Smart Companion Pillow – An EPS@ISEP 2019 Project

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Abstract. This paper describes the design and development of a Smart Companion Pillow, named bGuard, designed by a multinational and multidisciplinary team enrolled in the European Project Semester (EPS) at Instituto Superior de Engenharia do Porto (ISEP) in the spring of 2019. Nowadays parents spend most of the day at work and become naturally worried about the well-being of their young children, specially babies. The aim of bGuard is to provide a 24-hour remotely accessible baby monitoring service, contributing to reduce parenting stress. The team, based on the survey of related products as well as on marketing, sustainability, ethics and deontology analyses, developed a remotely interactive Smart Companion Pillow to monitor the baby's health and room air quality. The collected data, once it is saved on an Internet of Things (IoT) platform, becomes remotely accessible. The bGuard pillow, thanks to its shape, reduces the risk of the baby rolling from back to tummy, lowering the risk of Sudden Infant Death Syndrome (SIDS).

Keywords: Baby Well-Being, Parent Stress Relief, Room Air Quality, Smart Pillow, Sudden Infant Death Syndrome

1 Introduction

The bGuard smart companion pillow was an EPS@ISEP project [1] developed by a team of undergraduate students in the spring of 2019. The team was composed by students from different study fields and countries as follows: biomedical engineering from Germany; electrical engineering from Estonia; mechanical engineering from Germany and Portugal, industrial product engineering from Netherlands and product development from Belgium. This project provided the team with the opportunity to create an out-of-the-box object while contributing to infant and parent well-being.

Parents are always worried about the health of their children. According to a study looking into the parental worries of 2000 parents conducted by OnePoll in conjunction with Lice Clinics of America [2], the average parents worry about their children around 37 h a week. In addition, according to the American Academy of Pediatrics, SIDS remains unsolved [3]. As referred by Kinney and Bradley [4] and the National Institute of Child Health and Human Development of the United States of America [5], the biggest risk factors of SIDS are the sleeping of the baby on the stomach or side, overheating, exposure to tobacco smoke and bed sharing. Therefore, the problem statement of the project focus on worried parents and SIDS.

Based on the problem statement, the objectives of this project are to lower the risk of SIDS and parent stress by monitoring the baby's sleeping environment. The next chapters report the teamwork performed to achieve these objectives.

This document includes a background section, where related projects, marketing, sustainability, ethics and deontology analyses are presented. Then, the design and development are explained. Afterwards, planned functional tests are described. Finally, the conclusions of the project are summarised.

2 Background

The background studies, which included a survey on related products together with marketing, sustainability and ethics analyses, allowed the team to derive bGuard's requirements.

2.1 Related Products

The survey on domestic products addressing the monitoring of the room environment and vital signs, sleep and motion of babies contemplated:

- **Smart Pillows** are designed to improve the quality of the night rest. The more advanced pillows, like the iSense Sleep [6] contain sensors that monitor the pulse and respiratory rate. These pillows are often considered as gadgets because they include built-in speakers for streaming music or playing audio books as is the case of ZEEQ [7] and Sunrise [8].
- **Sleep Trackers** are focused on giving detailed information about sleeping patterns. Smart pillows are often equipped with a sleep tracker. These devices come in different forms such as wearable accessories (Fitbit Versa [9]), bed accessories (Withings Sleep [10]) or bed-side accessories (S+ [11]). They track the different sleep stages, the duration of sleep and overall sleep quality. The researched products also measure the pulse of the user.
- **Environment Monitors** gather information about their location. Although the market has a wide offer, this study selected three types of contact-less monitors: GLOCO, Sense Sleep, and Withings Aura. GLOCO [12] monitors temperature, humidity, and carbon monoxide levels of the child's room. It consists of a home station, which indicates when something is wrong, and an

app with additional information. The Sense Sleep [13] and Withings Aura [14] monitor the room conditions, the sleeping pattern and give advice on how to improve them.

– **Baby Monitors** are focused on the baby well-being. They monitor aspects such as temperature, movement and respiration of the baby. This is the case of Owlet [15], Nanit Plus [16] and Sproutling [17]. In addition, Sproutling alerts when the baby rolls over during sleep and Nanit Plus displays live images of the child.

