MAKING A BREATHING WEARABLE WIRELESS

Graduation Project

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Abstract

The Breathline is a breathing wearable which monitors diaphragmatic breathing throughout the day to encourage and support users with correct breathing. Diaphragmatic breathing is proven to have positive effects on physical and mental health. Currently, data from the Breathline can only be retrieved over a USB connection or wirelessly with a dongle. Making the Breathline completely wireless is the goal of this project. The following research question helps to reach this goal. *How can the data communication of the Breathline breathing wearable be made wirelessly to facilitate real-time displaying of measurement data on portable devices?*

With the help of a literature and market research, the decision is made to utilise Bluetooth Low Energy as a wireless communication technique.

The development of wireless functionality is guided by the Creative Technology Design Process. This process starts by analysing the problem which shows that Breathline users have different technical skills. It also identifies that setting up a wireless connection is an important activity in this context. Next, requirements are set for the development of a system that receives data from the Breathline and transfers this to a smart device. Requirements for the technologies to be used, connection stability and user interaction are set.

For the realisation of a proof-of-concept of the system, a special GATT profile design is made. The GATT is part of the Bluetooth Low Energy protocol stack. Parts of this stack are explained in depth. The profile is implemented on the Breathline with an RN4871 Bluetooth Module by Microchip Technology. In parallel, an application is developed in the Android framework, implementing the same GATT design.

Also, a novel method of establishing a connection between the Breathline and a smart device is developed. The Breathline will go into advertising mode by shaking it. A user test is done, which shows that users can set up a connection using this method. However, also concerns about its security rise. In the end, the set requirements are checked to be met. It is found that most are.

To conclude, a system is created, in which a Breathline-like device and an Android application can communicate sensor information gathered by the Breathline in real-time. Which shows that the Breathline can be made wireless to facilitate real-time data communication by using Bluetooth Low Energy.

In the last chapter, suggestions for future work are made.

Acknowledgements

This project would not have become what it has if it had not been for several people. In the first place, I give big thanks to Erik Faber for his total supervision throughout the project. Not only was his feedback valuable, but also his ideas, guidance and constant support were very much appreciated. Finally, thanks to Cora Salm and Erik for their assessment.

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Contents

Chapter 1

Introduction

This report walks trough the process of setting up a wireless connection for a wearable. This is done as a graduation project (GP) for the Bachelor study Creative Technology at the University of Twente. This first chapter will provide the problem statement and introduce the wearable for which a wireless connection will be made. Also the research question will be formulated, which will be a guide trough the said process. Finally, the remainder of this report will be outlined.

1.1 Problem Description

Breathing is an important element in one's life, it marks the beginning and end of life. However, breathing is also important for the physical and mental well being between these two moments. The way breathing is done influences this well being. In the Traditional Chinese Medicine Arts, good practice of breath is reported to have positive physical and mental effects. The focus is especially on diaphragmatic breathing (DB), breathing by contracting the diaphragm (see Figure 1.1). DB activates the parasympathetic nervous system, which decreases the heart and breathing rates, which reduces anxiety [1]. Individuals introduced to regular relaxation sessions using DB indicate that this helps to reduce perceived stress, anxiety and depression symptoms, of which the latter was statistically proven to be true [2]. Also, Hopper et al. [3] state that DB can be widely used as an intervention for physiological and psychological stress reduction, although they point out that further research should be done. DB could decrease aggression, as argued by Phillips et al. [4], although they also point out that more research needs to be done to fully prove this. Other studies have shown that diaphragmatic breathing, for example, helps against high blood pressures [5] and can potentially reduce psychophysiological responses during game-related cue of persons with a high risk of internet gaming disorder [6].

Acupuncturist Parviz Sassanian has applied DB training and found it successful in helping his patients with a wide variety of medical problems. He, however, encounters the problem that his patients lack training support outside training sessions. Okado et al. [2] also indicate that regular practice is important to achieve a positive result. The

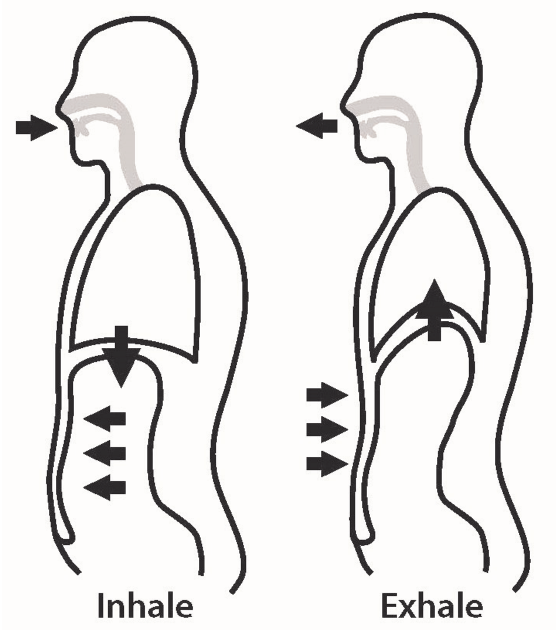


Figure 1.1: Inhaling and exhaling using DB [7]

importance of active DB training is also pointed out by Naumilkat [8], Mundkur [9], and Barakauskas [10].

To conquer this problem and support and stimulate DB regularly, Ben Bulsink, an entrepreneur and inventor based in Enschede, has developed Breathline (see Section 2.1). A device which can monitor diaphragmatic breathing to encourage and support users with correct breathing. Currently, there is a working prototype (see Figure 1.2), which is able to measure abdominal expansion and can roughly classify the data [9]. Besides, the design of a GUI is made to provide a user with all necessary data to improve on breathing habit [8]. What still is missing, is the ability to transfer data from the Breathline device to a phone or laptop in a convenient way. Currently, the data has to be retrieved from the device over a wired connection or with a special dongle. The wish is to create a fully wireless connection between the mentioned devices.

In this report, a suitable technique for wireless communication for the Breathline wearable is researched. To set up a real-time wireless connection with smart devices, a protocol must be defined. Hardware and software implementations must be made to enable software developers to create an application for real-time analyzation and display of the measurement data.

1.2 Research Question

To successfully research options for, and create a wireless connection between the current prototype and a phone or computer, a research question has been formulated.

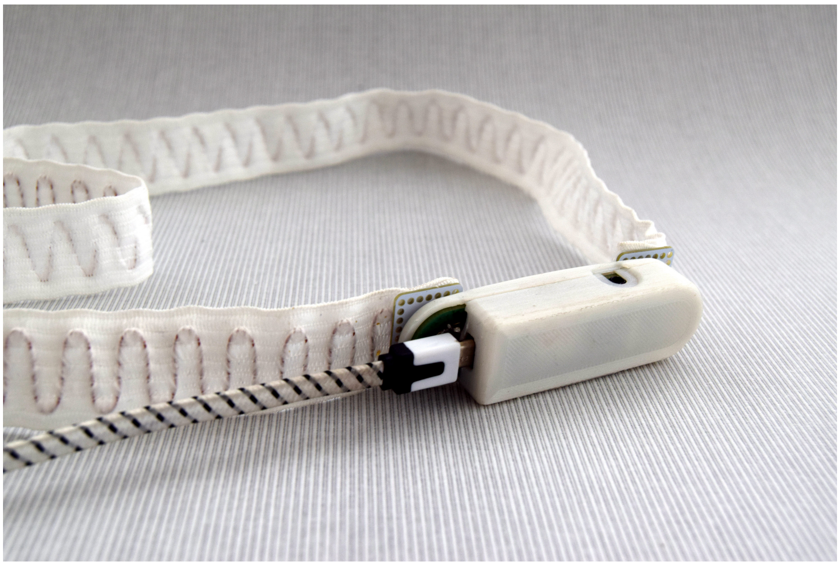


Figure 1.2: The current version of the Breathline with RIP belt and USB cable connected

> How can the data communication of the Breathline breathing wearable be made wirelessly to facilitate real-time displaying of measurement data on smart devices?

a. What information does the Breathline measure and store, and in which form?

b. How is the Breathline used and is there an added value to a wireless connection?

c. How can wearables communicate wirelessly with smart devices?

d. At what time interval should the information be transferred to facilitate real-time displaying of measurement data?

e. Which requirements should be met to guarantee a stable connection?

Having the ability to display real-time measurements on a computer or app, would greatly increase the usability and effectiveness of the product. The challenge is to create a wireless connection between the Breathline device and other devices such as smartphones and computers.

Different wireless technology standards must be compared to find which is best suitable for this application. Other requirements, such as battery usage, data transfer rate and connectivity range, must be set with Mr Bulsink. Hardware and software implementations must be made to enable software developers to create an application for real-time analyzation and display of the measurement data.

A word should be said about a current crisis having an impact on society and this graduation project. A virus, COVID-19, is going around the world, causing a lot of casualties. At the time of writing, no medicine and vaccine is available. Measures from governments are taken in enforcing a lockdown. Work should be done from home and contact with others should be avoided, demanding to carry out this graduation project from home. Also, contact with healthcare workers should be avoided, resulting, within this graduation project, in the inability to contact Breathline users in the Medisch Spectrum Twente, a local hospital.

1.3 Outline

After this introduction - addressing DB, the Breathline, work on this device in the past, challenges and practicalities - background research will be treated in chapter 2. More in-depth details about the Breathline will be provided, wireless communication technologies will be compared and a state-of-the-art will be provided. The rest of the report will be structured as following. Chapter 3 outlines methods and techniques used in the Creative Technology Design Process, which is also introduced in that chapter. The Creative Technology Design Process consist of four phases which make up the contents of Chapters 4 to 7. In Chapter 8 a conclusion will be drawn and in the last chapter, suggestions for future work will be made.

Chapter 2

Background Research

To successfully create a wireless connection for the Breathline, some things have to be sorted out first. This includes facts about how and what information the Breathline collects and how this is stored and transmitted. Also a literate research is done on which wireless communication techniques are most suitable for wearables. In a state-of-the-art research, wireless communication used by similar wearables are listed. In other words, this section will answers a subset of the questions stated in section 1.2 trough literature and market research.

2.1 The Breathline

As stated in the introduction, Ben Bulsink has already developed a prototype for the Breathline. His career as a product developer started 30 years ago with the development of game timing devices and game board object tracking technology utilizing RFID. Mr Bulsink has experience with the whole process of the development from idea to product.

The Breathline's core functionality is giving insight into DB. Information for these insights is provided by measuring abdomen expansion. There has been chosen to utilize respiratory inductance plethysmography (RIP) for gathering measurements. Mundkur [9] did an extensive literature review on RIP and other tidal volume measurement techniques, such as pneumotachometer, MARM and turbine flow meters. He concluded that the non-invasive nature and accuracy of RIP makes it a viable choice. Wolf and Arnold [11] describe RIP as "noninvasive respiratory monitoring technique that quantifies changes in the cross-section area of the chest wall and the abdominal compartment" [11, p. 163]. Two bands are used, to which a conductive wire in a zigzag pattern is attached. One is placed around the chest, the second around the abdominal, see Figure 2.1. This band is used to create a one-winded inductor which inductance is reciprocal to the cross-section area encircled [12]. When placed in series with a conductor, an LC circuit is created and by measuring electrical frequency or amplitude of the oscillator, the inductance can be calculated. A variety of techniques exist to measure these values. In the Breathline, oscillations within a 20 ms timeframe are counted, resulting in values around 42500, representing a frequency divided by 50.

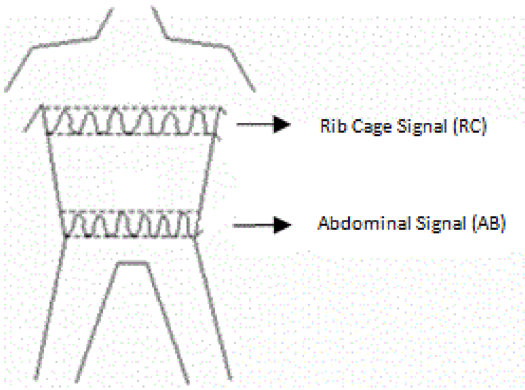


Figure 2.1: Placement of bands for RIP

Besides two RIP belts, the Breathline also contains a three-axis accelerometer. This can provide accelerometer data from -2 G (gravitational constant) to 2 G, encoded in three signed 2 bytes digit. These values, together with the frequencies and a timestamp, are stored in an 8 megabyte storage. One packet of data takes up 12 bytes. Data savings can be done at a frequency of 4 or 8 Hz. At 8 Hz, a transmission speed of 768 bit/s is required.

Also, the Breathline contains a LiPo battery with accompanying circuitry, a Microchip, RN4871 Bluetooth 5.0 Low Energy module, real-time clock, and microcontroller. The Bluetooth functionality can be utilized with the help of a dongle containing the same chip. This creates a serial device sending 10 bits, including start and stop bit, at 9600 Bd. Currently, data transfer over a USB-cable is more stable and provides more functionality. Both wired and wireless communication is established over a Virtual COM port device. Data is transferred using a simplified PPP protocol, by defining a start and end mark for each packet, with a header and payload in between.

2.2 Wireless Communication Techniques

Baños-Gonzalez et al. [13] observe that the upcoming Internet of things (IoT) applications are "enablers of innovative concepts such as smart cities, smart/e-health, smart metering and smart things" [13, p. 1]. All these applications require different data rates, energy management, implementation costs and device support, to name a few common requirements. This variety of desires have resulted in a wide range of wireless communication technologies. These different requirements have also resulted in no universal technology which will lead the IoT revolution, as pointed out by Baños-Gonzalez et al. In this section, the major wireless communication technologies are described and compared.

2.2.1 Bluetooth

Three well known short-range wireless technologies are Bluetooth Low Energy (BLE), Wi-Fi and ZigBee. BLE is one of the most popular of these. Liang and Yuan [14] point out that small wearable or implantable sensors communicate with short-range wireless communication techniques such as Bluetooth. As they describe, Bluetooth is designed as a replacement for wired connections while maintaining security, low cost and low power. Low power consumption is one of the most important requirements in wearables and wireless communication consumes a significant amount of energy. BLE especially is designed to provide extremely low power idle mode [15]. To illustrate this fact, a BLE device running on a 230 mAh coin cell battery can have a theoretical lifetime of up to 14 years [16]. BLE allows for uncomplicated device discovery and profoundly reliable data transfer. The availability of BLE in devices such as mobile phones and PDA's can be seen as an advantage [15]. Also Want et al. [17] point out that BLE is supported by most mobile devices. In addition, a Bluetooth network can be set up without the need for additional infrastructure [18]. BLE operates in the 2.4 GHz ISM band. With Bluetooth 5, the communication range is several hundred meters with a data rate of 2 Mbit/s [19]. Thus, BLE is widely used in wearables, mostly because of its low power consumption and secure data transfers.

There should be noted that Bluetooth and BLE are two different techniques. BLE is introduced with the Bluetooth v4.0 specification. Although both techniques share the same purpose as described above, there are fundamental differences between the two protocols. Bluetooth v1.0 was released in 1999, Bluetooth v4.0 in 2010. The explicit aim of BLE is to consume even less power and to communicate with very low power devices. Where traditional Bluetooth typically uses around 25 mA at peak transmission, in BLE this is only 15 mA with a sleep current of 1 μA [20]. In the first place, this is done by replacing a lengthy discovery process with a small advertising packet over dedicated advertising channels [17]. Besides, with traditional Bluetooth, once a connection is made, a link is maintained to enable a streaming throughput for transferring files. BLE does not have this option, it is designed to send small chunks of data in the form of parameters. Where in traditional Bluetooth paired devices periodically wake up to check-in, in BLE data can be read at any time by the client [20]. Between BLE version 4 and version 5, major differences are extended range, increased power efficiency and security updates [21]. In general, BLE is more energy efficient in comparison to traditional Bluetooth due to a redesign of the protocol stack.

2.2.2 ZigBee

Another low power wireless communication technique operating in the 2.4 GHz band is ZigBee. In this frequency band, the data transfer rate is 250 kbit/s. ZigBee also operates in the 915 MHz and 868 MHz bands with data rates of 40 kbit/s and 20 kbit/s respectively. This technique is for monitoring, control and sensor networks and designed to emphasize the need for low cost [14]. ZigBee supports low duty cycling which decreases the time its radio should be on which accordingly increases battery lifetime. Also, with the addition of ZigBee Pro Green Power, support is added for battery-less devices which harvest their energy from other means. Also, Ghamari et al. [15] state that a new IEEE 802 standard is developed which provide reliable low power from inside or in the vicinity of the human body. Overall, ZigBee should be considered when developing a low power or even battery-less wearable.

2.2.3 Wi-Fi

Although being one of the most popular wireless techniques, Wi-Fi is not power efficient. Wi-Fi is designed to replace a wired ethernet connection. Liang and Yuan [14] note that Wi-Fi is one of the most popular wireless techniques and one with a bright future. Nowadays, Wi-Fi is present in a lot of areas in life. Key features for Wi-Fi are its long transmission distance, high speeds and imperceptibility with other techniques and services. However, Liang and Yuan states that Wi-Fi is not much used in the field of telemedicine. One of the reasons for this is given by Abedi et al. [22]. They point out that Wi-Fi uses orders of magnitude more power compared to other techniques such as Bluetooth and ZigBee. Yet, Wi-Fi uses less power, up to three times, to send information at the physical layer. This is due to more efficient modulation techniques in Wi-Fi. Relatively more power is used in the application layer, requiring a device to maintain a connection with an access point. For example, a sensor making use of Wi-Fi would be turned off most of the time to save energy. Every time it would like to send data, it must be re-associated with a base station, requiring many management frames. This consumes a significant amount of power. And so, Wi-Fi does not seem to be a suitable technique for wearables running on batteries.

Hence, new techniques are being developed or proposed to make Wi-Fi suitable for wearables and the IoT. One of which is Wi-Fi Low Energy (Wi-Le), proposed by Abedi et al. [22]. Wi-Le provides the possibility for devices to enter power-saving mode without the need for re-association. Abedi et al. state that this is possible without changing the physical and MAC layer in the Wi-Fi stack. They also argue that Wi-Le outperforms, mostly on power consumption, similar Wi-Fi-based technologies such as backscatter, beacon stuffing, Wi-Fi direct and Wi-Fi ad-hoc. Wi-Le devices broadcast packages without joining a network (packet injection) similar to how access points advertise there SSID. However, by utilizing a hidden SSID and putting information in another field, the device won't appear in lists of available Wi-Fi networks. Using the vendor-specific field allows for up to 253 bytes of data. The authors note that the use case of Wi-Le is very similar to BLE. But, as they point out, it eliminates the need to add Bluetooth functionality to IoT devices and to utilize the 5 GHz band to avoid the crowded 2.4 GHz spectrum. On the other hand, concerns are raised about security. Wi-Le injects broadcast packets without any encryption, readable for all devices in range. In closing, Wi-Li seems promising but is still in its infancy. This makes it currently not attractive to use this technique in consumer electronics.

