Design for Fetal Heartbeat Detection and Monitoring in Pregnancy Care

Biyong Zhang[1,3(✉)], Iuliia Lebedeva[1], Haiqiang Zhang[3], and Jun Hu[1,2]

[1] Department of Industrial Design, Eindhoven University of Technology, Eindhoven, The Netherlands
b.zhang@tue.nl
[2] School of Digital Media, Jiangnan University, Wuxi, China
[3] BOBO Technology, Hangzhou, China

Abstract. The piezoelectric pressure sensor technology has been developed for many years and it shows broad possibilities of using this technology in development of smart wearables for heart rate monitoring. The project goal was to explore the possibility to use the pressure sensor technology in Pregnancy Care. The focus of this project was to come up with concepts of a product that can be used by pregnant women to monitor fetal heartbeat in home-based context, and to explore different ways of representation and visualization of real data.

Keywords: BCG (Ballistocardiograph) · Fetal monitoring · Pregnancy Care
Heartbeat detection

1 Introduction

Findings have confirmed the developing a relationship with the fetus is critical for a successful physical and psychological adjustment to pregnancy and parenthood. Stronger feelings of attachment towards the fetus have been associated with positive health practices of the mother during pregnancy. Mothers with more positive and stronger feelings towards their fetus report more positive feelings towards their infant in the postnatal period [5].

The idea to monitor fetal heartbeat at home-based context is actually not new. For expectant moms and dads, who wish to bond with their unborn baby, the market offers different kinds of dopplers, listening systems and monitors for listening to fetal heartbeat, hiccups and kicks. Most of them can be used already from 10–12 weeks of pregnancy. These devices use a probe to detect the high frequency sound waves produced by the fetal heart using low emission ultrasound technology. Some of the fetal heartbeat listeners offered by the market are connected to the special Apps on a mobile phone, which is actually an interface to use functions of listening to, recording and sharing of the fetal heartbeat. Moreover, some Apps of the devices, such as Modoo and Baby CTG, provide 1-on-1 consulting service from a professional medical team based on monitoring data, what gives the great possibility for expecting mothers to be always in contact with professionals just in case.

N. Streitz and S. Konomi (Eds.): DAPI 2018, LNCS 10921, pp. 156–167, 2018.
https://doi.org/10.1007/978-3-319-91125-0_13

The development of new technologies brings more possibilities to monitor a fetal heartbeat in a user-friendly way. The piezoelectric pressure sensor technology shows broad prospects in the field of the heart rate monitoring [1, 3, 4]. Indeed, some studies have been done for the fetal heart rate diagnostic by using the piezoelectric pressure sensor [6]. Couple of studies describe the ideas of a sensor for fetal heart rate monitoring at home and a wearable system for remote fetal monitoring [2, 7].

However, how a product could be designed combining the new technology and what do the users think of it are still the questions. We introduce several new product concepts and evaluate these concepts with international users from different cultural backgrounds in this project.

2 Concepts Development

The product we are going to develop is supposed to be composed of two main parts:

1. SENSING part: a physical wearable product with the pressure sensor inside to collect the data.
2. ACTUATING part: a product to represent the data (that also could be a physical product or digital representation/visualization).

2.1 Concepts of the SENSING

During the individual brainstorm the concept named 'Smart' maternity pillows was created as the SENSING for collecting the fetal heartbeat data. The idea was based on the existing maternity pillows with the function of 'reading' fetal heartbeat by using the pressure sensor inside.

Two different shapes of the existing maternity pillows C and D shapes were chosen. This choice was made for several reasons. The C pillow nowadays is the most popular maternity pillow that was uniquely designed to follow the natural contour and shape of pregnant woman's body from head to toe, and which is perfect for sleeping and relaxing. The D pillow is compact, portable and versatile pregnancy cushion to support pregnant woman's bump, knees and back. Both pillows are different not only in their shapes and sizes, but also the materials they made from: C pillow – polyester, D pillow – foam. For the both pillows the place for the sensor was chosen by taking into account position of pregnant woman's belly (=approximate position of a fetus) when the women are using the pillows. We assumed these places for the sensor as the best cases to get a better signal.

