generator (TEG) such as this is affected by several factors. Starting with materials used, we are looking for materials with a high electrical conductivity and a low thermal conductivity and at room temperature, in our case the likely choice would be bismuth telluride (Bi2Te3) as it provides these properties at room temperature. Note other materials exist but either exhibit these properties in the wrong temperature ranges or require use of complex and expensive nanotechnologies bringing costs above the already expensive bismuth telluride.

Research has already been conducted into the viability of this form of energy production (Melissa Hyland, Haywood Hunter, Jie Liu, Elena Veety, Daryoosh Vashaee, 2016) . They conclude that in a best-case scenario we can expect production of around 20 μW/cm2 with a more realistic output of 2-8 μW/cm2. Given that our device electronics will likely only have a footprint of a few cm2 additional TEG’s would need to be located in the wristband giving additional cost and complexity to the design.

### Solar

Solar cells have been relatively common in portable electronics since pocket calculators popularized them in the late 1970s (Tout, 2019) and with recent pressure for renewable energy sources have become popular to power everything from cars to homes. These cells, also known as photovoltaic cells receive energy in the form of light and use this to excite electrons in a layer of a semiconducting material to produce an electrical output. Being a relatively mature technology, these devices can be found in many form factors, the main one I will look at here is the BPW34 silicone pin photodiode (Vishay.com, 2008). This device measures 5.4 x 4.3 x 3.2 mm and has a surface area of 0.23 cm2. It can produce around 50 µA under good conditions. For our purposes this means several of them may be required to meet our power needs even under good near ideal conditions. Given that our device is going to be wrist mounted it is unlikely that these conditions will be met due to clothing covering cells, shallow light angles from the user having mobility of their hands as well as factors like being indoors. This means in order to meet our power requirements multiple cells would be required as well as a method to store the energy for continued usage, this would add complexity and cost to the project.

### Conclusion

Below is a table summarizing the above methods –

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Technology | Cost | Complexity | Size/Practicality | Power potential |
| Mechanical | High (Commonly <£100) | High as no pre made units are available | Acceptable as often already installed in wearables | Viable as already used to power similar wearables |
| Piezoelectric | Low (£1-5 for device and associated electronics) | Minimal as units already exist | Large to produce required power output | Low power density |
| Seebeck | Low(£1-5 for device and associated storage) | Minimal as units already exist | Large to produce required power output | Low power density |
| Solar | Low (£1.50 per cell as of 15/03/2019) | Minimal | Many cells required to negate physical limitations | Viable as multiple cells can be used |

A characteristic of the aforementioned energy harvesting methods is that they provide extremely low amounts of current. Given proper storage using a capacitor or even a small rechargeable battery the amount of energy collected even while being intermittent in delivery should be enough for the relatively low power but frequent draw of a microcontroller. However the use of a vibration motor will cause a high current draw for a relatively long time and is likely to overwhelm most of the above methods if used frequently – this should be taken as a consideration during the design process.

Given that a wearable device will often have a lifespan of less than 5 years, the complexity and cost of the above methods and the low cost and ubiquity of high capacity low volume batteries such as the CR-2477 by Panasonic (Mouser, 2019). The work involved in producing a product with a harvesting method like this is likely not worthwhile.

The aforementioned battery has an output of 3v meaning it can power the device directly, a capacity of 1000mAh meaning it can potentially power a low power device for several years. As well as having a large operating range in heat, solid state that is unlikely to be effected by movement and no reliance on light meaning it will likely provide a more reliable power source for the lifetime of the device.

### Suitable systems

Below are several chips and developments boards considered for the project plus a short description of their pro’s and con’s and suitability for the task at hand.

Note prices are taken from <https://uk.farnell.com> on the 23/2/2019 unless otherwise specified.

### CC2640R2F

This is an ultra-low power microcontroller (cortex m3) and RF system on a single chip, it is designed specifically to be capable of running on a coin cell battery or via an energy harvesting device (Texas Instruments, 2019). The wireless capabilities include Bluetooth 4.3 and Bluetooth 5le connected to an ultra-low power sensor controller (based on a cortex m0) this is designed to run independently of the main cortex m3 processor allowing for extremely low power consumption while the main processor is in sleep states.  
The cost of this chip is approximately £4.07 per chip and the development kit (Launchpad) is £23.55 and is available immediately.

* Wide Supply Voltage Range
  + Normal Operation: 1.8 to 3.8 V
  + External Regulator Mode: 1.7 to 1.95 V
* Active-Mode RX: 5.9 mA
* Active-Mode TX at 0 dBm: 6.1 mA
* Active-Mode TX at +5 dBm: 9.1 mA
* Active-Mode MCU: 61 µA/MHz
* Active-Mode MCU: 48.5 CoreMark/mA
* Active-Mode Sensor Controller: 0.4mA + 8.2 µA/MHz
* Standby: 1.1 µA (RTC Running and RAM/CPU Retention)
* Shutdown: 100 nA (Wake Up on External Events)

### NXP-QN908X

QN908x is an ultra-low-power, high-performance and highly integrated Bluetooth Low Energy solution for Bluetooth® Smart applications such as sports and fitness, human interface devices, and app-enabled smart accessories. It is specially designed for wearable electronics with a small capacity battery.(NXP products, 2019). This chip is based around the Cortex®-M4F microcontroller and is capable of providing floating point operations as denoted by the ‘F’ postfix and provides Bluetooth Low Energy support.   
This chip is based on a single CPU design and as such requires its main CPU to be active in order to use its Bluetooth functionality.  
The cost of this chip is approximately £4.52 and the development platform (QN9080-DK) is £88.93 but is currently out of stock.