Another Wi-Fi based technology, specificaly designed for the IoT, is Wi-Fi HaLow, commenly referd to by its standard IEEE 802.11ah. Bellalta et al. [23, p. 11] summarize characteristics of IEEE 802.11ah quite well: "the adoption of efficient power saving strategies, a minimum data rate of 100 kbit/s, the operation in the licenseexempt sub 1 GHz band, and a coverage up to 1 km in outdoor areas". They add that support for up to 8192 (2^{13}) devides connected to one acces point (AP) should be supported. Baños-Gonzalez et al. [13] state that in IEEE 802.11ah many new features are introduced aiming at more efficient transmissions and allowing for energy saving. Wi-Fi HaLow supports idle periods up to a year [13], in such a period, the transciever gets tured on once to listen for beacons. A beacond indicate that the associated AP has a packet waiting for the end station, from which point communication between the end station and AP will take place [23]. Baños-Gonzalez et al. [13] add that energy is saved by sending less packages due to for example shorter headers and implicite acknowlagement. To conclude, IEEE 802.11ah is a prommising technology suitable for IoT, however, it is more suitable for use cases such as large indoor and outdoor sensor networks within range of an AP. This is not the nature of the Breathline wearable.

2.2.4 Other Standards

A technique which is, in contrast to Wi-Fi, more focused on the short-range is Near Field Communication (NFC). Liang and Yuan [14] outline that NFC allows for point-to-point data transmission up to approximately 10 cm, at 13.56 MHz with data rates of 106, 212 or 424 kbit/s. This technology is based on RFID and similar technologies. Within NFC communication, a passive mode is available where only an initiating device provides an RF field. The other, NFC target, device can transmit data through the same field using load modulation technology. Ceo et al. [24] relate characteristics such as batteryless, fast, wireless and non-contact to NFC. Besides, they state that nowadays most smartphones are equipped with NFC. On the last note, Liang and Yuan [14] predict that inevitably the healthcare system will be influenced by the development of information technology. In all, NFC is a suitable technique for low-power of batteryless devices requiring to communicate at short range.

A unique standard, contrasting the standards above, is LoRa (Long Range). Shanmuga Sundaram et al. [25] state that this uniqueness of LoRa is because it is open-source and enables to set up autonomous networks at low-cost. The aim of LoRa is to create a Low Power Wide Area Network (LPWAN), which has comparable coverage to cellular technology but with low data rates to achieve high energy efficiency. LoRa operates in the unlicenced sub-GHz ISM band, in Europe specifically at 869 MHz, this can give a range up to 20 Km. Data rates are between 250 bit/s and 37.5 kbit/s with payloads up to 250 bytes. Mayer et al. [26] outline that on top of LoRa, an open-to-use protocol called LoRaWAN available is. This protocol allows creating a connection between an IoT device and server using the IP-protocol. Finally, the reduction of complexity in LoRa technology results in low fabrication cost and less overhead introduced during communication. This last result contributes to low power usage [25]. In brief, LoRa is unique due to it being open-source with design choices resulting in low cost and long lifetime.

Table 2.1: Overview of technologies and their characteristics

Technology	Standard	Frequency	Range	Rate	Power Consumption
BLE [14], [19]	IEEE802.15.1	2.4 GHz	300 m	2 Mbit/s	1-100 mW
ZigBee [14]	IEEE802.15.4	868 MHz 915 MHz 2.4 GHz	10-75 m	20 kbit/s 40 kbit/s 250 kbit/s	very low
Wi-Fi [14]	IEEE802.11a/b/g	2.4 GHz	100 m	11 Mbit/s	60-70 mW
Wi-Fi HaLow [19], [23]	IEEE802.11ah	54-928 MHz	1 Km	150 kbit/s	
NFC [14]	ISO/IEC18092	3.1-10.6 GHz	10 cm	106/212/ 424 kbit/s	very low
LoRa [25]		860 MHz	20 Km	0.3-37.5 kbit/s	10-150 mW

2.2.5 Comparing Technologies

In short, a variety of technologies are available, each with its own characteristics and advantages. Other techniques not yet mentioned include UWB, LTE, BodyLAN and Z-Wave, these are left out because they are intended for other usage than wearables. An overview of all discussed technologies and their characteristics is given in Table 2.1. Liang and Yuan [14] show that in wearable systems, most often Classical Bluetooth or BLE is used, or Classical Bluetooth combined with NFC, UWB and ZigBee for transferring information. Also Chamari et al. [15] state that from several available low-power wireless communication protocols, ZigBee and Bluetooth are most widely used. These two protocols are compared more in-depth. The authors argue that ZigBee is favourable concerning protocol efficiency and range, but Bluetooth outperforms on user flexibility and availability in consumer electronics. However, there has to be pointed out that this comparison is superficial, and in the same manner, little can be said about energy efficiency.

Kos et al. [27] suggest using Wi-Fi HaLow because of its high throughput and range. However, their selection was based on requirements set for biofeedback systems in sport, range and bit rate. They argue that such a system is limited by human endurance and thus battery life becomes less important. Punj and Kumar [28] show that ZigBee, followed by Bluetooth, is commonly used in Wireless Body Area Network (WBAN) devices. Overall, both Bluetooth and ZigBee are proposed communication techniques for medical wearables.

In conclusion, a variety of wireless communication techniques are available. And, as literature points out, ZigBee and Bluetooth are the most popular. Bluetooth seems to be the most suitable because of its wide adoption in consumer electronics.

2.3 Limitations of Wireless Technologies

As already briefly addressed in previous section, the nature of wearables gives some limitations. Liang and Yuan [14] point out that these limitations include battery technology, energy usage, the security of information transfer, sensor downsizing and efficiency. They add that besides these technological limits, also cultural barriers should be overcome, "such as standardization and cooperation at all levels and clinical validation" [14, p. 8196]. Power being the greatest limitation in wearable sensors is also pointed out by Lou et al. [29]. Also, Ghamari et al [15] note that low-power consumption is one of the most challenging requirement in wearables. Besides, they state that the introduction of wireless communication in wearables introduces constraints on transmission reliability and latency, data rates, security and privacy. They also point out that requirements relating these matters can negatively influence each other.

Kos et al. [27, p. 584] add another list of constraints, stating that the most important "are related to space, time and computational power". As discussed in the previous section, they argue that energy and accuracy are of less interest when designing sports wearables. Balaji et al. [30] state that one of the biggest challenges in IoT is security. Punj and Kumar [28, p. 1135] outline a whole list with design challenges in WBAN devices: "fabrication, implementation, hardware and software constraints, light weight, energy scavenging, efficiency, accuracy, reliability, interoperability, comfort, security, safety requirements to avoid physical and thermal injury, standardization and commercialization". To conclude, besides physical and financial constraints, energy usage and security are marked as important restrains.

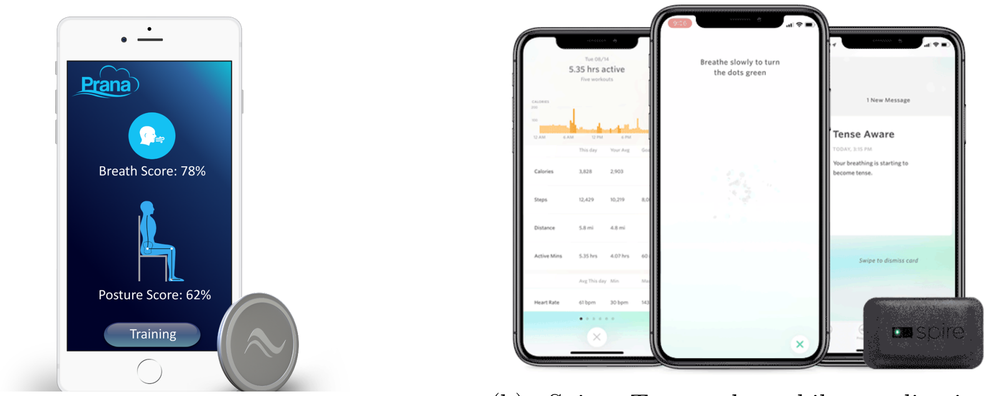
Some limitations and desires are also set by the developer of the Breathline. His main concerns are the added energy consumption of wireless communication and easy integration is the user's life. This latter requirement implies that a chosen technology should be widely available in consumer electronics.

2.4 State-Of-The-Art: Wireless Wearables and their Techniques

To get an overview of the usage of wireless technologies in similar wearables to the Breathline, state-of-the-art market research has been done. Not all manufacturers or developers were outspoken about the technology used in their products. Sometimes a deeper dive into publicly available information was needed to find out how the products work. In the end, for only the Skiin the communication technique could not be determined. All other devices make use of Bluetooth, some even specified whether version 4 of 5 was used. A more in-depth analysis is made below.

Prana

Prana, an American company, has created a wearable [31], see Figure 2.2a, which detects both breathing patterns and posture. And, as they claim, is the only wearable which



(a) The Prana and mobile application

(b) Spire Tag and mobile application screenshots

Figure 2.2

does this simultaneously. The device, a small metal cylinder, is worn on one's belt near the waist. It connects to a mobile phone app, both Android and iOS, via Bluetooth. However, there seems to be no active development from this company since the beginning of 2016.

Spire

Spire Health has developed two health trackers [32]. The Spire Health Tag, see Figure 2.2b, replacing their first wearable the Spire Stone, contains a respiration sensor, pulse-rate sensor and an accelerometer. In a white paper, they state that their device can produce data within the acceptable error range comparable to clinical gathered data [33]. Spire Health Tags are received as a pack of eight and should be put on underwear or pyjamas. Since the tags do not require charging and are washer and dryer safe, they can be left on the clothes [34]. This should allow for continues health tracking without the hassle of remembering to charge and put on a wearable. Both of there wearables make use of Bluetooth, however, the version is not explicitly stated [35], [36], [37].

BreathBalanze

New on the market is BreathBalanze, a company stationed in the Netherlands. There equally named product shows some similarities to the Breathline, both make use of a strap put around the user's belly, see Figure 2.3. Ben Bulsink and his partners have some contact with the team behind this product. They were able to inform that this product makes use of accelerometers and that the focus is on training DB. On their website, BreathBalanze reveals that the product makes use of Bluetooth Low Energy (BLE) 5.0 and a CR2032 coin cell battery allowing for at least one year of use [38]. The aim of this product is to provide breathing exercises to regain confidence in one's

Figure 2.3: BreathBalanze, mobile applications and accessories

body, reduce stress and become more relaxed. At the time of writing, pre-order is open, but the expected delivery time is not given. The founders of BreathBalenze were able to tell the Breathline team that the development of both the app and the product was outsourced but finished. However, due to the current pandemic, production and delivery were delayed.

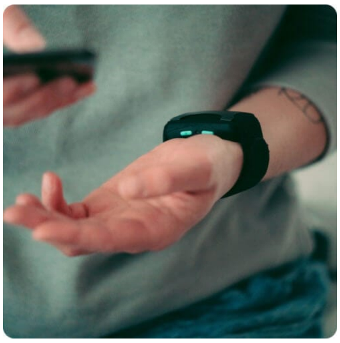
iBreve

Also new to the market is iBreve, founded by two former Google employees and stationed in Ireland [39]. Their wearable is designed for woman only and can be attached to a bra, as shown in Figure 2.4a. As they state on their website, it can analyze breathing patterns, activity and stress levels. They seem to have a prototype of both the device and accompanying app, however, only preorder through email signup is available. They state that the device works with Bluetooth, although no specific information is given. Since the device can be clipped to any bra and does not require a special band, it is expected that makes use of accelerometers or similar sensors. The developing seems to be in an early but active state.

Apollo

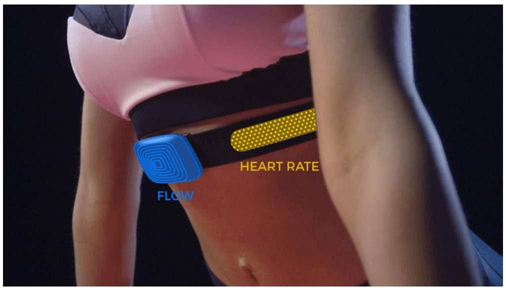
Apollo is, in contrast to the devices mentioned earlier, not a breathing wearable. It aims at improving or changing one's mental state with the help of gentle waves of vibrations [40]. The device is worn on the wrist or ankle, as shown in Figure 2.4b. The wearable uses the U-Blox ANNA-B112 module allowing communication with mobile phones via BLE 5.0 [41]. They state that the antenna is turned off when the device is put in airplane mode and that no Bluetooth communication takes place when the app, available for both Android and iOS, is closed. The Apollo System is available for ordering.

(a) iBrave on a user



(b) Apollo on user's wrist

(c) Skiin and accessories



(d) Flow on a user

Figure 2.4

Table 2.2: Overview of products discussed in market review

Device	Functionality	Technology	Supported Platforms	Price
Prana [31]	Breathing, Posture	BLE	-	-
Spire [32]	Respiratory Measurement	Bluetooth	Android, iOS	$399
BreathBalanze [38]	Breathing	BLE 5.0	Mobile	€199
iBreve [39]	Breathing, Activity, Stress	Bluetooth	Android, iOs	-
Apollo [40], [41]	Vibrations	BLE 5.0	Android, iOS	$349
Skinn [42]	Health	-	-	-
Flow [43]	Breathing	BLE 4.1	None Native	-
Focusband [9]	Brain Sensing	BLE	iOS	from $600

Skiin

Skiin is a product comparable to the Spire Health Tag. The Skiin can be worn in special underwear as shown in Figure 2.4c, both for men and woman [42]. On their website, the team states that the Skiin provides continues ECG tracking which can detect heart rate, stress, and atrial fibrillation. They do state that the device is available for investigative use only and not yet for sale. There aim is not only to provide insight into one's body and health but also share this information with "loved ones and caregivers". There is little to no information available about the workings of the product and means of communication. Ordering product is not yet possible and no new information is available latter than the beginning of January 2020.

Flow

Flow, see Figure 2.4d is a breathing wearable developed by Sweetzpot from Norway [44]. Expansion and contraction of the chest are measured with a spring steel component, which is then read by a Flow's strain gauge [43]. They claim to be able to measure breathing per minute in litres. The device also has a heartrate monitor. The device has a Bluetooth 4.1 connectivity, as stated on the site. However, it seems to require a dongle to make use of wireless connectivity. They state that an app is not available but only a SDK is available for developers. The device appears to be permanently out of stock, and no updates were given since September 2019.

Focusband

Mundkur [9] also included the Focusband in his State-of-the-Art. On their website, the developers state that the band makes use of Bluetooth smart, another term for BLE [45]. The version is not specified, but since production started in 2015 and version 5.0 was only released in 2016 [21], it is expected BLE version 4 was used. The Focusband is at time of writing still available for sale.

2.4.1 Comparison

In Table 2.2 an overview of all discussed products is shown. Only little information was available about the Skinn, all other devices communicate with Bluetooth. For not all products, a Bluetooth version was specified, but the majority makes use of Bluetooth Low Energy. In addition, supported platforms are listed. As far as information is available, most devices work with mobile phones only, the Flow has a SDK available allowing to develop applications on a variety of platforms.

2.5 Conclusion

This chapter started with stating some matters which should be sorted out to successfully create a wireless connection for the Breathline. One of these matters was to find suitable wireless communication techniques. Most popular techniques are compared, see Table 2.1. Literature suggests using either BLE or ZigBee. Comparing the characteristics of these two techniques to the technical specifications of the Breathline, they both show to be more than suitable. The breathline saves measurements in 12 bytes packets at a rate of 4 or 8 Hz, requiring a maximum data rate of 0.8 kbit/s. This data includes RIP measurements, 3-axis accelerometer data and a timestamp. The second argument in favour of BLE is the wide availability within smartphones. Also, market research has been performed, summarized in Table 2.2. For as far data is available, all devices use Bluetooth to communicate data between the wearable and a smartphone with apps available for mostly iOS and Android.

On the last note, the Breathline has already a Bluetooth module incorporated, the Microchip RN4871, with BLE version 5.0 functionality. This, together with the facts stated above, have resulted in the decision to set up wireless communication functionality for the Breathline using BLE. The information in this chapter is giving answers to some sub-research questions, specifically question *a.*, *c.* and partly *d.* (see Section 1.2). With these answers, the next step in this Graduation Project can be taken, the ideation described in Chapter 4.

Chapter 3

Methodology and Techniques

This chapter will introduce the methods used in the subsequent chapters. These chapters will follow the Creative Technology Design Process, which will be discussed first. Besides this process, techniques to analyse the current situation and problem, requirements, functionalities, prototypes and designed systems will be presented.

Faste et al. [46] points out the importance of idea generation as part of a creative design process and the existence of numerous techniques commonly employed in the field of Human-Computer Interaction. They note that the success and effectiveness of these techniques depend on factors such as the objectives of the project, expertise of the designers and other people involved, and cultural and personal factors.

3.1 Creative Technology Design Process

In this section, a overview will be given of the Creative Technology Design Process, developed by Mader and Eggink [47], see Figure 3.1. This process will be of a guide for this Creative Technology Graduation Project. The Creative Technology Design Process follows four phases: ideation, specification, realisation and evaluation, which all start and end with a defined set of intermediate results.

The method is based on two existing models. The first is a two-phase process of divergence and convergence. When diverging, the design space gets defined and opened up. The problem is viewed from multiple perspectives, sparking creativity in the designer. Also, experience and cultural background allow for exploring unexpected solutions. In the divergence phase, the design space is reduced until a suitable solution is found. By taking design decision, the design space gets reduced step by step. Because decisions often have to be taken on incomplete knowledge, the experience, preference and willingness to take risk of the designer become important. The second method is the use of spiral models, an analysis of the design steps a designer takes in the design process. Although literature gives a variety of interpretations, generally it consists of problem understanding and definition, project planning, idea generation and evaluation. As Mader and Eggink point out, each design problem starts with a specific sequence of questions. These are both design and knowledge questions interwoven with each other.

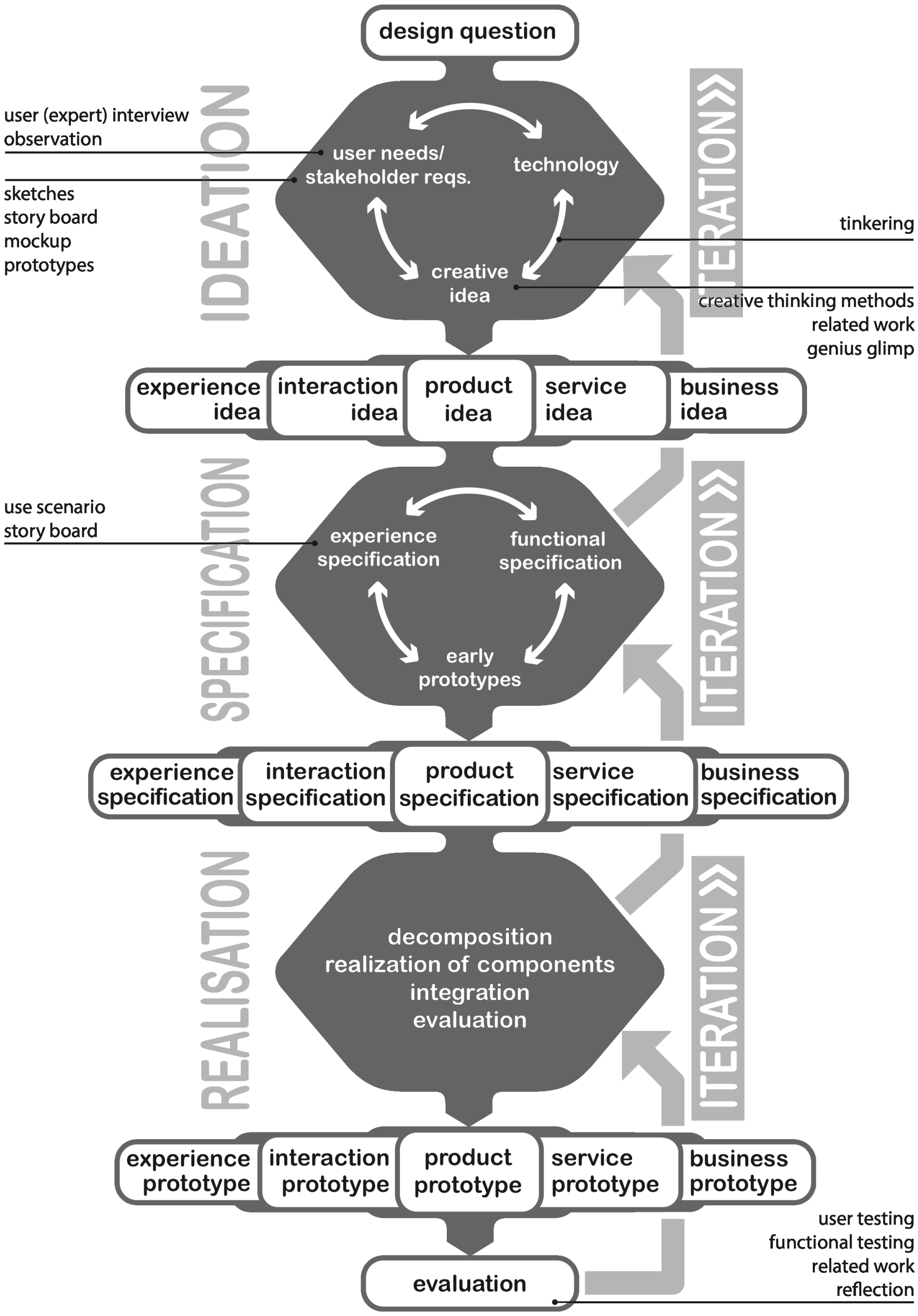


Figure 3.1: Creative Technology Design Process [47]

Both methods provide key elements for a creative design process.