Table 1 compares the products analysed, ordered by category. According to

Table 1. Product Comparison

				Room			
Category	**Product**	**Media**[a]	**Pulse** (bpm[c])	**RH**[b] (%)	**Temp.** (°C)	**CO_2** (ppm[d])	**App**
Smart Pillows	ZEEQ	✓					✓
	Sunrise	✓					✓
	iSense Sleep		✓				✓
Sleep Trackers	Withings Sleep		✓				✓
	S+		✓		✓		✓
	Fitbit Versa		✓				✓
Environment Monitors	Sense Sleep	✓		✓	✓		✓
	GLOCO			✓	✓		✓
	Withings Aura	✓	✓		✓		✓
Baby Monitors	Owlet		✓				✓
	Nanit Plus	✓		✓	✓		✓
	Sproutling			✓	✓		✓

[a] Image, Music, Sound or Video
[b] Relative Humidity
[c] beats / minute
[d] parts / million

this research, the market lacks devices which, simultaneously, reduce the risk of rolling from back to tummy, allow interaction, monitor the health of the baby, measure the room air quality and provide access to all this information through a mobile application. Taking into account these findings, the team embraced the concept of a four in one product for babies: (*i*) pillow with a special shape (to reduce the risk of rolling); (*ii*) microphone and speaker integrated in the pillow; (*iii*) pulse sensor incorporated in the sock; and (*iv*) room sensors (temperature, relative humidity (RH) and CO_2) in the home station. To contribute to relief the stress of parents, the team chose to create a mobile application to display the collected data and allow remote interaction.

2.2 Marketing

The saying "Customers do not buy products, they buy benefits" was the motto of the team. Concerning the psychological segmentation, nowadays, parents worry considerably about the well-being of their children [2]. Consequently, bGuard aims to lower the stress of parents by providing remote access to the baby's health and environment parameters. The benefits provided by bGuard comprise lower risk of SIDS, sleeping environment quality monitoring and parenting stress relief. Thus, the proposed promotional claim is "Sleepcurity for your baby".

bGuard was positioned with the help of the Porter model [18]. This model describes three different strategies a company can use from an outside-in point of view: cost leadership, differentiation and focus strategy. The target group is concerned parents (25 to 35 years), ranging from middle-class through upper-class, who were raised with technology and constantly rely on their smartphone. The team decided on differentiating the product compared to its competitors by creating a unique product combination. bGuard stands out from the crowd, inducing potential customers to pay more.

The four P marketing mix [19], which considers Product, Price, Place and Promotion, has been followed. First, bGuard is a pillow with a special shape to reduce the risk of rolling from back to tummy, with a speaker to sooth the baby when crying, a sock to measure the baby's pulse and a home station to monitor room air quality. The combination of all these elements makes it a unique Product in the market. Secondly, most of the comparable products vary between 113.00 € and 313.00 €. The estimated Price should be around 249.00 €. Being a smart product, the target group should be familiar with online shopping. Thus, in terms of Place, bGuard should only be sold through its website, saving money negotiating with large retail shops or re-sellers. Finally, advertisement on the Internet and social media will be considered for Promotion.

On the whole, bGuard will be promoted on the Internet and social media, sold on its own website and, due to its unique combination of features, the target group will be willing to pay 249.00 € for its benefits.

2.3 Sustainability

The team considered the 3 Pillars of Sustainability [20], the 12 Principles of Green Engineering [21] as well as the Good Health and Well-Being, Industry, Innovation and Infrastructure and Responsible Consumption and Production Sustainable Development Goals defined by the United Nations Educational, Scientific and Cultural Organization (UNESCO) [22]. Finally, the Life Cycle Analysis [23] was performed.