In addition, we also consider a variant of the D pillow as another option which is called double D shape. As shown in Fig. 1, the D shape pillow is available for one side, while the double D shape pillow is available for both sides.

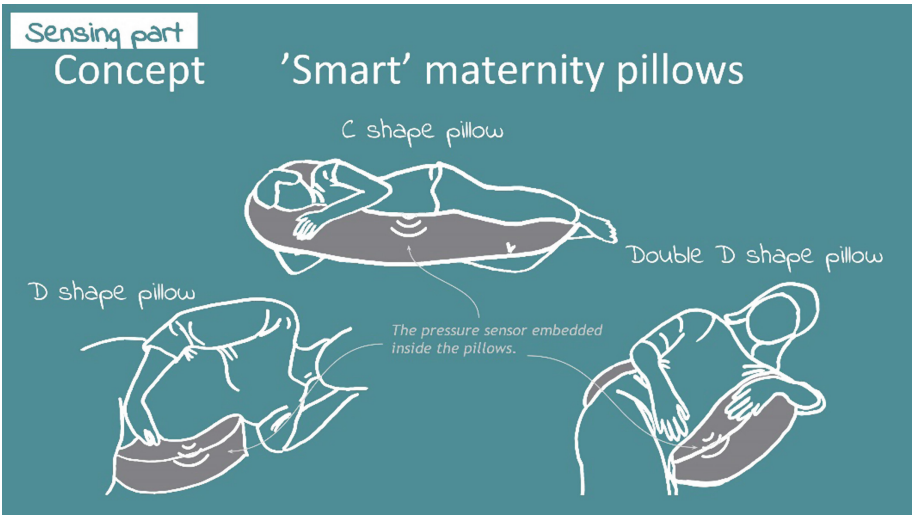

Fig. 1.

2.2 Concepts of the ACTUATING

We wanted to come up with an idea of the product that represents 'sign of life' of a baby and gives to a pregnant woman feeling of the 'connection with a baby', as well as for other family members.

During the Concepts development phase while brainstorming individually several concepts named 'Smart' bracelet, 'Creature' on a phone and 'Live' toy were created as different ideas of a second part of the product as the ACTUATING for visualization and representation of the fetal heartbeat real data.

1. Concept: 'Smart' bracelet

For the first concept as inspiration was a mood board with some existing fancy fitness trackers for women that look like jewelry.

The concept was named as 'Smart' bracelet (Fig. 2). The form of the main part of the bracelet is the shape of a womb with a baby (or an abstract shape of a fetus) inside. The baby on the bracelet has a small heart that supposed to blink when the real heartbeat of a baby detected by the SENSING. If it could be technically possible and we could extract data such as kicks we could also add indicators on the fetal feet to show kicks as well. On the bracelet there are 42 indicators around the womb shape that actually represent 42 weeks of pregnancy. On the bracelet a pregnant woman can see a current week of her pregnancy and how many weeks approximately left before the birth. The inspiration specifically for the last-mentioned feature was the idea of a pregnancy calendar that is used nowadays in the most of the pregnancy Apps. To be able to use this feature on the bracelet, a simple additional App is needed that can store some basic settings and collect data.

After coming up with the concept of the 'Smart' bracelet, some existing ideas of the 'smart' bracelets in Pregnancy Care were found (Fig. 3):