The four phases of the Creative Technology Design Process will be discussed in more depth.

3.1.1 Ideation

The starting point of a Creative Technology project can be a design question from a client, product idea, creative inspiration or a specific technology. Ideas can be generated in brainstorms or consulting related literature. The problem can be analysed with a variety of techniques such as stakeholder analysis, interviews or and iPACT analysis.

3.1.2 Specification

In the specification phase, in a feedback loop ideas are evaluated with the help of prototypes. User, client and designer evaluations can lead to change in functional specifications, leading to new prototypes. Often, prototypes are reduced to single or few aspects of the future end product, allowing for testing specific user experience. Together with the ideas generated in the previous phase, prototype iteration will lead to requirements. Methods such as requirement analysis, functional analysis, system architecture, FICS analysis and MoSCoW can be used to define and alter requirements.

3.1.3 Realisation

With the specifications, the product can be realised, generally in the same manner: "decomposition of the start specification, realisation of the components, integration of the components and evaluation" [47, p. 5]. In contrast to the previous two phases, this process is linear but allows to go back in case of missteps. Evaluations are done to validate whether specifications are met.

3.1.4 Evaluation

Besides the evaluation done in the realisation phase, evaluation could also be done in this phase by also including earlier functional requirements, user testing, comparison with related work and reflection on personal and academic progress. With user tests, decisions taken concerning user requirements and experiences can be checked. Related work can help place the final product within its market.

3.2 Brainstorm

Brainstorms are free-flowing discussion serving the purpose of generating ideas and expanding the design space. During a brainstorm, ideas should not be analysed and criticised. Classical methods include free form brainstorming and mind maps. Wiethoff et al. [48] present three brainstorming methods in the context of physical computing: using Post-Its®, Creative thinking and physical brainstorming. In physical brainstorming, a set of 3D primitives is used to build objects after which ideas are written down. This technique does not seem suitable for this project.

The term brainstorming as known today is introduced by Osborn [49] as part of a creative problem-solving process, as Faste et al. [46] argues. One of the three phases in this process is idea-finding. Osborn offers four guidelines which should result in an effective brainstorming session. Faste et al. summarises these:

1. **Criticism is ruled out** Judgement of ideas must be withheld till later.
2. **"Freewheeling" is welcomed** Allowing participants to be playful and to let imagination free.
3. **Quantity is wanted** The more ideas generated, the more likely a use full idea is found.
4. **Combination and improvements are sought** Besides bringing in own ideas, a participant should give suggestions how ideas of other can be altered into better ideas, or how multiple ideas can be joined into a new idea.

Osborn points out the rules are specifically designed for group brainstorming and that working in groups is preferable. But, group brainstorming is recommended only as a supplement to individual ideation.

3.2.1 Post-Its®

Participants write ideas in short on Post-Its®, these ideas are clustered and votes are given for good ideas. Wiethoff et al. add that early prototypes can be made out of foam and Post-Its® can be stuck on these. With this technique, a lot of ideas can be created, although it can be hard to make the distinction between a good thought and an idea.

3.2.2 Creative Thinking

Creative thinking, or mind mapping, is a technique where an umbrella term is placed in the middle of a paper and associated terms are placed in branches around them, grouping related concepts. New associations can again be put around branched terms. This continues until no new branches can be created or when new branches do not generate new ideas. The step of going from related concepts to ideas can be hard with this technique. Also, only relating terms can minimise enlarging the design space. Creative thinking can also be done individually.

3.2.3 Electronic Brainstorming

Unfortunately, due to the current circumstances regarding a pandemic, face-to-face brainstorming groups is impossible. Traditional methods such as Post-Its® and Creative Thinking can still be performed with the help of a variety of online tools such as

Ideaflip [50], WiseMapping [51] and Stormboar [52]. Also dedicated online brainstorming techniques has been developed.

For example, Faste et al. [46] experimented with online brainstorming. In a prior, face-to-face brainstorm, a set of opportunity areas were created. For the online brainstorm, these opportunity areas were rewritten as seven "How could we..." questions. Each question was placed at the top of a separate Google Docs document. Over 30 participants were invited to these documents and asked to at least add five ideas in response to the seven brainstorm questions. All participants had knowledge of the matter discussed and had experience with group brainstorming. In total over 50 ideas per question were submitted. Seven of the most involved participants were given the opportunity to give out votes for the best idea in each document, generating 35 favourite ideas.

3.2.4 Chainstorming

In chainstorming, described by Faste et al. [46], participants are asked to build on the idea of the previous participant. The first participant generates a question and one or multiple ideas in response to this question. These questions and ideas are passed on to the next participant which can generate new ideas. Thereafter, only a subset of the ideas is passed on to the next participant, introducing a degree of randomness at every stage. By only passing along a subset of all generated ideas for a question, potentially unrelated or even contradictory, new unexpected socially-generated concepts could be sparked. This method of brainstorming can be done offline on paper, or online with the help of email, social media or internet fora.

3.3 Stakeholder Analysis

Stakeholder analysis is introduced by Freeman [53] in his book *Strategic management: a stakeholder approach*. He defined a stakeholder as "any group or individual who can affect or is affected by the achievement of the organisation's objectives" [53, p. 46]. Bryson [54] lists more definitions, all being comparable. Olander and Landin [55] add that stakeholders can be of a threat or benefit. Bryson also points out the reasons why a stakeholder analysis should be performed in any problem-solving. A set of fifteen techniques to identify stakeholders is given, from which five are particularly important, as Bryson states. The author has identified two to be suitable for this project.

3.3.1 The Basic Stakeholder Analysis Technique

Bryson [56] outlines several steps for "identifying stakeholders and their interests, clarifying stakeholders' views of a focal organization (or other entity), identifying some key strategic issues and beginning the process of identifying coalitions of support and opposition" [54, p. 29].

The process begins with brainstorming the list of potential stakeholders. Each written at the top of a big sheet on which a narrow column is made on the right side. On the sheets, criteria are listed which the stakeholder would use to judge the project or organisations performance. In the right column terms such as *good*, *fair* and *poor* can put for each criterion, indicating how the stakeholder evaluates the project or organisations as thought by the creator. From these overviews, short-term actions can be identified aiming at satisfying each stakeholder directly. Also, long-term issues with individual stakeholders or a group of stakeholders can be noted. Additionally, for each stakeholder, their influence, importance and usability to the project or organisation can be noted.

3.3.2 Identifying Stakeholder Roles

Sharp et al. [57] points out that it can be more useful to think of stakeholders in terms of roles instead of specific people. They propose a more systematic approach to discover all relevant stakeholders and roles. Two groups of stakeholders are defined: baseline and satellite stakeholders. The former type of stakeholders can be a supplier, providing information or supporting tasks, or a client, processing or inspecting the product. Satellite stakeholders interact with the baseline in various ways, for example, communication, setting rules or guidelines or providing information. Four groups of baseline stakeholders are identified by Sharp et al.

- **Users** The people who will interact with the product and control it directly, and those who will use the products (e.g. results or information) of the product.
- **Developers** The developers of the product, important stakeholders when defining requirements.
- **Legislators** Organisations such as "professional bodies, government agencies, trade unions, legal representatives, safety executives, quality assurance auditors" [57, p. 3].
- **Decision-makers** (User) managers, clients and financial controllers.

For each group, the same five-step procedure is followed to identify stakeholders, as also outlined by Sharp et al. [57, pp. 3-4]:

1. Identify all specific roles within the baseline stakeholder group;
2. Identify 'supplier' stakeholders for each baseline role;
3. Identify 'client' stakeholders for each baseline role;
4. Identify satellite' stakeholders for each baseline role;
5. Repeat step 1 to 4 for each of the [baseline] stakeholder groups.

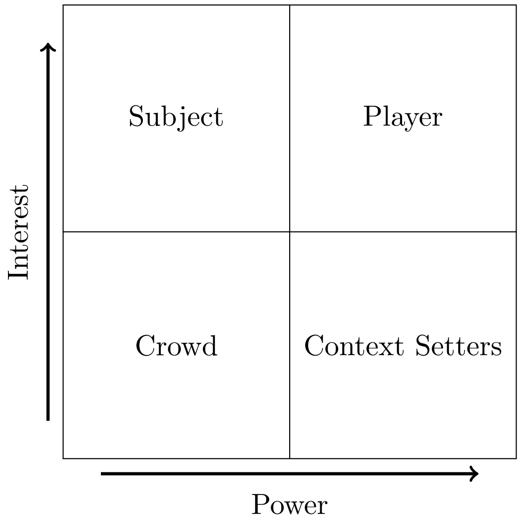


Figure 3.2: Power versus Interest Grid [58]

3.3.3 Stakeholder Mapping

Stakeholders can be put in a stakeholder map, a two by two matrix of interest versus power (see Figure 3.2), as described by Eden and Ackermann [58]. A more elaborate explanation is given by Johnson and Scholes [59]. The stakeholder are put in four categories: players, subjects, context setters and crowd, as also shown in the diagram in Figure 3.2. The grid helps to determine which stakeholders must be taken into account when finding solutions, which influences should be encouraged or discouraged and which stakeholders should be included in different stages of a process. Players for example should at all time keep informed about and include in the process and decisions made. The crowd should be kept satisfied, but it must be avoided to actively involve them in decision making.

Additionally, stakeholders can be connected by arrows, identifying influences from one on another stakeholder.

3.4 iPACT Analysis

Whereas with a stakeholder analysis an organisation or project is evaluated, an iPACT analysis is used to analyse a situation and identify improvements. “People undertake activities, in contexts using technologies” [60, p. 2]. Benyon [60] states that the variety of elements in this statement makes designing systems a difficult challenge. Technology can allow people to undertake activities (in a context), changing technology changes also the activities or context. This cycle is shown in Figure 3.3.

An iPACT analysis originates from the PACT analysis. PACT is an acronym for people, activity, context and technology. In such an analysis, a designer scopes out the possible Ps, As, Cs and Ts in a domain. Techniques such as brainstorming, interviews

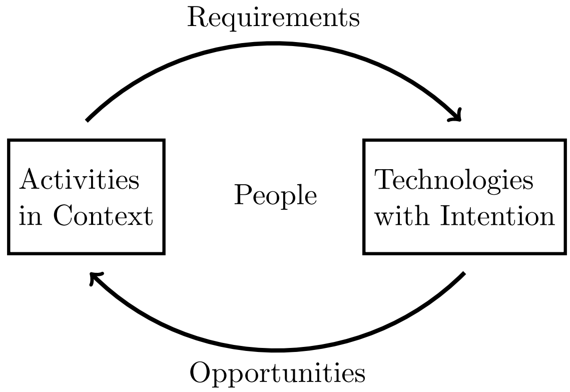


Figure 3.3: Activities and Technologies [61]

and observations can help with this. PACT can help with developing personas and scenarios. Each element is discussed in the following sections.

3.4.1 People

The most important takeaway within the people element of the PACT is that everyone is unique. In the first place physically, both in characteristics such as height and weight as in differences in perceiving senses. These variabilities influence how technology is enjoyed in different contexts.

Furthermore, psychological capabilities vary from person to person. Benyon [60] notes examples such as spacial understanding, language differences, attention and memory. He also introduces a mental model, understanding and knowledge one has of something. This can be a device or system a user interacts with. Having a good mental model will help understand a user how to troubleshoot problems and find causes of malfunctioning.

The last variation listed by Benyon is social differences. Motivations to use a product can differ from person to time. A distinction is made between a homogeneous and heterogeneous target group. Both groups require a different approach.

3.4.2 Activities

An activity, simple or complex, can be described by many characteristics. For a designer, the most important is the purpose of an activity. Other main characteristics are summarised in five terms, as described by Benyon.

- **Temporal aspects** Includes all characteristics related to time such as the frequencies and duration of an activity. Also, time pressure can have an influence on the user experience. Activities can require to be performed continues or may be interrupted. When an activity is stopped intermediate, it may or may not be possible to continue at a later point. At last response time on actions is pointed out.

- **Cooperation** Activities can be performed alone or with others, matters related to communication and coordination can then become relevant.
- **Complexity** More defined tasks allow for simple step-by-step activities, more vague tasks need to give a user more freedom to browse around and scan for options.
- **Safety-critical** For some activities, mistakes can have a serious impact. The effect of making mistakes should be incorporated into the design process.
- **The nature of the content** Activities can require data in- and output, this data is the basis for the content processed and presented by the product. Putting content in can require a full keyboard or only a few buttons. Presenting content can require a full-colour display or a speaker output.

3.4.3 Context

Defining and analysing the context element within a PACT analysis can be challenging. A context can be seen as something surrounding activities, or as something connecting activities together. Benyon notes that "it is important to consider the range of context in which activities can take place" [60, p. 35].

He starts by describing the physical environment in which an activity takes place. Weather conditions and subsurfaces can be considered, but also (wireless) connectivity and data transfer rates from remote or crowded locations. Additionally, a social context can influence activity performance. Training and tuition can help a user, but surveillance, social norms or lack of privacy can be of negatively effect. Lastly, the organisational context has to be considered, especially when working with technology. For example power and communication structures.

3.4.4 Technologies

The last letter in the PACT acronym stands for technology, the medium a designer works with. Typically hardware and software are combined, which should be able to communicate mutually, process input data and present output data and often contain information content. This gives the four key features of the technology.

To begin with input devices. Benyon [60] lists some examples of input devices, including switches, keyboards, touchscreens, styles, mouse, sensors, speech input, etc. Input devices help users enter data and instruction securely into a system.

Also for output devices, a long list of available techniques can be made. In general, all these techniques depend on the three perceptual abilities of vision, hearing and touch, as Benyon states. The most common output to display data is a screen, available in a wide range of sizes and characteristics. Also sound is a commonly used medium to notify users of certain activities. Speech output or text-to-speech becomes more generally available. Examples of other output devices are vibration, printers, plotters and 3D printers.

Besides wireless connections discussed in Chapter 2, wired communication techniques are available such as USB and Ethernet.

The last feature to discuss is the content of technologies, often the key part to understand how the technology relates to activities as discussed in the introduction of this section. Content should be up-to-date, accurate and relevant, especially in systems just about information such as websites. Information can be pulled or pushed when required or synchronised real-time. The type of content can have an influence on what in- and output techniques should be available.

3.4.5 Intention

Larburu et al. [62] argues that intention is such an important concept that the iPACT notion is preferred. Intention refers to the aim of the scenario or system.

3.5 Personas and Scenarios

Personas can help to empathise with potential users and describe user profiles. These "fictitious users" [63, p. 122] can be part of the people element within the iPACT analysis. Personas are introduced by Cooper [64] to represent behaviour, goals and aspiration. Personas can serve as a design or communication tool [65]. Benyon [60] adds that personas want to achieve certain actions using the to be designed system. They can help designers create a product for not only themselves.

Benyon suggests developing multiple personas covering the variety of users. Nielsen et al. [63] state that a persona should include work-related areas such as workflow, goals, context, attitudes and also personal details can be added. Goals can be personal life or experience goals, corporate goals or practical goals. Including system goals is considered wrong and often referred to as a *false goal*.

"Scenarios are stories about people undertaking activities in contexts using technologies" [60, p. 55]. Scenarios can arise form persona descriptions or from needs in the system. Personas should be considered in accordance with the design area [63].

3.6 FICS Analysis

Benyon and Macaulay [66] state that scenario development helps finding the dimension of the design situation and illustrate the different aspects of these dimensions. The dimensions are set by the various domains in which the system will be used, the content the system will encounter, the designer-centric components and its users. The designer-centric components include function and events, interaction and usability issues, content and structure together with style and aesthetics, summarised in the acronym FICS.

Where with the iPACT the the user-centred perspective is explored, the FICS helps analysing the design-centred perspective of a situation, scenario or system.

Larburu et al. [62] and van 't Klooster et al. [67] describe the different components of FICS as following.

- **Function** The functionality of the intended system which allows for user activities.
- **Interaction** The interaction between user and system or system and components which realise user activities.
- **Content** The data, information and knowledge stored in the system.
- **Service** Types of sets of coherent interactions expressed in terms of technology.

3.7 Requirement Analysis

Hatton [68] points out that requirement analysis is a critical phase of a development process. Prioritising requirements in a early state helps to direct and distribute resources. A variety of techniques for prioritisation exist. Hatton concluded that the MoSCoW method is a suitable technique in early stages of the design process. When more information on the *Must Have*'s and *Should Have*'s is needed another method such as the Hundred Dollar Method would be appropriate.

3.7.1 MoSCoW

MoSCoW is yet another acronym, used to divide requirements in four different priorities, as described by both Hatton [68] and Waters [69].

- **Must have** Requirements that must be delivered, else the project will result in a failure.
- **Should have** Features that would be nice to have when possible and which are considered to be important to the user.
- **Could have** Features which are nice to have and can be included when resources are available, but which are less important thatn should have's.
- **Won't have** These features will not be implemented in the current design but are not considered unimportant. These may be included in future stages.