All bGuard parts were thought to fulfil these sets of principles. Firstly, the parts on the home station, the pillow and the sock are easily disassembled, allowing the maintenance of electronic components and part recycling. The main raw material of the home station - Acrylonitrile Butadiene Styrene (ABS), is recyclable up to 99 % [24]. A further advantage of the home station, once the baby grows, is that it outlives the pillow and the sock since it will keep on monitoring

the room air quality - temperature, humidity and CO_2. Secondly, the cover textiles of the pillow and sock are made in Lyocell (Tencel) [25,26] fabrics that are naturally biodegradable. During manufacturing, 99 % of the water and non-toxic solvents are recyclable, resulting in an eco-friendly production. Thirdly, the foam of the pillow is certified with OEKO-TEX STANDARD 100 [27], class I, which corresponds to the strictest baby requirements. This certified foam contributes to high and effective product safety.

Thus, bGuard will contribute to relieve the stress of the parents and improve the quality of life of the family with minimum waste over its life cycle, without jeopardising the needs of future generations.

2.4 Ethics and Deontology

Ethical issues inevitably arise when developing a product. Engineering Ethics [28], Sales and Marketing Ethics [29], Environmental Ethics [30] and Liability [31,32,33,34,35] help to deliver a safe and environmentally friendly product both for the users and the world. Objectively, this means the team wants to limit the commercialisation of the product to the European market in order to keep the footprint small, work with local providers and design according to the Design for Disassembly (DfD) [36] principles. Furthermore, bGuard wants to deliver a safe and user-friendly product. The aim is to ensure that users and manufacturers are guarded from dangers and liabilities, respectively. To help the user, bGuard is to be shipped with a manual detailing operation and maintenance instructions. Last but not least, the team envisages launching marketing campaigns to build a realistic image and promote this solution.

Above all, bGuard wants to be safe and live up to customer expectations.

3 Design and Development

Based on the conducted background studies, the team defined the design, concept and proceeded with the development of the bGuard proof-of-concept prototype.

3.1 Design

Figure 1 displays the bGuard design, which was driven by safety, sustainability and aesthetics concerns.

The pillow and the sock are covered with Lyocell (Tencel) [25,26]. Lyocell is a breathable hygienic material, which means it is less prone to the growth of bacteria. The pillow has two side bumpers to reduce the risk of rolling from back to tummy. These side bumpers are made of polyurethane foam. The home station, to avoid sharp angles, has a round shape. In terms of sustainability, bGuard was designed according to the DfD [36] principles like, for instance, the manual screwing of the home station parts. This means that when the product is at the end of its life it can be easily disassembled and the parts recycled. Considering the aesthetics, the home station has a clean look, presenting a smooth and bright surface made of ABS.

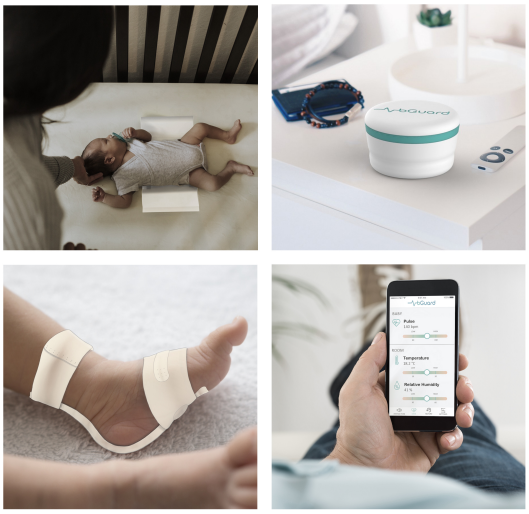

Fig. 1. bGuard Design

As a result, bGuard will be a safe, eco-friendly and attractive product.

3.2 Concept

Fig. 2 displays the bGuard concept with the sock and the pillow on the left, the home station in the middle and the IoT platform and mobile application on the right.

The smart pillow has two side bumpers to minimise the risk of the baby rolling from back to tummy. One of the bumpers contains a micro-controller, a battery, a microphone, an MP3 player and a speaker. This equipment allows the pillow to play music or voice recordings when the baby cries. In the case of the end product, the sock integrates a pulse sensor, a small battery and a thin micro-controller. In the case of the prototype, the sock pulse sensor is wired to the micro-controller of the pillow.

The home station measures the room temperature, humidity and CO_2, the sock reads the pulse of the baby and the pillow records the sound of the baby. The data collected by the sock and pillow are sent to the home station through a Bluetooth link and the home station sends all the gathered data to the IoT platform through a Wi-Fi link.