* Single 1.8 V ~ 3.6 V power supply
* 1 µA deep sleep mode
* 2 µA sleep mode (32-kHz OSC/RTC on)
* 3.5 mA RX current with DC-DC at 3 V supply
* 3.5 mA TX current @0dBm Tx power with DC-DC at 3 V supply

### NXP-QN902X

QN902x is an ultra-low power, high-performance and highly integrated Bluetooth LE solution. It is used in Bluetooth Smart applications such as sports and fitness, human interface devices, and app-enabled smart accessories. It is specially designed for wearable electronics and can run on a small capacity battery such as a coin cell battery(NXP products, 2019).   
This MCU is designed around Cortex® M0 design and also provides Bluetooth Low Energy support.   
The cost of this chip is approximately £3.95 and the development platform (QN9020DKUL) is £37.40 but is again unavailable at the time of research.

* Single power supply of 2.4 V to 3.6 V for QN9020/1
* Single power supply of 1.8 V to 3.6 V for QN9022
* Integrated DC-to-DC converter and LDO
* 2 μA deep sleep mode
* 3 μA sleep mode (32 kHz RC oscillator on)
* 9.25 mA RX current with DC-to-DC converter
* 8.8 mA TX current @0 dBm TX power with DC-to-DC converter

### Comparison

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Chip | Architecture | Power Consumption | RF support | Cost for chip | Cost for development |
| CC2640R2F | Cortex® M3 + Cortex® M0 components |  | Bluetooth 4.3, Bluetooth 5 low energy | £4.07 | £23.55 |
| NXP-QN908X | Cortex®-M4F |  | Bluetooth 5 low energy | £4.52 | £88.93 |
| NXP-QN902X | Cortex®-M0 |  | Bluetooth 5 low energy | £3.95 | £37.40 |

## Hardware decision

The decision for what MCU to use was almost made for us due to time/availability constraints, with the only device both available and at a reasonable cost being the TI CC2640R2F. In actuality the NXP-QN902X may have been the better choice as its simpler design based on a Cortex M0 is likely to yield minor power efficiency advantages however the larger costs of the development kit and at the time of research being unavailable made the CC2640R2F the better choice. The NXP-QN908X was largely ruled out due to its very high development cost, also being based on a Cortex M4 means its computational power is fay beyond what is required – its inclusion of a floating-point math coprocessor as denoted by the ‘F’ part of Cortex M4F is also an addition that would be unused in this project.  
An advantage of using the TI CC2640R2F allows for usage of Texas Instruments own Eclipse based ‘Code Composer Studio’ development environment which we already have some experience with.

# Requirements

This section of the document outlines the overall requirements for the project and uses MoSCoW (Must have, Should have, Could have, Won’t have this time) prioritization. They are split into two sections functional and non-functional.

## Functional

|  |  |  |
| --- | --- | --- |
| Requirement # | Requirement description | Category |
|  | The product must provide simple near silent notification (vibration) | Must have |
|  | The product must enable communication between itself and a local device to acquire notifications | Must have |
|  | The product must enable communication with other band users via a wan enabled device (smartphone) | Must have |
|  | The product must provide differentiation between sources of notification (pulse and duration of vibration) | Should have |
|  | The product must be simple to connect to a local device | Must have |
|  | The device must automatically reconnect to local device if disconnected | Should have |
|  | The device should provide a method to silence notifications locally via a button or motion | Could have |

## Non-Functional

|  |  |  |
| --- | --- | --- |
| Requirement # | Requirement description | Category |
|  | The device must provide long service life without servicing | Must have |
|  | The device must provide usage without the need for charging | Should have |
|  | The device must have physical attributes that enable comfortable wearing | Must have |
|  | The product must provide notification in a timely manor (> 10s) | Must have |
|  | The product should be of near disposable cost ( > £10) | Should have |
|  | The product must work over a reasonable range between device and companion and between users | Should have |
|  | The device must have low energy Bluetooth link to user’s mobile device | Must have |

# Methodology

The methodology being used for this project is the Agile method. This will allow us to change features and design considerations throughout the process.

Two methodologies were considered for the project, Waterfall and Agile. Though for a single person project with limited scope the waterfall method may work, it does not allow for additions or revisions to the end product without significant time delays. It also introduces the potential for scope creep turning the project into an impossible task as features are proposed during any resets in the design process.

Using an Agile methodology allows us to expand on features continuously throughout the project while not suffering from the scope creep issues of Waterfall – this is accomplished using the previously mentioned MoSCoW method. This allows new features to be proposed and logged without requiring them to be in the final product while also giving a list for any new iterations or revisions to follow – saving on future development time.

# Design

## High level design

### Outline

The device being created is a small low-cost wearable for personal notifications.

Its purpose is to provide discreate notifications to a user with minimal setup and configuration.

It is intended to be used by children and adults with access to a smart phone but without any prior experience with such devices.

#### Design goals

* Be easy to use
* Require no prior knowledge to use
* Provide discreate notification for local or remote matters using a vibrate motor
* Be energy efficient to run long term from an embedded battery

## Architecture

For this project research has been performed as above into potential competitor’s devices with the aim to show any pitfalls in similar designs and to allow the final product to outperform other similar devices on the market.

The hardware will be based around the CC2640R2FRSMT MCU and developed on the relevant ‘Launchpad’ development board for this chip and using technical data from the ‘CC13x0, CC26x0 SimpleLink™ Wireless MCU Technical Reference Manual’ (Texas Instruments, 2017). Once development is completed