3.7.2 Functional and non-functional requirements

Glinz [70] points out that requirement engineering a distinction is made between functional and non-functional system requirements. He also observes that no clear and aligned definition for both types can be found in literature. Glinz suggests to employ the concept op concerns to define a taxonomy of requirements. Concerns are defined as following:

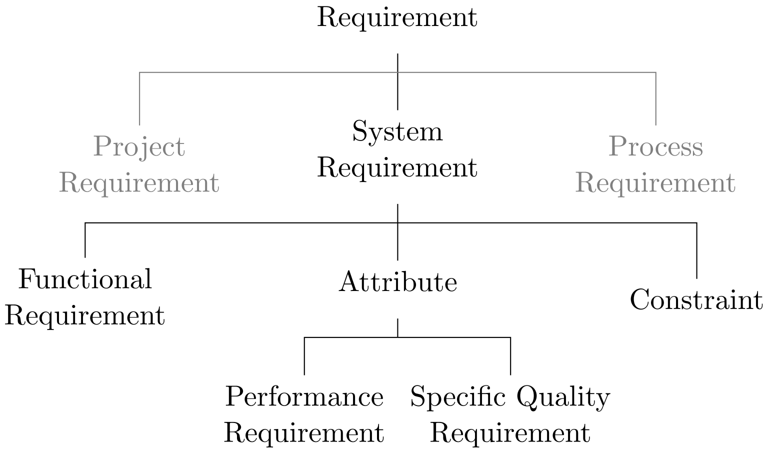


Figure 3.4: Concern based taxonomy of requirements [70]

> A concern is a matter of interest in a system. A concern is a functional or behavioral concern if its matter of interest is primarily the expected behavior of a system or system component in terms of its reaction to given input stimuli and the functions and data required for processing the stimuli and producing the reaction. A concern is a performance concern if its matter of interest is timing, speed, volume or throughput. A concern is a quality concern if its matter of interest is a quality of the kind enumerated in ISO/IEC9126. [70, p. 4]

The taxonomy of requirements developed with this principle is shown in Figure 3.4. As can be seen, requirements are divided into four groups: functional requirements, performance requirements, specific quality requirements, and constraints. The first, a functional requirement, pertains to a function concern. The second relates to a performance concern. A specific quality requirement pertains to a quality concern, but not the quality of meeting the functional requirements. The last type, a constraint is not related to concerns but is a requirement that constrains the solution space other than set by the boundaries from functional, performance or quality requirements. At last, an attribute is a performance or specific quality requirement. A non-functional requirement is a attribute or constrain. Instead of classifying requirements by the rule of *what the system does/how the system behaves* (functional/non-function requirements), Glinz suggest to follow the questions in Table 3.1, in the order as in the first column.

3.8 System Architecture

Mapping out the architecture of system can be beneficial in multiple ways. Such system architecture description or documentation can include elements related to both hardware and software. Garlan et al. [71] outlines that a software architecture of a system outlays a high-level structure, exposing its main components and interconnections. They list that properties are included such as protocols, bandwidths, latencies, locations of central data

Table 3.1: Classification Rules [70]

	Question	Result
	Was this requirement stated because we needed to specify...	
1	... some of the system's behavior, data, input, or reaction to input stimuli – regardless of the way how this is done?	Functional
2	... restrictions about timing, processing or reaction speed, data volume, or throughput?	Performance
3	... a specific quality that the system or a component shall have?	Specific Quality
4	... any other restriction about what the system shall do, how it shall do it, or any prescribed solution or solution element?	Constraint

stores and expected dimensions of evolution. Clements [72] states that a description can be made by drawing out the components and interconnections or with the help of a architecture description language. Clements lists roles a architecture description can full-fill. Most importantly it can be the basis for communication allowing stakeholders to gain a basic understanding of the system. Secondly, the description can help planning the project in terms of choosing components, work assignment, scheduling and test plans. Additionally, making a architecture description can help make early design decisions. As Clements points out, architectural decisions are hard to change and result in far-reaching consequences. An extensive explanation on documenting software architecture is given by Clement [73].

3.9 Activity Diagram

An activity diagram is a graphical representation of activities and actions broken down to steps allowing for choices, iterations and concurrences. The activity diagram is specified in the Unified Modeling Language (UML) [74]. Bock [75] states that the diagram in general determines when other behaviour should start and which inputs are available. Available nodes to create an activity diagram are action, control and object nodes. An arrow connecting activity nodes indicates that the action pointed , can not start until the source action has finished. Examples of control nodes are initial and decision nodes. The flow in an activity diagram starts in an initial node, indicated as a filled circle. At a decision node direct the flow, depending on the guards. A decision node is shaped in the form of a diamond.

3.10 Conclusion

In this chapter, a long list of methods and techniques have been described. These will be used in the next chapters in the different phases of the Creative Technology Design Process.

Chapter 4

Ideation

In this first phase of the Creative Technology Design Process, the ideation, the problem stated in Chapter 1 is analysed together with all the aspects involved. This is done with the help of a stakeholder analysis, iPACT analysis and interview which are all explained in Chapter 3. This helps to generate suitable ideas leading to a potential solution.

4.1 Stakeholder Analysis

With the help of the techniques described in Section 3.3, a stakeholder analysis has been performed. The steps as given by Sharp et el. [57] were followed to identify stakeholders in each stakeholder group, after which the stakeholders were put in a stakeholder map.

Users

Everyone interacting with the Breathline and setting up, or trying to set-up, a wireless connection is a user. Some sub-groups can be identified. Younger and elderly people, the two ends of the age spectrum, can use the Breathline to improve breathing habits. Both groups are likely uninterested in the product and technology, the more in results. Besides, not much technological experience is expected and tasks such as connecting the Breathline to a mobile phone with Bluetooth can be considered difficult.

Students and adults can use the Breathline to reduce anxiety. Familiarisation with simple technological operations is more likely, but interest in the workings of the Breathline is in general absent. Adults active in sports can use the Breathline with an interest in training diaphragmatic breathing, there may also be more interest in the Breathline.

Special users are therapist such as Parviz Sassanian, that may use the Breathline as part of therapy of treatment for dysfunctional breathing or anxiety. Other specialists such as physiotherapist can be included in this category too. Their interest can be higher than other users, although their power (with the exception of Mr Sassanian) equally low. These users are indirect users.

Developers

Currently, a team of developers is working on the Breathline wearable. The main developer is Ben Bulsink, creator and co-vision maker of this project. Two fellow students, Radhika Kapoor and Martijn Poot are working on implementing posture recognition functionality to the Breathline. Also, the author, working on wireless connectivity, is part of the development team.

Legislators

Some organisations have a direct influence on the Breathline. Firstly, specifically applicable for this project is the Bluetooth SIG, requiring all devices which make use of Bluetooth to be certified. Fortunate, hardware used in this project is already certified, but changes in the Bluetooth specification can have influences on the Breathline.

Secondly, are national governmental organisations, setting requirements and register medical devices. For the Netherlands, both the company and their product must be registered by Farmatec [76].

In the last months, it became apparent that the national government can have a great influence on the development and manufacturing in the whole country. Due to the COVID-19 pandemic, the national government has enforced a lock-down. This influences also the development of this graduation project.

Other organisations influencing the Breathline include lawyers and medical policy-makers form both the national government and the European Union.

Decision Makers

The decision-maker within the development of the Breathline is Ben Bulsink. Besides this, he also has a decision-making role within this graduation project, by guiding according to his goal and vision. Also, the supervisors, Erik Faber and Cora Salm, are decision makers withing this project by overseeing the progress, providing direction and feedback, making suggestions and setting deadlines. Other students working on this project, including Radhika Kapoor and Martijn Poot, are deciding within there projects, influencing the choices and decisions made in this project.

Lastly, the author is a decision-maker in terms of defining how wireless communication is implemented within the Breathline.

4.1.1 Stakeholder Map

An overview of stakeholders is given in Table 4.1, including there interest and influence. This is made into a stakeholder map, as shown in Figure 4.1.

4.2 iPACT

In this section, the analysis described in Section 3.4 will be preformed with the help of personas and the methodology described by Benyon.

Table 4.1: Overview of stakeholders and there position in the Stakeholder Map

	Stakeholder	Role	Interest	Power
A	Younger and elderly people	User	Low	Low
B	Students and adults	User	Low	Low
C	Athletes	User	Medium	Low
D	Specialists	User	Medium	Low
E	Ben Bulsink	Developer and Decision Maker	High	High
F	Fellow Students	Developer and Decision Maker	High	High
G	Erik Faber	Decision Maker	High	High
H	Cora Salm	Decision Maker	High	High
I	Bluetooth SIG	Legislater	Low	Medium
J	Policy Makers	Legislator	Low	High
K	Author	Developer and Decison Maker	High	High

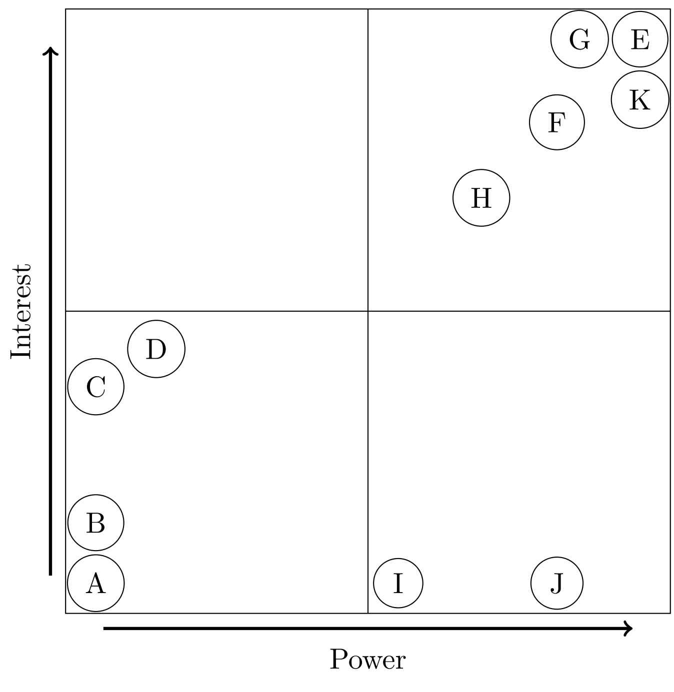


Figure 4.1: Stakeholder Map with stakeholders as listed in Table 4.1

Intention

The goal of this project is to set up a wireless connection between the Breathline and a smart device, allowing for real-time measurement display and interaction with the user, providing feedback to help them advance the habit of diaphragmatic breathing and to inform them of their breathing performance throughout the day.

People

As stated in the referred section, no person is the same. To help empathise with potential users, making personas can be helpful. Oscar and Lucy will be introduced, see Figure 4.2.

> Oscar is a 25 years old student at the University of Twente doing a master in Interaction Technology. He sometimes faces anxiety when exams approach. From time to time he uses the Breathline to get a grip on his breathing patterns. In his spare time, Oscar likes to work on personal projects which include software and hardware. One of the projects he is proud of is his self-made home domotic system he builds in his room. From his phone, he can control his lights, curtains and stereo installation. He tries to follow technological news sites such as The Verge and The Outline to keep up to date with the last technological developments.

Oscar is comfortable using technology and interacting with wearable such as the Breathline. On the other side of the spectrum is Lucy.

> Lucy is a 56 years old doctors assistant. She is married, has two children, a daughter and son in the age of 20. Lucy works four days a week. In her spare time, she likes to perform sports such as race biking and hiking. She also enjoys being creative by painting and drawing. This helps her take rest after a busy day at work. As a doctors assistant, see knows the influence of good breathing on her physical and mental well being. Throughout the day Lucy wears the Breathline to get insight into her breathing patterns and to improve this. She has a simple smartphone and knows how to use apps such as an instant messaging app and music player. However, opening the settings menu and having to install or search for new apps scares her and in such situations, she tends to ask help from her children.

From users such as Oscar, it can be expected that connecting the Breathline to there smartphone is not a hard task. If the connection establishment fails or other problems occur, these users are often capable of troubleshooting the problem and finding a solution. Users such as Lucy on the other hand, can have a hard time finding the right menu to change Bluetooth settings. Lucy may find it convenient to get feedback and breathing guidance from the Breathline directly. This omits the need of interacting with multiple devices at the same time and having *to do hard thing on the phone*. Oscar however would like to get extensive insights into his breathing behaviour, share achievements with friends trough social media and adjust vibration patterns generated within the Breathline.

(a) Lucy

(b) Oscar

Figure 4.2

Activity

The main activity the Breathline is designed for (gives the opportunity for), is tracking breathing patterns. This can be done proactively during exercises or training or reactive throughout the day. Duration and frequency are up to the user to decide, although frequent use can be encouraged to allow for better results. Interaction with the Breathline intends to be not complex. To conclude, the most important characteristic is the purpose of the activity. This purpose can change between users, as indicated in the previous section. A user can use the Breathline to reduce anxiety and stress, yet another user can wish to breath more conscious.

In the context of this graduation project, one activity from the usage of the Breathline can be highlighted, setting up a wireless connection between the device and a smart device. An initial pair should ideally be done only once, after which setting up a connection should only require a simple action. Most likely, the duration will be short, but when aborted or disrupted, it may be required to start over. At last, setting up connectivity can require user input on both the Breathline and the smart device.

Context

As already pointed out, analysing the context can be challenging. In the context of a wireless connection, the stability of the connection can be considered, related to the physical environment. The stability is, for example, influenced by other devices communicating on the same frequency. This included other Bluetooth and Wi-Fi devices. Another factor is the distance between the Breathline and the smart device it is connected with, users should be aware of this. The device should keep working when a connection is (temporarily) lost.

Technologies

Parts for this last element have already been addressed. Besides the input data described in Chapter 2, a simple button input can be added to help setting up a wireless connection, although optional. Also, communication is discussed in the same chapter. Output data will be discussed in more detail by Radhika Kapoor and Martijn Poot.

In this project, new technologies will be included in the Breathline. A Bluetooth chip should be configured to allow wireless communication. Also new software has to be developed. Applications should be programmed to interact with the Breathline on a smart device.

4.3 Interview with Ben Bulsink

An interview and short brainstorm session were planned with Ben Bulsink. The aim was to first get a better understanding of Mr Bulsinks view and wishes and secondly, discuss possible solutions to the problem stated in Chapter 1. The questions and information send to Mr Bulsink can be found in Appendix A. Additionally, a short explanation about BLE profiles, services and characteristics was included. The results of the interview are summarised in the following points.

- In the consumer end-product, data will be processed and summarised on the Breathline after which it can be sent to a smart device wirelessly or retrieved over a USB-connection.
- This summarised data packet is expected to be approximately 10 kB.
- However, currently no data analysis algorithm is developed for the Breathline. In the development phase of the Breathline, real-time data transfer is needed to allow for the development of a data processing algorithm on a smart device.
- The consumer end-product requires storage in which analysed data can be stored.
- This storage should be read by the wireless data transferring protocol and as a whole be transferred to the smart device.
- The philosophy of Mr Bulsink can be found in the following quote, "The user should not be fixed to his phone, but focus on breathing." (translated). In other words, the attention of the user should go to his or her breathing instead of getting distracted by a phone.
- Mr Bulsink indicates that the Breathline must work with or without an active wireless connection.
- Pairing and setting up a connection between the Breathline and a smart device should be done securely.

- Addition of buttons is not desired. Mr Bulsink suggests using other input such as shaking the Breathline device.
- Mr Bulsink wishes that the data transfer takes as short as possible. On the other side, energy usage should be kept to a minimum, but no strict goal is set.
- Data transfer should be done in a save way which prevents man-in-the-middle attacks. Most likely, no more encryption than already present in the BLE stack is needed.
- When possible in the future, a wired data connection will be removed to allow for simplifying the circuitry inside the Breathline. However, a charging port will stay on the Breathline.
- Mr Bulsink wishes to have a working prototype communicating with a Windows machine. However, a proof-of-concept, interacting with any smart device is the first goal.

There appear to be two different situations for which a solution is required. In the first place, real-time communication is needed during the development process which allows for development and evaluation of off-device data analysis. On the other hand, in a later consumer product, data-transfer is only required once or twice a day which contains only analysed subset of data.

Technologically the difference is sending often small packages of data versus sending occasionally a large amount of data. This split results in different requirements. It is not yet ruled out that one solution can be applied to both situations.

4.4 Brainstorm

With the two possible directions in which this project could be taken, the decision was made to take a step back and have a brainstorm. The goal of the brainstorm was to generate ideas and opportunities and also list advantages and disadvantages regarding the different directions.

Due to the COVID-19 pandemic, no physical brainstorms could be held. A selection of techniques described by Faste et al. [46] (as also outlined in Section 3.2) was made to use for this brainstorm. A shared document was created, see Appendix B, in which first an introduction and explanation was given on this project. Also the three general possibilities of data communication was explained: a wired connection, a wireless connections transferring data real time or a wireless connection transferring data in bulk.

Six participants were invited and asked to makes slides in one of three sections, relating to the three possibilities of data communications. With two invitees also a video call was held discussing the brainstorm. As a suggestion for ideas in these slides, the following questions were given to keep in mind.

- How could the implementation contribute to the functionality of the Breathline?

- What functionality can be added uniquely to this implementation?
- How can an implementation be realised technically?
- What are advantages related to this implementation?

Although some new insight were gained, unfortunately the brainstorm was not exceptionally successful. This was also discussed with some participants. They indicated that the lack of direct interaction made this type of brainstorm hard. There was also said that the brainstorm was maybe too framed to make it successfully online.

In conclusion, unique possibilities and new views were found for the different implementations of wireless communication in the Breathline. For example, real-time communication could make it possible to give on-screen breathing training with real time feedback. This feedback seems to be key and turns out to be, for the participants, the biggest bottleneck for bulk data transferring. A participant noted that it would already be helpful to have some indication on the screen that the devices is working and "doing its thing". However, regarding the bulk data transferring, one interesting comparison was made with services such as Strava. This is an application and online platform on which users can upload there sports presentations in the form of a GPS recorded track. Analysis such as time, average and maximum speed and distance are presented to the user and its network. A similar system can be developed for the Breathline.

Another feature proposed in the Brainstorm was the ability to share real-time breathing measures with a specialist or friends and family. If the Breathline is continuously connected to a smartphone, this information can be shared easily and would allow for monitoring users with mental or physical problems.

4.5 Preliminary Solutions

Up until the interview with Ben Bulsink, the research, analyses and ideas generated pointed to one solution for the problem described in Chapter 1. It became clear that the most suitable wireless technology which would allow for real-time communication is Bluetooth Low Energy. This technique can theoretically meet the desired throughput and energy efficiency. Also, BLE is already widely available in smart devices.

However, in the said interview, it became apparent that in later versions of the Breathline, data would not be communicated real-time but occasionally with higher amounts. This new understanding makes the proposed solution less definite because in such new version, other technologies can be as interesting as BLE. For example, NFC is also energy efficient and widely available in smartphones. For this situation, no complete solutions is found yet.

In the next section, requirements are set for both solutions. However, after discussing the two solutions and the different problems they solve with both Ben Bulsink and Erik Faber, the decision was made to develop a prototype aimed at real-time communication.

4.6 Preliminary Requirements

For both solutions proposed in previous section, some preliminary requirements can be set. Two sets of requirements are be made. The two solutions are referred to as real-time data transfer and data offloading. Some requirements are relevant for both implementations and will be discussed first.

General Requirements

1. Data will be transferred wirelessly, as supplement or replacement for a wired connection.
2. The data have to be transferred completely with no data lost during the transfer.
3. The Breathline should keep on functioning when a connection is lost and remain 100% operational.
4. Preferably, no extra buttons or similar hardware should be added to accommodate wireless connections.

Situation A: Real-Time Data Transfer

A-5. Data will be transferred real-time.

A-6. Raw data will be sent to facilitate later data analysis on a device other than the Breathline.

Situation B: Data Offloading

B-5. Data will be read from local storage on the Breathline

B-6. The Breathline should keep on functioning when the storage is full and remain 100% operational. Old measurements should be overwritten.

B-7. Communication between the Breathline and a smart device will take place on a daily basis.