Finally, the baby and room data can be monitored online and seen on a smartphone. When the measured values are outside the predefined ranges, a notification is sent by the mobile app. Because of the limited time, the app will not be developed for the prototype. Nevertheless, the measurements will be monitored on the IoT Platform to prove the concept.

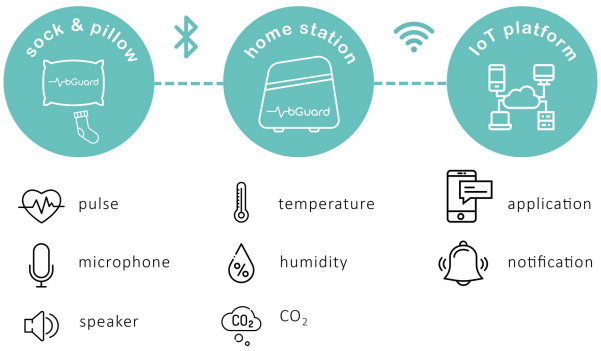

Fig. 2. Concept of the Prototype

3.3 Development

The development of bGuard, a four in one product for babies, was a great challenge for the team not only in technological but also in design terms. The home station has to allow ventilation for the sensors to measure the air quality, the pulse sensor has to be encapsulated inside the sock and the pillow must be covered with a waterproof and sound permeable textile to protect simultaneously from the potential spillage of liquids and to allow the microphone and the speaker to work properly. Fig. 3 depicts the final prototype with the smart sock, the smart pillow and the 3D printed home station.

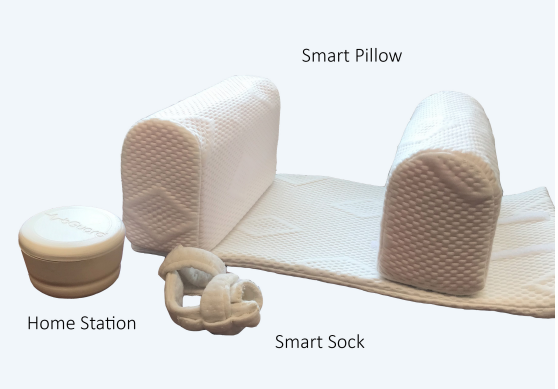

Fig. 3. Final Proof-of-Concept Prototype

Once the connection with the IoT platform is established, it is possible to access and monitor remotely all sensor readings (Fig. 4).

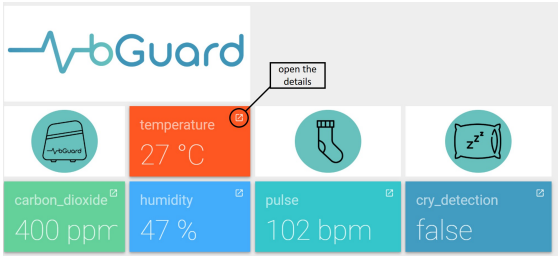

Fig. 4. IoT Dashboard

All things considered, the design and development decisions, which took into account ethics, sustainability, marketing and the state of the art, resulted in the creation of a real scale proof-of-concept prototype.

4 Tests and Results

The team devised a set of functional tests, concerning the physical product, the software and the hardware, to verify the correct operation of the prototype immediately after the specification of the prototype requirements. Table 2 lists the tests and the results.

Table 2. Tests and Results

Test	**Results**
DHT22 Sensor Accuracy	The temperature and humidity readings obtained with the DHT22 sensor for 20 °C, 26 °C, 28 °C, and 30 °C were compared with those of a reference device. The calculated and the expected accuracy matched (±2.5 % for the temperature and ±5 % for the humidity).
CO_2 Sensor Calibration	The sensor was calibrated for a CO_2 concentration of 400 ppm [37]. The readings, however, were not compared with those of a reference device due to a lack of resources.
Pulse Accuracy	The pulse measurements of a young adult matched the data sheet specifications. Next, the sensor accuracy was determined using the medical device Silvercrest SPO55. All readings were within ±5 % accuracy.
Microphone	The microphone was calibrated using the Sound Level Meter and Spectrum Analyser SC310 from CESVA. Since the baby cry spectrum ranges typically from 336.9 Hz to 502 Hz, the frequency stability was tested. The microphone displayed an acceptance range of 5 %.
Cry Detection	With a baby crying recording playing, the software analysed the microphone output signal and correctly identified the situation. As a result, the MP3 player played the stored sound recordings through the loud speakers.
IoT Platform	The sensor readings submitted in real-time to the IoT Platform Thingsboard were available through the user dashboard. In addition, the user was able to visualise the historical data and preset the minimum and maximum notification values. Whenever the values were out of range, a notification was issued.