B-8. The process of data transfer should at maximum take ten seconds.

4.7 Conclusion

In this section, the design space was bounded and explored. With the help of stakeholder and iPACT analysis, the current situation was defined. The most important takeaway is that the the activity that especially should be kept in mind is establishing a wireless connection. Also, the wide variety of potential users gives a bread range of technical capabilities to be expected from the user.

An interview with Ben Bulsink was conducted, together with an open brainstorm. This helped setting requirements but also showed that two situations appear.

Following these two situations, a brainstorm was held discussing different communication options, transferring data between the Breathline at real-time or only transferring an analysis or summary of this data once in a while, and the advantages of these.

For both situation a concept solution was formulated. For these concepts, some preliminary requirements were set. In the next chapter the requirements will be refined and fixed.

After discussing the two options with both Ben Bulsink and Erik Faber, the choice was made to develop a prototype aimed at real-time communication. One of the main reasons for this choice, is that Bluetooth Low Energy is designed to target wearable devices requiring real-time data communication.

Chapter 5

Specification

The second phase of the Creative Technology Design Process is the specification, in which the goal is to find requirements useful for the realisation phase. These will be found with the help of a system architecture, activity diagram and FICS analysis. This latter will be the start of this chapter.

5.1 FICS

A FICS analysis, as outlined in Chapter 3, provides an overview of system usage from the system's point of view. The four elements of the FICS are outlined below.

5.1.1 Function

The system to be developed has one main function, transferring information between the Breathline and a smart device. This functionality is achieved by implementing a Bluetooth chip in the Breathline and developing applications for a smart device. The Bluetooth chip receives sensor readings or a summary of these readings form a central controller chip. This is communicated over Bluetooth Low Energy to the smart device application which can present this information to the user.

5.1.2 Interaction

The system should not need much user interaction. As already found in the iPACT analysis in previous chapter, the only important activity related to the BLE communication, is the establishment of the connection for this communication. Interactions for this activity are either indirect through the central chip of the Breathline or directly from within the application.

5.1.3 Content

The system will communicate gathered sensor data or an analysis or summary of this data.

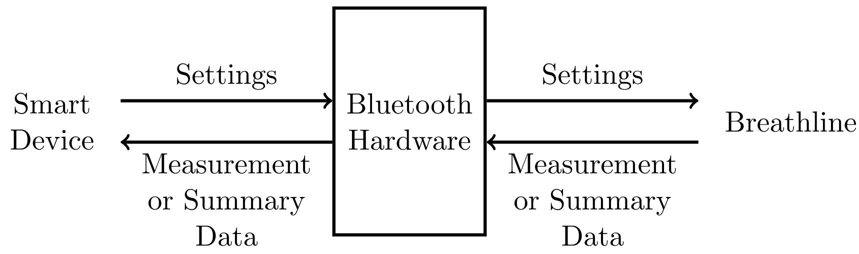


Figure 5.1: Top level system architecture

5.1.4 Service

Besides transferring data from the Breathline to a smart device and vice versa, the system provides no additional services.

5.2 System Architecture

The focus within this system architecture will be on the communication between components and what information is exchanged between them. As a convention in the diagrams in this section, communication protocols are printed in italics, the information is printed in regular typeface next to the arrow indicating the direction of the information flow.

In Figure 5.1 is the top-level architecture shown of the system. The system receives data from the Breathline and transfers this to the smart device. This data can be in the form of raw measurement data or a generated summary of the raw measurement data. In the other direction, settings are transferred by the system. The system makes use of Bluetooth.

The freedom and creativity of implementing Bluetooth Low Energy is restricted by the core specification defined by the Bluetooth SIG. A developer has however some freedom in choosing the desired communication speed and type of information communicated by changing different parameters when implementing.

5.2.1 Smart Device Architecture

Going a level down into the smart device, the diagram shown in Figure 5.2 can be constructed. The diagram is constructed form the information flow in an Android phone. However, this is similar to how the information is handled in other smart devices including Windows computers and iOS phones.

The Bluetooth Radio is part of of the top level system. Most operations related to Bluetooth are handled in this component, such as packet combining and encryption. The received data is than presented as a GATT service element to an application, from which the different attributes can be extracted and stored in variables. Within the applications, date representation elements can be chanced depending on the variables.

Settings changed from within the application (e.g. measurement frequency) can be send to the Breathline. Also settings related to the Bluetooth connection are defined in

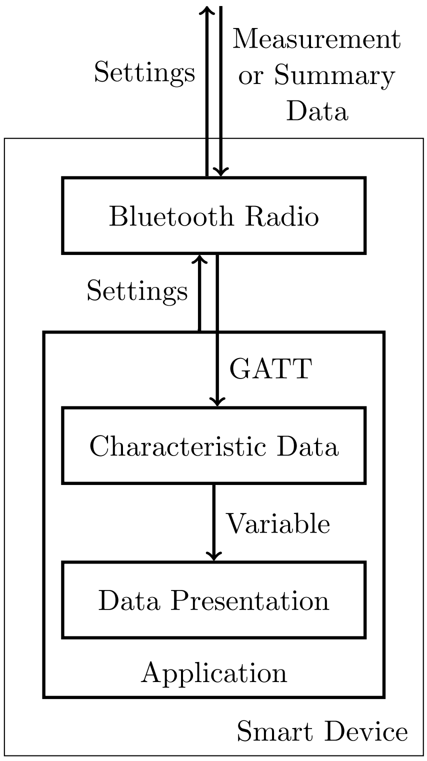


Figure 5.2: Smart Device architecture

the Bluetooth chip and communicated by the system.

5.2.2 Breathline Architecture

In the Breathline, the RN4871 Bluetooth module is part of the system. The architecture is shown in Figure 5.3. Settings intended for this chip are intersected, other settings are passed to the microcontroller unit (MCU). The MCU periodical retrieves measurement data from the respiratory inductance plethysmography (RIP) bands, the accelerometer (Accel.) and the real-time clock (RTC). These measurements are either directly forwarded to the Bluetooth chip which communicates it to the smart device or stored in the storage.

Stored data can be retrieved by the MCU in a later stage whereafter it is analysed and summarised. This summary is sent to the Bluetooth chip, communicating it to the smart device. Alternatively, raw data can be retrieved from the storage by the Bluetooth chip directly and communicated to the smart device.

Communication between the MCU, storage and RN4871 module can be over communication protocols such as I2C and UART.

In the system designed in the next phase, a Breathline-like device will be used. This device consist of a MCU, RN4871 and an accelerometer. This is sufficient to create a proof-of-concept of the system.

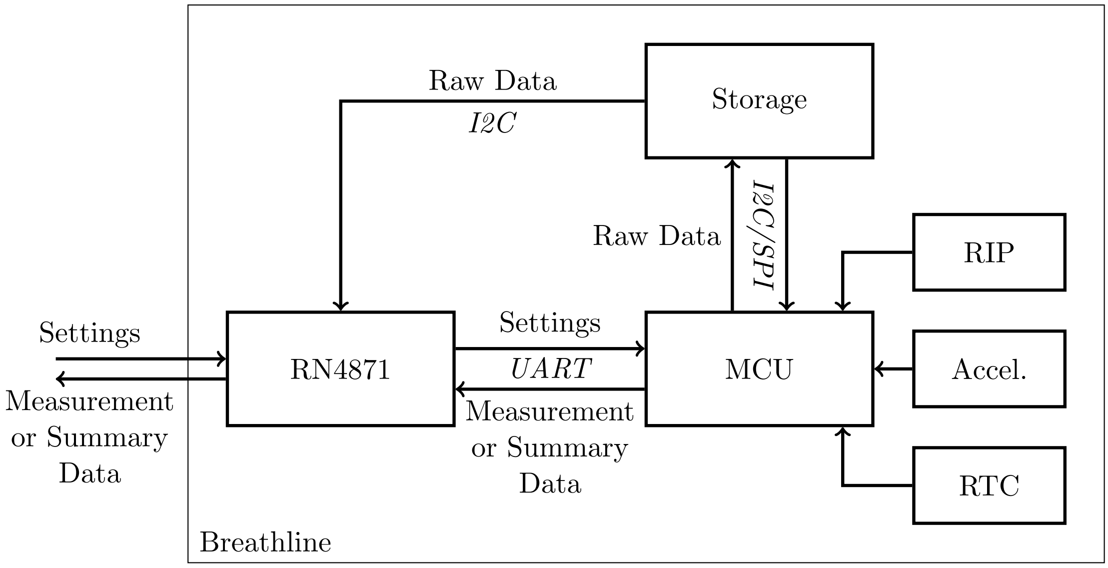


Figure 5.3: Breathline architecture

5.3 Activity Diagram

Where in a system architecture the information flow and communication between different components in the system is illustrated, in a activity diagram the interaction between a user and the system is analysed, see Section 3.9. In the previous chapter, the most important activity related to the wireless connection of the Breathline is establishing a connection between the Breathline and a smart device. Such a connection is initiated and directed by the smart device. The activity diagram for this activity is shown in Figure 5.4.

When the user opens an application on the smart device, the system should check if the user had Bluetooth enabled. If this is not the case, the user should be asked if Bluetooth can be enabled. The system will then check if the device has a bond with a Breathline, and when this is the case the system tries to connect to this device. If not, the user is asked to set their Breathline in advertising mode and the system can scan for it. If it is found, the user is asked to accept the bonding after which a connection can be established. When a connection is established, information from the Breathline can be retrieved and displayed to the user. User interactions or system timer can trigger the system to again retrieve data from the Breathline and display this to the user.

This diagram shows that a connection between the Breathline and a smart device should be made in only a few simple steps. The user can be guided trough these steps by a manual or by a setup procedure when launching the application.

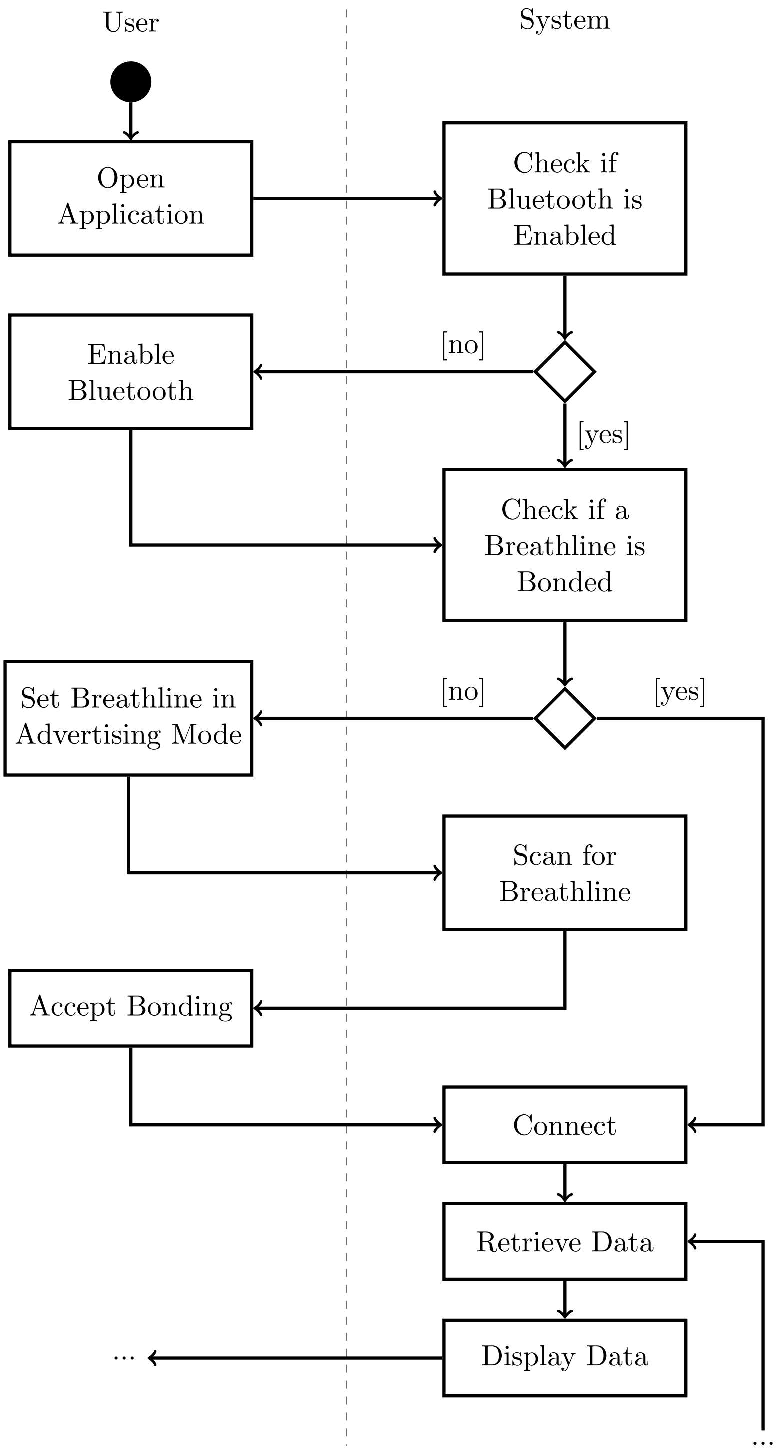


Figure 5.4: Activity diagram of establishing a connection

5.4 Requirements

The final requirements are listed below. A division in priorities is made as described in Section 3.7. In this same section a explanation is given about the classification stated in the last column.

5.4.1 Must Have

	Requirement	Type
1	Transfer data wirelessly from the Breathline to a Android smartphone.	Functional
2	The Breathline will keep fully working when the wireless connection fails.	Functional
3	Use Bluetooth Low Energy as communication technique between the Breathline and a smart device.	Functional
4	Send data eight times per second.	Performance
5	Send packets with a throughput of around 800 bit/s.	Functional
6	Minimise energy usage due to wireless communication to less than 3 mAh.	Functional
7	Connection stability is guaranteed up to 8 meters.	Functional
8	Setting up a wireless connection between the Breathline and a smartphone should only require maximal three simple steps.	Functional
9	Setting up a connection between the Breathline and a smartphone should succeed in 95% of the times.	Functional
10	Setting up the wireless connection should be easy.	Specific Quality
11	The user should intuitively see that a connection is established successfully.	Specific Quality

5.4.2 Should Have

	Requirement	Type
12	Transfer data wirelessly from the Breathline to a iOS smartphone.	Functional
13	Transfer data wirelessly from the Breathline to a Windows computer.	Functional
14	Setting up a connections does not require for extra input functionality to be added to the Breathline.	Functional
15	Present measurement data from the Breathline in the smartphone app.	Functional

5.4.3 Could Have

	Requirement	Type
16	Integrate wireless communication functionality into the Breath application written for Windows.	Functional

5.4.4 Won't Have

	Requirement	Type
17	Allow users to change parameters from the communication protocol.	Functional

5.5 Conclusion

In this chapter, the goal was to set requirements. To do that, first multiple analyses were done. These analysis each gave some important findings.

The fist is that implementation of Bluetooth should follow the rules and requirements set by the Bluetooth SIG. However, some degree of freedom is given to the developer by means of setting parameters influencing the speeds, energy usage and reliability of the Bluetooth Connection. Requirements for these matters are set in consultation with Ben Bulsink in the previous chapter.

It was also found that the most important user interaction related to the wireless connection between the Breathline and a smart device, is setting this up. With the different users in mind, as identified in the ideation phase, an activity diagram for this specific activity was made. From this, requirements were set demanding that the setting up of a connection should be easy.

All requirements from this chapter will be used in the next chapter to create a prototype of the Breathline that can communicate in real-time with a smart device.

Chapter 6

Realisation

With the specifications made in the previous chapter, a prototype can be created. The process of doing that is outlined in this chapter. In order to implement Bluetooth Low Energy, some parts of this protocol are investigated in more depth. Also the tools to program the used Bluetooth chip are outlined. The third part of this chapter contains superficial information about the design of an Android application.

6.1 Information Structure

The Bluetooth Low Energy (BLE) protocol is specified by the Bluetooth Special Interest Group in the Core Specification [21]. Among others, Townsed et al. [77] and Gomez et al. [16] have described the protocol. In Figure 6.1 is the Bluetooth Low Energy protocol stack shown. Information goes form top to bottom and back from one application to another application. Some key features of different layers will be touched upon.

6.1.1 Bottom Layers

The Link Layer directly interfaces the LE Physical Layer (PHY) and manages the connection and link state of the radio. A connection is established after an interplay between an advertiser and scanner. After a connection has been made, a master and slave are defined, where the master manages the connection. One of the matters the master manages in the Link Layer are connection events. During these fixed periodic events, the slave wakes up from a sleep and information can be transferred between the two devices. To every packet, the Link Layer adds a *More Data* bit, which signals if the sender has more information to transmit. Additionally two more bits are added: one Sequence Number and one Next Expected Sequence Number. This provides both a stop-and-wait flow control and an error recovery mechanism. The last information added by the Link Layer are a Cyclic Redundancy Check to allow bit error detection.

The host has hard real-time requirements because of the timing requirements defined by the specification. Many task form the Link Layer are implemented in hardware to gain speed and energy efficiency. The host on the other hand implements a more complex but

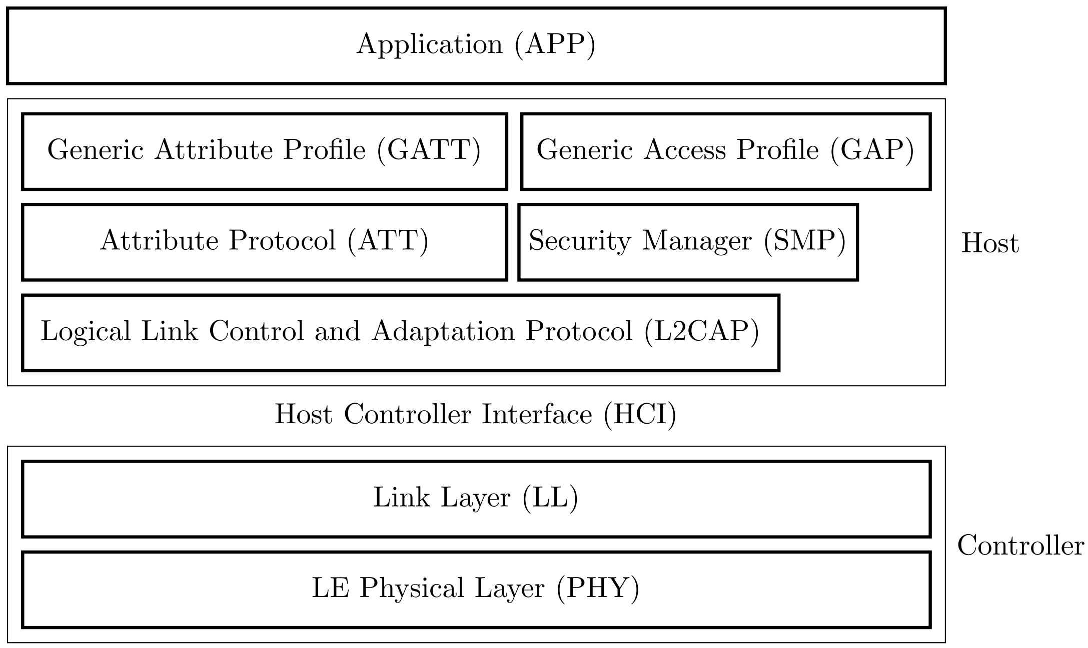


Figure 6.1: Bluetooth Low Energy protocol stack

less timing-stringent protocol stack better suited for more advanced CPUs. The Host Controller interface manages the communication between the host and controller, which goes over UART. It also defines a set of commands, events packet format and rules such as flow control.

The lowest layer of the controller, the Logical Link Control and Adaptation Protocol (L2CAP) has as main function to protocol multiplex the protocols form the upper layers. It directs received packets from the link layer to the right protocol layer. Additionally, it preforms fragmentation and recombination, where data form upper layers is broken up into chucks of 27 bytes which are transferred to the Link Layer.

6.1.2 Attribute Protocol

The Attribute Protocol (ATT) defines a server and client structure. Data is retrieved from a server by a client. In this project, generally, the Breathline acts as a server and the smart device as a client. Each server contains data in the form of attributes.

Attributes are the smallest data entity and contain all user or sensor data, meta data or information about the structure and grouping of different attributes on the server. Each attribute has a unique 16-bit handle, universally unique identifier (UUID), a set of permissions and a value. Handles of an attribute are guaranteed to not change and make the attribute addressable. The type of a attribute defines what kind of data present in the value of the attribute, specified as a UUID. The value of an attribute can take any form, although restricted to 512 bytes. Attributes can be read or written by a client, or the server can send a notification to the client when an attributes value changes. All

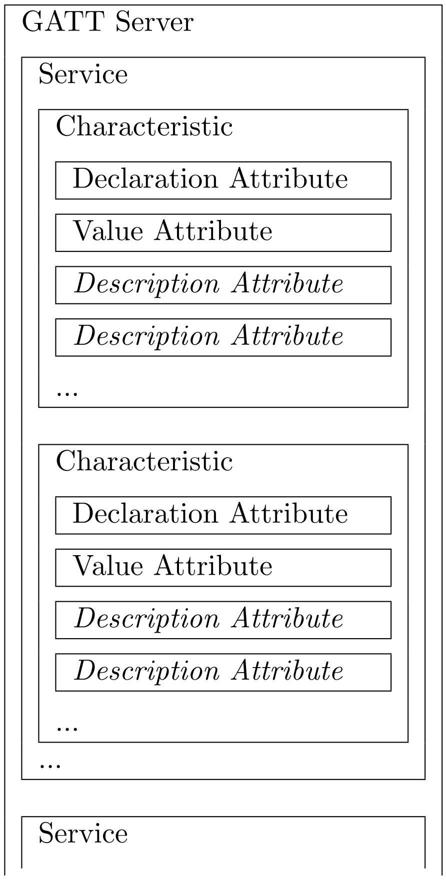


Figure 6.2: GATT hierarchy

these operations can be preformed with or without acknowledgement.

6.1.3 Generic Attribute Profile

The Generic Attribute Profile (GATT) establishes a strict hierarchy to organise attributes in a reusable and practical manner, see Figure 6.2. A characteristic is a container which holds a piece of user or sensor data. A characteristic includes at least two attribute. The first is a characteristic value attribute containing the characteristic value. The second is the characteristic declaration, containing metadata about the value. A characteristic has an UUID which can be referenced by the application on the server or client when reading or writing the attribute value. Table 6.1 show two attributes which can make up one characteristic.

Similar characteristics are grouped into a service. For example, in the Breathline, the characteristics containing the accelerations of the three axes of the accelerometer are grouped in one service.

Handle	Type	Permissions	Value	Value length
0xNNNN	0x2830	Read only	Properties, value handle (0xMMMM), characteristic UUID	5 - 19 bytes
0xMMMM	Charac. UUID	Any	Actual value	Variable

Table 6.1: Characteristic declaration and value attribute [77]

6.1.4 Profile Design

For the Breathline a GATT profile was designed containing characteristics for both sensor and device information. For the sensor information, no standard characteristics or profile designed by the Bluetooth SIG was available. Thus a profile for the RIP sensor and for the Accelerometer was designed. The result can be found in Table 6.2 and 6.3. For both services, a unique UUID was generated with the help of an online tool. The UUIDs form the characteristics are subsequent to the UUID of their service, the first three bytes and a nibble as well as the last twelve bytes are the same.

Table 6.2: RIP Service

UUID:23c81d9a-7729-4b4b-9a38-3c8631e9f2ae

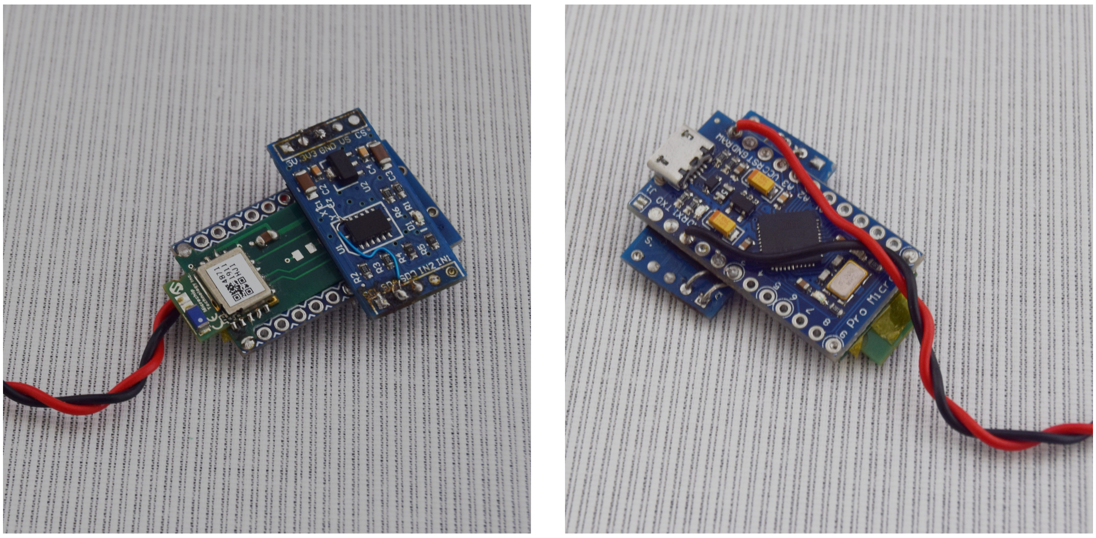
UUID	Name	Permission	Value Format
23c81d9b-...	Band one Frequency	read (notify)	uint16
23c81d9c-...	Band two Frequency	read (notify)	uint16

Table 6.3: Accelerometer Service

UUID:68d5151a-d0ec-4683-80e7-3ca4dd42034d

UUID	Name	Permission	Value Format
68d5151b-...	x-acceleration	read (notify)	sint12
68d5151c-...	y-acceleration	read (notify)	sint12
68d5151d-...	z-acceleration	read (notify)	sint12

Beside these two services also three services related to device information were implemented. The first is the mandatory Generic Access Service which contains a device name and an appearance, indicating the type of device. The other two are a battery service and a service to synchronise time. More information, including UUIDs can be found in Appendix C.



(a) The top with on the left the RN4871 and on the right the ADXL345

(b) On the bottom the Arduino pro micro and power connection

Figure 6.3: The Breathline-like device used in the realisation

6.1.5 RN4871 Programming

In the earlier development of the Breathline, a RN4871 Bluetooth module from Microelectronics was incorporated. This module runs Bluetooth Low Energy version 5.0 and has a special Transparent UART functionality [78]. This functionality allows for "simplified serial data transfers over Bluetooth Low Energy (BTLE) devices ... providing an end-to-end data pipe to another Bluetooth device such as RN4870/71 module or Smartphone" [79, p. 11].

The choice was made to utilise the same module for the development of new and advanced Bluetooth functionality. For this project, Ben Bulsink has prepared an RN4871 module connected to an Arduino pro micro (see Figure 6.3) according to schematics provided by the RN4871 data sheet [78, Fig. 5-4], which allows for easy serial communication. The standard serial communication baud rate between the Arduino and Bluetooth chip was reduced to 38400 Bd because the communication was not reliable at higher rates. The parameters for serial communication between an laptop and the Arduino are shown in Table 6.4, where the baud rate could be defined in the program running on the Arduino. A serial port terminal application such as CoolTerm [80] can be used to set up the RN4871 module with the ASCII commands as defined in the RN4870/71 Bluetooth Low Energy Module User's Guide [79].

Once a serial connection between a computer and the RN4871 is made, the latter can be put into command mode by sending `$$$`. Optionally, an echo mode can be enabled by sending `+` to the chip. Note that, except the command to enable command mode, all commands require a carriage return at the end.

To configure the services and characteristics as designed in previous section, the

Table 6.4: UART serial communication settings

UART setting	value
Baud Rate	9600 Bd
Data Bits	8 bits
Parity	none
Stop Bits	1 bit
Flow Control	disabled

user guide advises to first clear all settings of services and characteristics by sending `PZ`. The first and mandatory characteristic to define is the Device information. This service is added by sending `SS,00`, whereafter the device name and appearance can be set by `SDN,Breathline` or `S-,Breathline` and `SDA,0000` respectively.

The other services and characteristics can be added by first setting the UUID of a service (e.g. `PS,180F` for the battery service) and than setting its characteristics. For setting characteristic, the `PC` command is used which requires three arguments. The first argument is the UUID of the characteristic, the last is an 8-bit value that indicates the maximum data size in octet where the value of the characteristic is held. The second argument is an 8-bit property bitmap of the characteristic, which could include for example indicate (0b00100000), notify (0b00010000), read (0b00000010) and write (0b00000100). Setting the battery level characteristic as specified in Appendix C, is done by sending `PC,2A19,32,01`. The property bitmap for this characteristic is defined as `0x32` which is equal to `0b00110010`, a combination of indicate, notify and write without response. All set services and characteristics can be listed by sending `LS`.

6.2 Android Application

Besides the RN4871 Bluetooth module, a second device was needed to accomplish and test a Bluetooth connection and test its performance. This device is in the previous chapters referred to as the smart device, which can for example be a Windows desktop, Apple iPhone running iOS, GNU/Linux laptop or Android smartphone. The choice has been made to create an initial prototype for this latter platform, because most devices running Android have Bluetooth functionality incorporated and because of the availability of such a device to the author.

The basic fundamentals of an Android application is explained by Developer of Android [81]. An application is written in Java in which the Android framework provides some standard classes referred to as app-components. The four types of app components are activities, services, broadcast receivers and content provider. The first two will be used in the application and will be discussed.

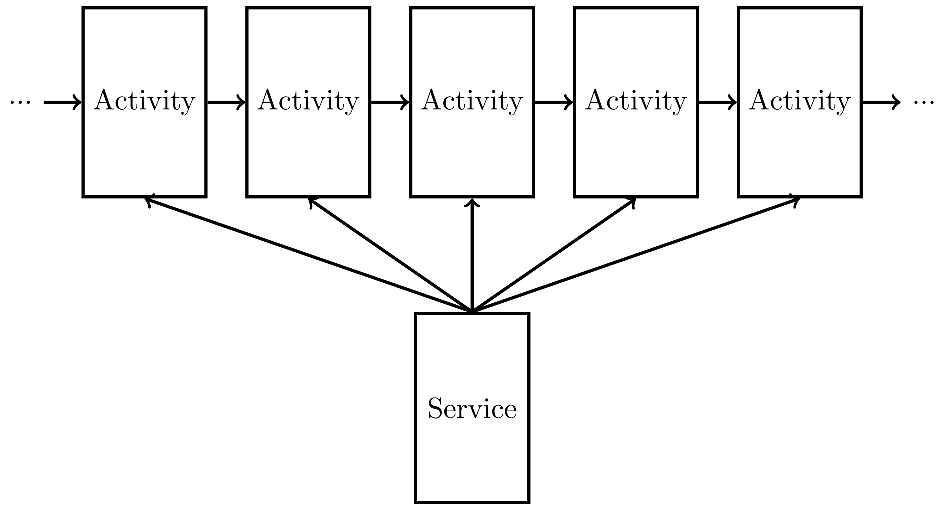


Figure 6.4: A service interacting with multiple activities

6.2.1 Activities

An activity presents the user information and a user interface and handles user interactions. It represents only a single screen and an application typically has multiple to many activities, all independent to each other. An activity also interacts with the system by keeping track of what processes are important for the current user interaction. This also included starting and stopping these processes or keeping them alive when a user is given the availability to return to this process.

6.2.2 Service

A service runs in the background to perform long-running operations. It does not provide a user interface but does provide information or functionality to an activity. This activity can start the service and let it run or bind to itself. However, also other activities can bind and interact with the same service, as illustrated in Figure 6.4. In the application to be developed, a service will be used to interact with the Bluetooth radio in the android device.

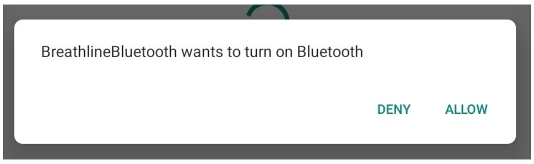
6.2.3 Breathline application

The application created for this project consist of one main activity, supported by a service. The service is based on the *BluetoothLeService* class by Chung [82]. The main activity follows the structure as presented in Figure 5.4. When the application is launched and the first activity (`MainActivity.java`) is loaded, the `onCreate()` is run. In this function the `BluetoothConnectionService` service is created and bound to. Secondly, a check is done if the `bluetoothAdapter` is enabled, which indicates if Bluetooth is enabled or not, and if not, an intend is created asking the user to enable Bluetooth, see Figure 6.5

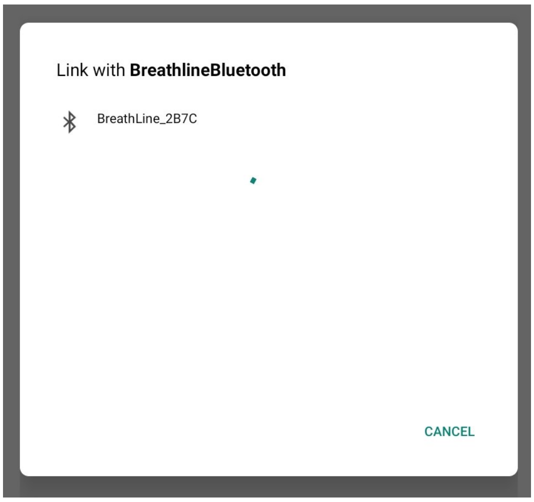
```
if (bluetoothAdapter == null || !bluetoothAdapter.isEnabled()) {
    Intent enableBtIntent = new Intent(BluetoothAdapter.
                                ACTION_REQUEST_ENABLE);
    startActivityForResult(enableBtIntent, REQUEST_ENABLE_BT);

}
```

Figure 6.5: A check if Bluetooth is enabled



(a) Enabling Bluetooth



(b) Select the Breathline

Figure 6.6

and Figure 6.6a.

The third action done in the `onCreate()` function is scanning for nearby Bluetooth Low energy devices. For this, a filter can be applied which filters on parameters such as names, mac-addresses and GATT services. The user is then presented with a list of available devices trough which a connection can be set up as shown in Figure 6.6b. If a connection with a Breathline is made, also the device's MAC-address is returned. This address can be used to connect to the GATT server of the Breathline.

A successful GATT connection, between the Breathline as a server and the Android application as a client, initiates a GATT services discovery process. This returns the available Bluetooth GATT services and its characteristics. In these characteristic objects, information is contained such as a value, permissions and UUID. In the current application, the characteristics for the three axis of the accelerometer are filtered with the help of there UUIDs, for which then notifications are enabled.

Characteristic notifications are enabled and managed by the `BluetoothConnectionService`. In this service, a function called the `setCharacteristicNotification()`, gets the characteristic's notification descriptor and sets this to an `ENABLE_NOTIFICATION_VALUE`. This makes that the Breathline send a notification to the smartphone every time a value is written to the characteristic. This is received by the service, converted to a binary value and forwarded to the `BroadcastReceiver()` in the main activity. The received binary value is then converted to a float and displayed to the user.

6.2.4 Other platforms

A short review was done into the implementation of Bluetooth Low Energy in applications for other platforms. For Universal Windows Platform (UWP) apps, implementation is similar to the Android framework [83]. Apple has different approach by providing a Core Bluetooth framework which provides classes allowing for interaction with Bluetooth Low Energy devices [84]. This framework is made on the basis of centrals and peripherals, in contrast to the GATT profiles and roles used by the other platforms.

6.3 Advertising

In the Bluetooth Low Energy protocol, as shown in Figure 6.1, is the Generic Access Profile (GAP) responsible for device discovery, connection and security establishment. The GAP interacts with multiple layers underneath. Part of this protocol is already touched upon in a previous section, namely the GAP service. This GATT service is mandatory to implement in every device and contains at least the device name and appearance.

6.3.1 Generic Access Profile Modes

Besides providing other Bluetooth devices with the most basic information about its host, can the GAP also put the device in different modes. These modes are related to advertising and setting up a connection. Associated with each mode are roles and procedures. The two roles related to setting up a connection are the central and peripheral. The central is capable of establishing a connection with one or multiple peripherals. Peripherals sends advertising packets to allow centrals to find it and establish a connection with it.

Additional to the modes discussed next, other GAP modes, procedures or functionality include name discovery, parameter updates, connection termination and security settings.

Discovery

"A device's discoverability refers to how the peripheral advertises its presence to other devices and what those devices can or should do with that information." [77, p. 39] A peripheral can be put in a discoverable mode which allows centrals to discover the device. Although common, it is not necessarily to create a connection or exchange data when discovery is done. On the central, discovery procedure can be initiated which starts scanning.

Essentially, these discoverability modes and procedures make the Link Layer start advertising or scanning. When advertising, advertising packets are send on specific advertising channels. When scanning, the device will listen on these channels. Advertising packets can contain information whether the peripheral is connectable, a response is desired or if the packet is directed to a specific device.

Connection

A connection is always initiated by a central. However, for it to be able to connect to a peripheral, the latter should be in a connectable mode. Different modes are available which are all executed by the Link Layer.

In this layer, a connection request is send to the peripheral by the central. If the peripheral replies to this packet, a connection is made. A connection is nothing more than the exchange of data between the two devices at predefined times. These predefined times are determined (but not fixed) by parameters send with the connection request. Parameters included are the time between the beginnings of two consecutive connection events, the number of connections events a peripheral can skip before a connection is considered lost and the maximum time between two received valid data packets before the connection is also considered lost.

6.3.2 Bonding

To conclude this section, a note on the difference in the usage of the terms pairing and bonding. The Security Manager provides support for both of these procedures. When two devices are paired, a temporary security encryption key is exchanged and a secure link is made. After a connection is lost, security keys have to be exchanged again. When bonding, a permanent security key is exchanged (over a paired connection), allowing to quickly set up a secure link in subsequent connections without having to perform a bonding procedure again. Confusingly, setting up a bond on an Android and iOS device is done by performing a pair action.

6.3.3 Breathline Advertising mode

Ben Bulsink indicated that he does not like the idea that any smartphone can connect to the Breathline without any form of verification or user input. Additionally, he indicated that he prefers no buttons on the Breathline. He suggested utilising the accelerometers in the Breathline to initiate a connection process and complete the pairing process. This can, for example, be done by shaking the Breathline.

The RN4871 Bluetooth module can be put directly into advertising mode by sending the `A` command to it.