5 Conclusion

Based on preliminary analyses, the team designed an out-of-the-box product, providing parents with remote access to information about the health and environment of their baby. Moreover, even when the infant naturally outgrows the pillow and the sock, the home station will continue to monitor the air quality of the room. The bGuard Smart Companion Pillow is a product of the IoT era, where smart devices become part of daily lives. The target group is made of worried parents (25 to 35 years old), ranging from middle-class through upper-class, who were raised with technology and depend on their smartphone. Taking everything into account, the team is confident that bGuard has the potential to become a real product in the market due to its unique combination of features that lower the risk of SIDS, monitor the quality of the sleeping environment and reduce parenting stress.

EPS@ISEP, as a cross-cultural and multidisciplinary engineering capstone programme, challenged the team to execute an integrated design-implementation-and-business solution – bGuard. The collective effort of the team was the key for the success. Besides the different kinds of expertise and the distinct visions of the problem – worried parents and SIDS, the team was able, with the help of the supervisors and the teachers, to establish its own way to plan and navigate along the semester – in an agile way, using SCRUM.

Considering that EPS@ISEP aims to promote hard and soft engineering skills in undergraduates, here are the testimonials left by the team members at the end of the semester:

- "Living in a globalised world, the EPS gives students the possibility to spend a semester in a foreign country while working with people from all over the world in close cooperation. Putting together a team from different academical backgrounds, different countries and different strengths, has the potential to create something big. The project allowed me to learn many things with the others and to improve my skills just by recognising how they tackle things and find solutions. What I liked especially about the EPS is that it simulates a start-up company in quite a realistic way. All the know-how was transferred in a practical way to be directly used for the project. It is great to see how motivated colleagues can be and how much effort they put inside when they have a great project which is really progressing."
- "EPS@ISEP was really a great experience for me, specially because of the different fields of expertise of the team members. Furthermore, it was very interesting how the team always managed the time in order to distribute tasks towards the success of the project. On the whole, I must say that EPS@ISEP was really above my best expectations."
- "Choosing to participate in the European Project Semester was one of the best choices of my life. I learned a lot during these few months. Not only did I develop new skills as a Product Designer, but I also learned so much about teamwork. It was not always easy to work with people who do not speak the same language as you or study the same courses, but we always managed to

communicate one way or another. I would definitely say that our different backgrounds were not a weakness but a strength, which made us stronger as a team."
- "EPS is a good way to interconnect with students from different countries and cultures as well as the way to create a complete advised product for the real market is a great challenge."
- "I am grateful for the experience EPS has provided. It is such a nice opportunity to meet so different people from other countries, see how they work and get to know other areas than my speciality. EPS is a good way to learn how to make things work in a totally new environment and in a group where each person has different ideas and viewpoints. It has taught me to be patient, tolerant and to consider much more the ideas of others. The opportunity to see and learn about this beautiful country is also priceless."
- "I am thankful for having the opportunity to take part on the European Project Semester. During the semester I learned a lot about the different cultures and their way of working. It was great to see that every part of the team was much focused to create a product that supports young parents in the daily life. Also, I liked the way of thinking about ethical and sustainable topics during the project. This experience gave me a new view of generating solutions during the project. Moreover, the EPS enabled me to improve my English skills."

Acknowledgement

The authors thank their home institution, Instituto Superior de Engenharia do Porto, as well as the faculty and staff involved in EPS@ISEP, for the support and contribution to the success of the programme.

Funding

This work was partially financed by National Funds through the Portuguese funding agency, Fundação para a Ciência e a Tecnologia (FCT), within project UID/EEA/50014/2019.

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