To detect the shaking, an ADXL345 accelerometer by Analog Devices was connected to the Arduino pro micro with RN4871 module (see Figure 6.3). To interface, an Arduino library developed by Adafruit was used. Also a `shakeDetection()` function shown in Figure 6.7 was implemented, as designed by Yinrow [85].

```
float prevAccel[3] = {0, 0, 0};
bool shakeDetection(float accel[3], float treshold) {
  float shakeSpeed = abs(accel[1] + accel[2] + accel[3] -
                     prevAccel[1] - prevAccel[2] - prevAccel[3]);
  prevAccel = {accel[1], accel[2], accel[3]};
  if (shakeSpeed > treshold) return true;
  return false;
}
```

Figure 6.7: A function to check if the Breathline is shaking

6.4 Conclusion

This chapter outlined the process of designing Bluetooth Low Energy services and characteristics, implementing these in the RN4871 module by Microchip Technology and creating an Android application alongside. Additionally, a function was implemented which could detect shaking of the Breathline device and subsequently put it in advertising mode.

In contrast to the other phases in the Creative Technology Design Process, is the realisation a linear process. However, to conclude if this process was completed satisfying the requirements, an evaluation should take place. This will be done in the next chapter, where not only the requirements will be verified, but also the unique fashion of putting the Breathline in advertising mode will be tested.

Chapter 7

Evaluation

In the evaluation, the designed product is evaluated. In this last phase of the Creative Technology Design Process, it is checked if the product meets the requirements as set in the specification phase. Besides a performance test, a user test is done to validate if potential users understand the developed connection method.

7.1 User Test

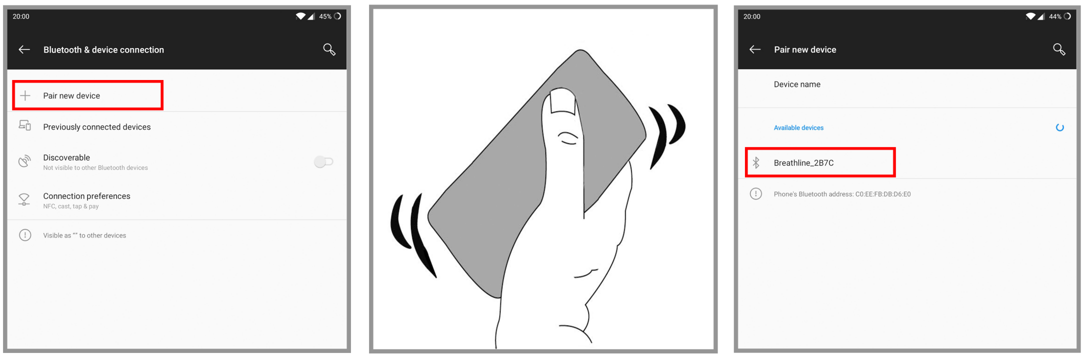
A user test was done in which the ease and intuition of pairing the Breathline with a smartphone is tested. As described in the previous chapter, the Breathline goes into advertising mode by shaking it. This will make it visible in the Bluetooth discovery menu on smartphones. When the user chooses to connect with the Breathline by selecting the device and following the steps presented, a bond is made. Depending on the configuration of the Breathline's Bluetooth chip, this bonding can require additional user input. However, for this user test, this functionality has been disabled. After the Breathline and the smartphone are bonded, information can be exchanged.

For the user test, the participant was given a paper instruction on how to set up a bonded connection between the Breathline and an Android phone, utilising the standard settings application on the phone. The instructions are shown in Figure 7.1.

Before the user test started, the participant was given a brochure and asked to sign an informed consent form, both are included in Appendix D.

7.1.1 During and After the User Test

The participant was observed and asked (and encouraged) to think out loud while following the provided steps. If the participant failed to set up a bonded connection or got stuck in a different way, no guidance was given to investigate what the participant would do in a similar, uncontrolled, event. If this took too long or lead to no success, the participant was asked what he or she would do in such a situation. When the participant indicates quitting as a next action, the participant was given little guidance. If the participant succeeded or chose to quit, the user test was done.



(a) Open your settings, navigate to the Bluetooth settings and press *Pair new device*.

(b) Shake the Breathline until it appears in the list with available devices.

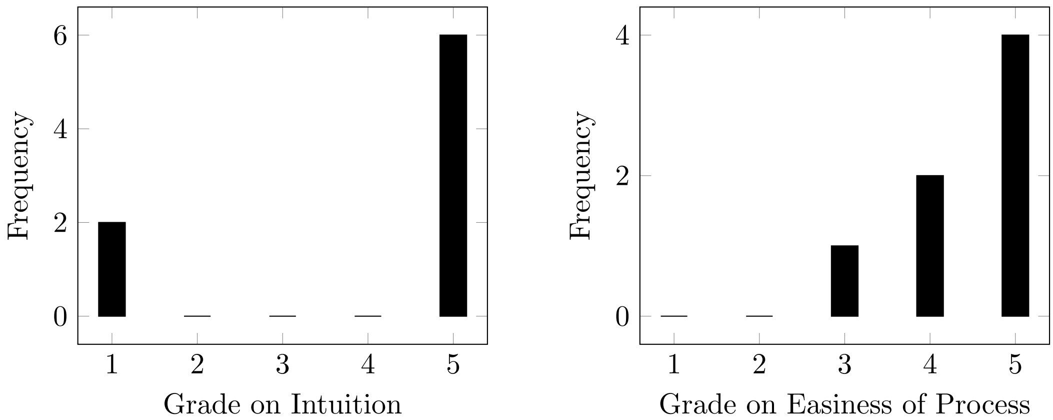
(c) Press the *Breathline_2B7C* to pair. Go back and confirm this device is connected.

Figure 7.1: Instructions for bonding the Breathline with an Android device

After the User Test

When the user test was over, the participant was invited to answer some questions in a semi-structured interview. The questions guiding this interview are shown below. Afterwards, the participant was assisted with unbinding the Breathline device.

1. Could you shortly describe what you just did?
2. Do you think you succeeded in successfully pairing the Breathline wearable with the smartphone? How do you know this?
3. Did you find it intuitively to see that you succeeded (or failed)? Can you give a rating from one to five, where one means extremely counterintuitive and five extremely intuitive?
4. Were you able to follow the provided instructions?
5. Did you find the procedure easy? Can you give a rating from one to five, where one means extremely hard and five extremely easy?
6. Do you think that setting up a connection as you just did is secure? Do you think other people can unwittingly connect to the device, perhaps on accident?
7. What did you think of the way you initiated the connecting process on the Breathline, i.e. shaking the device? Can you compare this to other methods of setting up a Bluetooth connection?
8. How are you used to set up a Bluetooth connection?
9. Do you have any recommendations, suggestions or questions?



(a) Intuition ($N = 8$, $\bar{x} = 4.0$, $\sigma = 1.9$) (b) Easiness ($N = 7$, $\bar{x} = 4.4$, $\sigma = 0.7$)

Figure 7.2: Histograms on the indicated intuition of bonding state and the easiness of the connection process

7.1.2 Findings

In total, eight participants participated in both the user test and the interview. From the participants, two were in the age 50-60 and six in the age 20-25 years old. Because of the COVID-19 pandemic, it was only possible to test with family and friends, this can give some bias. One participant used an iPhone and searched for the Breathline in the Bluetooth Settings. However, Bluetooth Low Energy devices will not appear in these settings and thus this participant was unable to bond. However, this participant's results are included in the findings. The author thinks these are relevant because it shows what a user can do if the device does not appear directly in the list of available devices, and secondly, it can be expected that iPhone users will try to connect to the Breathline trough the settings application.

The participants were asked to give a grading from one to five on how intuitive one can see the bonding was successfully made and grade how easy the total procedure was. The result are shown in Figure 7.2. Two participants indicated that seeing the bonding was successfully was extremely counterintuitive. These users expected more feedback from either their phone or the Breathline. On their phones, the Breathline only changed from the available devices to the saved devices. Interestingly, both of these participants were using a Samsung phone, whereof the screen layouts did not match the images on the explanation. Although the other participants received only the same feedback, their settings application was more outspoken whether a bond was made. The participants found the procedure of establishing a connection mostly easy. Some found it unclear how exactly they were expected to shake the device.

The findings of both the user test and interview are summarised in the points below.

- Six out of eight participants succeeded in bonding the Breathline with their Smartphone.

- Except two, all participants knew for certain if the connection was set up successfully or failed. These are the same participants who grade extremely counterintuitive.
- Participants are not sure how, how hard and for how long to shake the Breathline. Four out of eight explicitly indicated this. This was also visible in their interaction with the device.
- Four participants could already connect to the device before deliberately shaking the device. The threshold of the shaking detection was altered between user tests, trying to find an optimum. For some used settings this had the result that the Breadline would go into advertising mode when only picking it up.
- Five participants indicated that shaking the device felt awkward.
- Three participant said that shaking was not a logical thing to do.
- Two participants indicated that pressing a button would just be as easy. Although one of them said that not having to search for the correct button is convenient.
- One participant thought that initiating the advertisement process by shaking took longer compared to pressing a button.
- Five participants indicated that shaking the device to initiate the advertising process felt secure.
- Four participants preferred having to enter a code before bonding. One pointed out that shaking could also happen unintended, for example when in a bag which is handled rough or when running with the device.
- One participant said that if the device contained personal health data, maybe no Bluetooth connectivity would be preferable at all or at least entering a code should be necessarily.
- Seven of the participants were able to follow the instructions. One said that the images were not matching with the screens on the phone. Only one participant read the full instructions first before starting interacting with the phone or Breathline. Some participants were able to connect the devices without reading the instructions fully.
- One participant said that some feedback on the device was missing, indicating if it was advertising of successfully bonded. A comparison was made with a portable speaker which makes sounds to indicate these events. There was suggested to use a vibration motor in the Breathline, since the user already has the device in its hand.
- Participants tend to keep going trough their settings when the Breathline did not appear immediately or when they thought the devices did not bond, while mostly leaving the Breathline untouched.

7.1.3 Conclusion

Connecting the Breathline to a smartphone by shaking the device to put it in advertising mode is promising. Detecting a shaking movement with the help of accelerometers is possible, however, setting the right threshold is found to be hard. Also, participants did not know how to shake the device and found it uncomfortable. More testing should be done to find the right threshold as input in the function shown in Figure 6.7. In the user test it was found that a threshold of 80 is too high an 30 is too low.

A second concern is the security of this method. Shaking could happen unintentionally which than allows an unwanted device to bond with the Breathline. Either a second security step, such as a bonding code, should be added or another method of putting the Breathline in advertising mode should be implemented.

In general, the tested process of bonding the Breathline to a smartphone was considered intuitive and easy. The difference in the user interfaces of the settings app on different Android phones makes it hard to create one clear explanation. This resulted in the fact that the two participants with a Samsung phone found it counterintuitive whether the device was bonded or not.

7.2 Connection Performance

Also the performance of the connection was tested with the goal of verifying the performance related requirements. There should be noted first however, that the tests done to find the information stated below were done in a uncontrolled home environment and should by no means considered scientific due to the lack lack of professional testing equipment.

In a simple test there was found that at a distance of approximately 10 meters, an Android smartphone was still able to discover and connect to the RN4871 module. This was done indoors with with no other Bluetooth devices but with multiple Wi-Fi networks nearby. Both Bluetooth and Wi-Fi operate in the 2.4 GHz band.

The frequency at which data is measured and send over Bluetooth was tested up to 50 Hz which is approximately equal to a throughput of 1.2 kbit/s. As stated in Chapter 2, the Breathline requires a throughput of 0.8 kbit/s. The Bluetooth protocol sets the theoretical throughput to 1 Mbit/s, but is limited by the RN4871 module. It's datasheet specifies that the maximum throughput is 10 kbit/s. This latter value is not further specified and because of the lack of details in the datasheet, no calculations could be done to further verify this value.

The energy usages was measured by putting a multimeter between the Breathline and a battery. A current of less than 1 mA was found. However, no guarantee can be given that this is truthfulness.

7.3 Reducing energy usage

Although no precise measurements on energy usage could be done, some practices to reduce the energy usage are available. The goal of all these practices is to reduce the time the radio should be on. As already outlined in Chapter 2, the most energy intensive operation is sending and receiving information for which the radio should be turned on. In general, a developer has three instruments to extend the time a Bluetooth device can run on one battery charge. The first is changing parameters in the link layer. As described in the previous chapter, data between two devices is exchanged at predetermined connection events. The connection interval should be refined so connection events only take place as often as new data is available. This, however, is a trade off between transmission speed and energy usage. For advertising and advertising packets, similar parameters can be adjusted. Also this is a concession between the time until a device is discovered and the energy this process uses.

The second feature a developer can play with, is the desire to receive a response after writing or notifying. This is related to different Attribute operations. A read operation always requires two packets to be send: a request from the client to the server and a response back. Notifications however, when enabled by the client, are initiated by the server and send whenever the value of a characteristic changes. Notifications can require a receive confirmation by the client, in which case it is called an indications. This feature ensures successful data transportation but requires the server to keep the radio on after sending a packet until a response is received. For write operations, a similar option is available. A write request expects a response from the server, but a write command does not expect any response or acknowledgement.

The third method is reducing the amount of packets send. The simplest approach is lowering the measurement frequency. Another way can be to misuse the fact that the characteristic value attribute can contain any data in any form. After presenting the designed services to Ben Bulsink, he asked if it was possible to combine all the sensor values of one measurement instance into one characteristic, reducing the overhead needed for communicating four or five characteristic individual. The maximum length of an characteristic value is 512 bytes, which can easily contain the 12 bytes of one measurement packet.

Another approach to reduce packets, is making optimal use of the Maximum Transmission Unit (MTU). This defines the maximum payload of one packet. The MTU value is communicated by the GAP at connection establishment, but is typically 20 bytes. If the maximum size of a characteristic value is set to this value or lower, it can be communicated with only one packet. Again, the 12 bytes of measurement data could easily fit in this. From BLE 4.2, this maximum length is enlarged to 250 bytes [86].

7.4 Discussion

As stated in the introduction of this chapter, the goal was to verify if the requirements (RQ) set in the specification (Chapter 5) were met. The *must have* requirements are

Table 7.1: The set must have requirements and their status

	Requirement	Met
1	Transfer data wirelessly from the Breathline to a Android smartphone.	Yes
2	The Breathline will keep fully working when the wireless connection fails.	Unknown
3	Use Bluetooth Low Energy as communication technique between the Breathline and a smart device.	Yes
4	Send data eight times per second.	Yes*
5	Send packets with a throughput of around 800 bit/s.	Yes*
6	Minimise energy usage due to wireless communication to less than 3 mAh.	Yes*
7	Connection stability is guaranteed up to 8 meters.	Yes*
8	Setting up a wireless connection between the Breathline and a smartphone should only require maximal three simple steps.	No
9	Setting up a connection between the Breathline and a smartphone should succeed in 95% of the times.	No
10	Setting up the wireless connection should be easy.	Yes
11	The user should intuitively see that a connection is established successfully.	Yes

* Due to lack of professional testing equipment, can this not be established with a high degree of certainty.

repeated in Table 7.1.

In the realisation phase, both a minimal Android application was developed and a chip compatible with the Breathline was configured, which were able to communicate sensor data with each other (RQ1). This communication made use of the Bluetooth Low Energy protocol (RQ3). Although the developed system is not implemented in a full Breathline, it is designed to ensure that the Breathline keeps working if no connection with a smart device is made or if a connection is lost (RQ2). However, this depends on the further development of the Breathline.

The requirements related to the stability of the connection (requirements 4 to 7) were discussed in the previous section. Although some experiments gave promising results, no unambiguous conclusion can be given due to the lack of proper testing equipment. However, so far no indications were found that they were not met.

The last four *must have* requirements were checked in a user test. Participants indicated that establishing a connection between the Breathline and a smartphone, by first putting the Breathline in advertising mode trough shaking it, was easy (RQ10). In the user test, only 75% of the users succeeded in connecting the Breathline with their smartphone (RQ9). This requirement should be tested in more depth to rule out if this is due to the specific test group or if the requirement is indeed not met. Most participant also indicated that they found it intuitive to see if the connection was set up successfully

(RQ11). However, two participants found this extremely counterintuitive because their settings menu layout did not match the images in the explanation.

This explanation consisted of three steps (RQ8). However, the activity diagram in Figure 5.4, which is also used in the development of the application, indicate that there are more steps. In practice, these steps could not be combined. However, the total number of steps depend on the starting state of the user's phone.

Furthermore, requirements 14 and 15 are met. Measurement data is shown in in the smartphone app and connection can be set up by utilising the accelerometer in the Breathline. However, this last feature raises some questions about the security of the connection. This should be investigated in more depth and other solutions should be considered.

7.5 Conclusion

In this chapter, both the requirements are verified and an user test is done.

In the user test, the functionality of putting the Breathline in advertising mode by shaking it was tested. Eight friends and family participated, which can give some bias. Some participants were unsure how to to shake. Also, the pictures in the explanations given did not mach for all phones which was confusing for some participants.

However, several valuable insights were gained. The addition of feedback on the Breathline, indicating it is in advertising mode or connected, can make the process more clear. Besides, some users indicated that the ability to connect to the Breathline by only shaking it, felt not secure. Especially if it contained personal health information. Adding an extra security step, such as having to input a code, could take this concern away.

In this chapter, also the developed system was checked against the set requirements. Unfortunately, no professional testing equipment could be used. However, as far as could be determined, the requirements related to the connection speed and stability and energy usage were met. Other requirements were checked in the user test or could already be quickly checked during the realisation. In total, eight out of the eleven *must have* requirements were met. Additionally, two more requirements of other categories were met.

In the end it can be concluded that a prototype of the system defined in the specification phase was created successfully, but that the system is far from fully developed.

Chapter 8

Conclusion

In this chapter, answers will be given to the main research question and its sub-questions, as stated in Chapter 1. But first, the different phases of the Creative Technology Design Process will be revisited.

8.1 Creative Technology Design Process revisited

The majority of this report followed the Creative Technology Design Process, as explained in Chapter 3. This process consists of four phases: the ideation, specification, realisation and evaluation. The results of every phase are shortly reviewed.

8.1.1 Ideation

By doing a stakeholder and iPACT analysis, the design space was explored. This showed that the potential users can have a wide range of technical capabilities and that the most important user interaction is setting up the wireless connection. The design space was further broaden in an interview with Ben Bulsink. This interview was very valuable for the specification phase, but also gave the insight that there were two possible directions in which the project could be continued. These two directions were taken as base for a brainstorm. With the knowledge gained in this brainstorm and after further discussion with both Ben Bulsink and Erik Faber, the decision was made to focus on real-time data communication.

8.1.2 Specification

The specification started with a FICS analysis. After also creating a system architecture, focusing on the communication between the Breathline and a smart device, and making an activity diagram, requirements were set.

8.1.3 Realisation

The requirements from the specification were used in this phase to create a proof-of-concept of a system in which the Breathline communicates sensor measurements to an Android application. To accomplish this, first a design for a GATT services was made. These were implemented in a Bluetooth module made by Microchip Technology. In parallel, an Application was developed in the Android framework.

The last job in this phase was adding a functionality which puts the Breathline in advertising mode. With the desire of not adding extra input features on the Breathline, the idea rose of setting the device in this advertising mode by letting the user shake it.

8.1.4 Evaluation

In the last phase, the feature of shaking the Breathline to put it in advertising mode was user tested. It was found that this functionality is promising, but attention should be paid to the security of it. In the evaluation, also the the requirements set in the specification were tested. Not all requirements could be tested to satisfaction, but those that could be tested mostly met the requirements.

8.2 Conclusion

For all sub-research questions and the main research question, an answer will be formulated.

What information does the Breathline measure and store, and in which form?

The Breathline contains two sensors, a RIP sensor and an accelerometer. Measurements from these sensors are stored with a sample rate of four or eight times per second in packets that also contain the current time. Each packet is 12 bytes in size. The storage on the Breathline is 8 MB and can store measurements for up to 23 or 46 hours depending on the sample rate.

In a future version of the Breathline, the measurement data will first be analysed and summarised on the Breathline, whereafter it is communicated to a smart device. Such summary will be created throughout the day and stored in a storage on the Breathline device. This storage should be read by the wireless data transferring protocol and as a whole transferred to the smart device.

How is the Breathline used and is there an added value to a wireless connection?

The idea for the Breathline originates form Parviz Sassanian, who wishes to use the Breathline with his patients. However, the target group of the Breathline is much wider than that, and includes everyone who wants to improve their health or conquer mental problems with the help of breathing.

In a brainstorm, different implementations of communication were given to the participants. The participants came up with unique use-cases for each of these implementations. Real-time wireless communication would primarily advance the possibilities for feedback. The user would know if the device is installed and working properly. But also, real-time feedback gives the opportunity to create interactive breathing training's on the smartphone.

However, it is not ruled out that (part of the) feedback could also be implemented in the Breathline device itself.

How can wearables communicate wirelessly with smart devices?

A full comparison of different wireless technologies is done in Chapter 2. In short, two techniques are most suitable for wearables such as the Breathline: ZigBee and Bluetooth Low Energy. Because of its characteristics, wide availability in smartphones and because it is the only technology used by similar products, Bluetooth Low Energy is chosen.

To implement BLE, a Bluetooth chip is connected to the Breathline. Services and characteristics are designed and programmed on this chip. An accompanying application is programmed for a smart device, specifically an Android phone. Trough the characteristics, sensor values can be passed from the Breathline to the smartphone, either on bases of notifying or with read requests. Also information can be send from the smartphone to the Breathline.

At what time interval should the information be transferred to facilitate real-time displaying of measurement data?

The Breathline gathers sensor data at four or eight hertz. With measurement data packets of 12 bytes. This requires a maximum of 768 bit/s. BLE has a theoretical maximum throughput of 1 Mbit/s, but this is practically limited by the Bluetooth chip used. According to its data sheet, the limit for the RN4871 is 10 kbit/s.

Configuring the BLE connection, it is a balancing act between higher speed communication and lower energy usage. In a discussion with Ben Bulsink, he indicated that no strict goal is set related to this choice.

To conclude, no definite answer can be given to this question, but the rate of 8 Hz is used throughout this project.

Which requirements should be met to guarantee a stable connection?

In Chapter 5, requirements were set to ensure a stable connection. This includes a throughput of minimal 0.8 bit/s, battery usage of maximum 3 mAh and a coverage of at least 8 m. Not all requirements can be verified with complete certainty, because of the lack of proper equipment. But in practical experiments no indications were found that they were not met. Additionally, according to the BLE specification, it is possible to meet them all.

The main research question was:

How can the data communication of the Breathline breathing wearable be made wirelessly to facilitate real-time displaying of measurement data on smart devices?

The final question to answer is the research question. In short, the Breathline can be made wirelessly to facilitate real-time data communication by using Bluetooth Low Energy. This technique is most suitable for this use-case and can be implemented in both the Breathline and most common smart devices.

In this project, a working prototype has been created of a system in which a Breathline-like device and an Android application can communicate sensor information gathered by the Breathline in real-time. Next to this, a functionality has been implemented of initiating a connection process by shaking the Breathline device, contrasting conventional advertisement initiation methods. User testing has shown that this last functionality is promising, but attention should be given to security concerns.

Chapter 9

Future Work

This chapter discusses interesting topic discovered during this project, requirements which were not met or issues found which all fall outside the scope of this project. These can all be the starting point of future work.

Non real-time communication

Although the goal of the project was to create a real-time wireless connection for the Breathline, this is only useful during the development phase of this product. In this development phase, measurement data can be retrieved directly form the Breathline on a computer so analysing algorithms and feedback mechanisms can be developed. The end goal is to implement these functions on the Breathline itself, which makes real-time communication obsolete. At that point, only summarised data has to be retrieved at moments further apart. The whole research and development done in this project should then be redone with this new goal in mind. Techniques such as NFC become interesting for this new device.

Also, a feature in Bluetooth Low Energy called LE credit based flow control mode can be interesting for this use-case.

Performance Testing and Energy Usage

As already indicated in the evaluation, no appropriate equipment was available to test the maximum performance of the developed products. It would be interesting to test what maximum transmission speeds the hardware is capable of and thinker about the possibilities this gives. Also, by tuning the connection parameters and combining or altering characteristics, lower energy consumption should be achievable. To what limit this can be pushed is interesting to investigate.

Additionally, the RN4871 Bluetooth module by Miro Electronics has different energy saving modes, as described in Appendix C of its user manual [79]. The full capabilities of these modes and there influences on battery usage have not been explored yet.

Other Bluetooth Chips

The RN4871 has a scripting feature in which tasks or functions can be embedded in the Bluetooth chip, utilising the GPIO pins available on the the chip. This function and the available GPIO pins are limited on this chip, but another chip in the same series, the RN4870, has more advanced features. This could be used to implement some, or all, tasks now done by the MCU. This could result in a more stable and energy efficient system and may make the MCU redundant.

Also, an issue found while working with the RN4871 is that putting it in command mode can be challenging. Unfortunately, this has to be done every power cycle. This makes it hard to create a stable system with this Bluetooth chip. The author has also experienced that this chip would sometimes do an unexpected factory reset for an unknown reason. In online fora, other developers also endorse this behaviour of the RN4870/71.

A comparison with other chips should be made to find other suitable candidate Bluetooth chips. In this comparison, features such as Bluetooth version, available communication protocols, energy usage and development support should be included.

Secure Advertisement

As concluded in the evaluation, putting the Breathline in advertising mode by shaking it is a promising and novel feature. However, the security of the pairing process when using this feature is not yet guaranteed. Especially because the device gathers personal health related information. Requiring a password or code before pairing or bonding the Breathline with a smart device would be a good step in the right direction.

Also, more research should be done on how the Breathline is handled throughout the day. Results of this can be used to set the right threshold for what movements is considered as shaking.

Development of Applications

Only the beginning has been made with the development of an Android application. As outlined in Chapter 6, applications for other platforms have to be developed separately. Still a lot of work can be done for this part of the development of the Breathline.

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Appendix A

Interview Questions with Ben Bulsink

A short document as introduction and preparations for the interview and brainstorm with Ben Bulsink.

A.1 Questions

Questions to guide a unstructured interview with the goal of getting wishes and ideas of Ben clear and setting some technical requirements.

1. The Breathline has multiple use cases such as support training with real-time feedback or continues tracking throughout the day. The former requires real-time data transfer, in the later case it may be preferred to only poll for data periodically, demanding a buffer storage. What is your view and preference on this matter?
2. Should both the Breathline and app keep working when a connection is lost?
3. Currently the Breathline does not have any user input capability. Do you mind if a button for setting up Bluetooth pairing is added?
4. BLE allows for a wide verity of parameter configurations influencing on the one side data transfer rate and on the other side battery life. What is the desired balance in this? Does the user need to have influence on this, either direct or indirect?
5. Do you have any comment on the safety of data transfer and affairs such as encryption?
6. Some ways of implementing BLE may require pre-processing. Is that a problem?
7. Do you want to keep wired connections available?

Appendix B

Online Brainstorming Session

B.1 Introduction

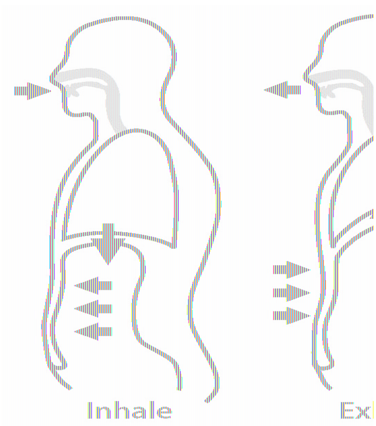
Introduction

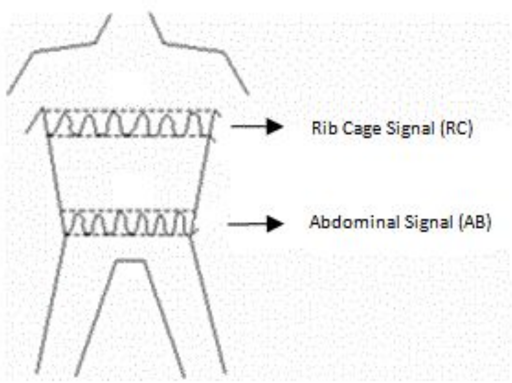
Studies have shown that diaphragmatic breathing (Middenrifademhaling, see the first figure) positively influences both physical and mental wellbeing, by reducing perceived stress, anxiety, and depression symptoms. Correct diaphragmatic breathing can be trained under supervision of a specialist. However, such training sessions only take place a limited times a week. To facilitate also training and monitoring or tracking breathing the rest of the time, a device has been developed, the Breathline.

The Breathline makes use of a technique where two bands are put around the user's belly and chest (see the second picture). The expansion in these two areas can be measured and breathing patterns can be distinct and tracked.

Currently, the Breathline can store breathing data, from throughout the day, in a storage on the device. At the end of the day, the Breathline can be connected to a PC with a USB cable and the data can be retrieved after which it can be analysed.

Now, the main developer wishes to add wireless functionality to the Breathline. This can be done in a variety of ways and can allow for new functionality. That is what I would like to discuss in this online brainstorm.





1

Brainstorm Setup

Unfortunately, due to the current situation around the COVID-19 pandemic brainstorms can not be done in the usual way.

In this brainstorming form, you can make a slide per idea in response to the problems stated on the next slide. You can use (at max) this bigger text box to explain your idea, add pictures, videos, drawings, etc. Feel free to add as many ideas as you wish.

The textbox at the bottom of each page can be used by other participants to respond, react or add to an idea. Additionally, comments may be used to respond to specific parts of an idea. I would kindly ask you to not only add ideas but also check out other ideas and respond to this. When possible, try to visit this site again later to interact with responses on your ideas or remarks.

As usual, avoid wearing the black hat. In other words, please keep a positive and creative vibe and only add to an idea instead of pointing out problems or issues of it.

I really appreciate your participation in this brainstorm, every contribution helps! Please send me a message if you did, I will buy you a KitKat, Snicker or beer when I am allowed again.

The brainstorm will be open till Tuesday the 19th around noon. If you have any questions, message me via t.t.smit@student.utwente.n.

Thank you very much! - Tijmen Smit

2

Problems to Discuss

In an earlier brainstorm, two ways of implementing wireless functionality has been found. Data could be transferred real-time from the Breathline to a phone or computer allowing for the user to directly view data and get feedback.

A second way is that data analysis takes place on the Breathline device and only a summary of ones breathing behaviour from one day is transferred to and presented on a phone or computer. This is like the current functionality with a USB connection.

Thus, three situations occur: wired bulk data transfer, real-time wireless, wireless bulk data offloading.

Think of yourself as a user of the Breathline or compare it to using other health trackers such as a heart rate monitor or step counter. Think of each implementation of data transfer of a separate Breathline product and generate ideas related to the following questions:

- How could the implementation contribute to the functionality of the Breathline?
- What functionality can be added uniquely to this implementation?
- How can an implementation be realized technically?
- What are advantages related to this implementation?

The last part consist of free idea generation where you can let your imagination flow free on all concepts related to the Breathline.

3

B.2 Implementation 1

Simplicity

If data from the Breathline can only be retrieved using a USB cable with plug-and-play not much can go wrong. No hassle with setting up and configuring a wireless connection. This can even work on a phone.

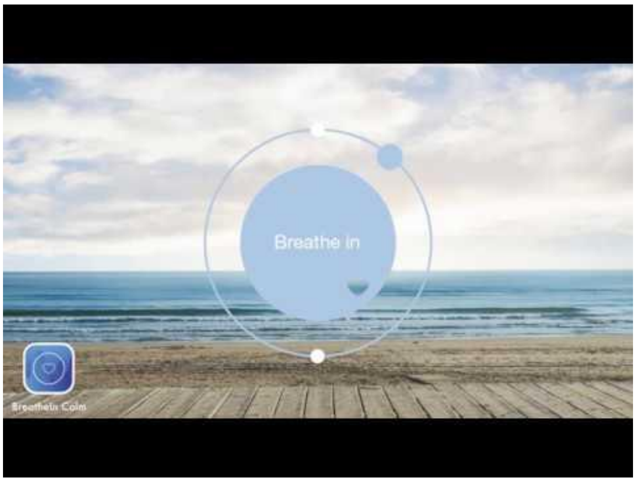
PB: the usage of a phone in this instance with the help of a OTG cable is a nice concept of thinking outside the box to make the system “wireless” or better named moveable. Possible downsides are the wires causing restrictions of movement.

5

B.3 Implementation 2

Real time games

Correct breathing can be trained using real time interaction on the phone with games. For example, the exercise shown in the video below can be made interactive. Or other more fun games can be added which respond to your breathing.



PB: The implementation of real time animations and gifs can be used to influence the breathing in a positive ways. Think about using a standard animation that is played "and overlaying" another animation with the real time data from the breathing. Downsides could be being distracted by the animation. However it could thus also be used as a stimuli to breath in accordance with animations. (Implementation ideas HID bluetooth modules connecting to computers and phones)

7

B.4 Implementation 3

Focus on breathing

On of the arguments given in advantage for not giving real time feedback is that the user can than focus on his or her breathing instead of having to keep an eye on the phone and getting distracted by other apps.

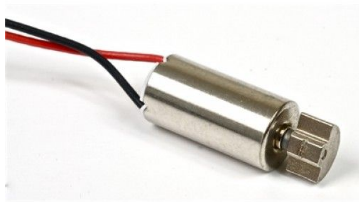
PB: the focussing on breathing seems to be the main goal. However the visualisation of data is not the only important aspect. You could make an interactive applet which uses the breathline as controller. This would mean that someone is more connnected to their breathing to influence the situation on the screen.

When one would use wired bulk off loading, it could only be to later visualize the effort put into the breathing. This would be reminiscent of things like Garmin devices that could track running and such (Strava, Garmin, etc.)

9

Real time feedback in the Breathline

When data is processed on the Breathline, real time feedback can be provided by sound of vibrations from the Breathline self.



PB: Dependent on the usage of vibrational motors and sounds, it could be very distractive. (pretty sure my lungs don't vibrate when breathing, could be too "unnatural")

10

Appendix C

GATT design

C.1 Service Design

C.1.1 Generic Access Service

UUID:1800

UUID	Name	Permission	Fields	Values
2A01	Device Name	read (write)	Name	
2A01	Appearance	read	Category	16bit:0

C.1.2 Battery Service

UUID:180F

UUID	Name	Permission	Fields	Values
2A19	Battery Level	read (notify)	Level	uint8:0-100

C.1.3 Current Time Service

UUID:1805

UUID	Name	Permission	Fields	Values
2A2B	Current Time	read (write) notify	Exact Time 256, Adjust Reason	-, 8bit:1100
2A14	Refference Time Information	Read	Source, Accuracy, Day Since Update, Hour Since Update	-,-,uint8, uint8

C.1.4 RIP Service

UUID:23c81d9a-7729-4b4b-9a38-3c8631e9f2ae

UUID	Name	Permission	Fields	Values
23c81d9b-...	Band one Frequency	read (notify)	Frequency	uint16
23c81d9c-...	Band two Frequency	read (notify)	Frequency	uint16

C.1.5 Accelerometer Service

UUID:68d5151a-d0ec-4683-80e7-3ca4dd42034d

UUID	Name	Permission	Fields	Values
68d5151b-...	x-acceleration	read (notify)	proper acceleration	sint12
68d5151c-...	y-acceleration	read (notify)	proper acceleration	sint12
68d5151d-...	z-acceleration	read (notify)	proper acceleration	sint12

C.2 RN4871 Full Configuration Commands

```
# Setup default services
PZ
SS,00

# Battery Service
PS,180F
PC,2A19,32,01

# Current Time Service
PS,1805
PC,2A2B,0E,02
PC,2A14,0E,04

# RIP sensor
PS,23c81d9a77294b4b9a383c8631e9f2ae
PC,23c81d9b77294b4b9a383c8631e9f2ae,32,02
PC,23c81d9c77294b4b9a383c8631e9f2ae,32,02

# Accelerometer
PS,68d5151ad0ec468380e73ca4dd42034d
PC,68d5151bd0ec468380e73ca4dd42034d,32,02
PC,68d5151cd0ec468380e73ca4dd42034d,32,02
PC,68d5151dd0ec468380e73ca4dd42034d,32,02

# Reboot
R,1

# Result:
CMD> LS
1805
  2A2B,0072,0A
  2A14,0074,0A
180F
  2A19,0092,02
  2A19,0093,10,0
23C81D9A77294B4B9A383C8631E9F2AE
  23C81D9B77294B4B9A383C8631E9F2AE,00B2,02
  23C81D9B77294B4B9A383C8631E9F2AE,00B3,10,0
  23C81D9C77294B4B9A383C8631E9F2AE,00B5,02
  23C81D9C77294B4B9A383C8631E9F2AE,00B6,10,0
68D5151AD0EC468380E73CA4DD42034D
  68D5151BD0EC468380E73CA4DD42034D,00D2,02
  68D5151BD0EC468380E73CA4DD42034D,00D3,10,0
  68D5151CD0EC468380E73CA4DD42034D,00D5,02
  68D5151CD0EC468380E73CA4DD42034D,00D6,10,0
  68D5151DD0EC468380E73CA4DD42034D,00D8,02
  68D5151DD0EC468380E73CA4DD42034D,00D9,10,0
END
```

Appendix D

User Test Brochure and Informed Consent Form

Information Brochure

In this research the participant is asked to preform one or multiple tasks related to setting up a wireless connection between a smartphone and a provided wearable device. Both succession and failure of requested actions are considered valuable for the research. The participant is asked to use its own smartphone when possible. Participating or failing to set up a connection will not change anything on this phone. Afterwards some follow up questions will be asked.

The purpose of this research is to test if participants understand the procedure of setting up a wireless connection between the designed wearable and a device they are familiar with.

Findings and answers will be processed anonymously. Findings will be presented in a generalized manner. In case the researcher wishes to use a directly quote, additional approval will be asked. No data will be disclosed to third parties without the permission of the subject.

Participation can be withdrawn at any moment without giving a reason. This can be done during or after (withing 24 hours) the experiment or interview. Findings from both the user test and interview (when applicable) will be removed and will not be used in an evaluation.

For questions please contact:

Tijmen Smit
[redacted]
t.t.smit@student.utwente.nl

Complains about this research can be directed to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente:

drs. P. de Willigen
P.O. Box 217
7500 AE Enschede (NL)
+31534892085
ethics-comm-ewi@utwente.nl

Informed Consent Form

'By signing this form, I declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the provided brochure. My questions have been answered to my satisfaction. I agree to participate in this research of my own free will. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission.'

To request further information about the research, now or in the future, contact Tijmen Smit. If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente.

Signed in duplicate:

....	....
Name participant	*Signature participant*
....	....
Name researcher	*Signature researcher*