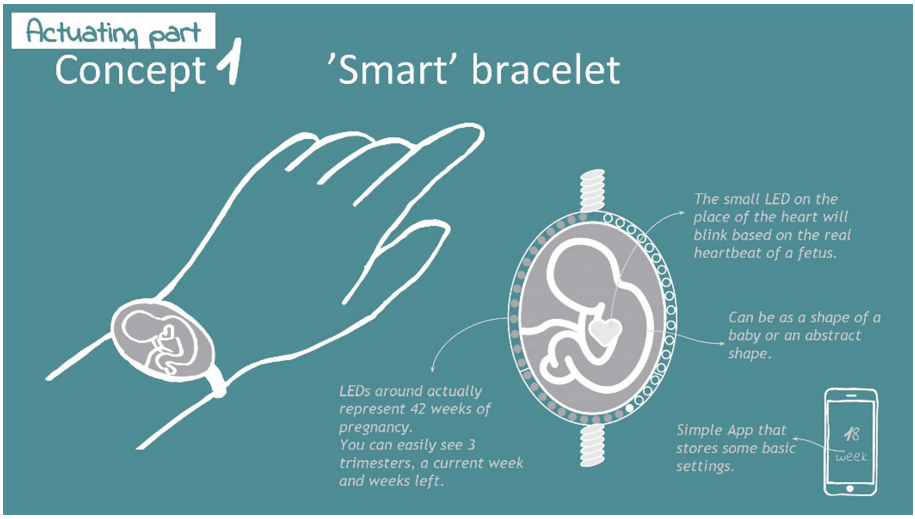

Fig. 2.

- Lisawatch – a bracelet that works as a sensing tool for fetal kicks and the actuating is displayed a mobile phone App (developed in Beijing, China) [8].
- Birthstone – an anti-radiation healthy band smart bracelet for pregnant women.
- Fibo bracelet – a smart bracelet for men to feel kicks of their unborn babies (an idea from Danish startup) [9].

Fig. 3.

2. Concept: 'Creature' on a mobile phone

For the second concept as an inspiration were some beautiful pictures of the body art on pregnant women's bellies. This idea was about the visualization of a 'creature' inside a belly on a mobile phone screen. Moreover, to keep the idea of the visualization to be different over time we were inspired by the idea of the digital game 'tamagotchi' that was so popular in 90s, where creatures in the game grew up during the definite period of time (Fig. 4).

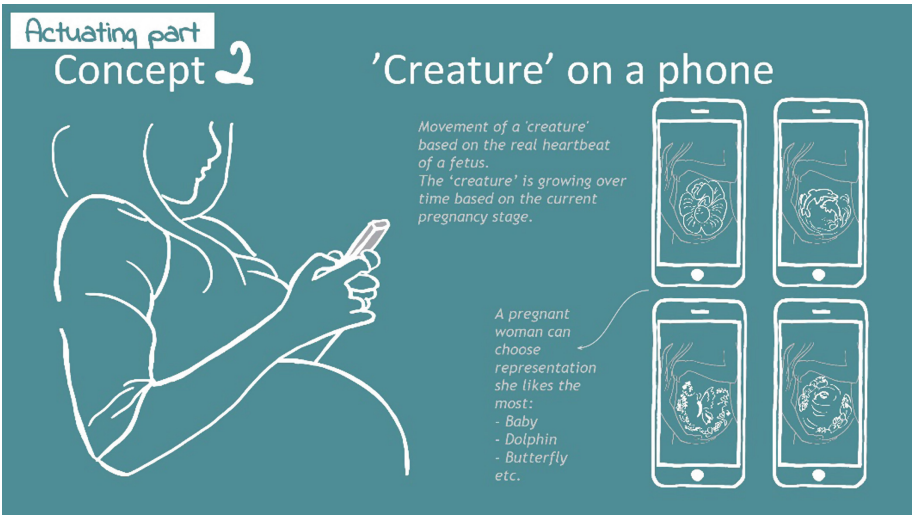

Fig. 4.

The concept was named as 'Creature' on a mobile phone (later on as just Visualization on a mobile phone). The idea was as a visual representation on a mobile phone screen a belly with a 'creature' inside. A pregnant women can chose representation she likes the most of feeling her baby, for example, baby, clam, fish, butterfly, flower, etc. Movements of these 'creatures' supposed to be based on the real heartbeat of a baby – fish is floating, butterfly is moving her wings, flower is moving its petals, etc. The size of the 'creatures' supposed to be changed over time based on a stage of pregnancy, thereby the 'creatures' will grow.

3. Concept: 'Live' toy

For the third concept as an inspiration was a mood board with different kind of pillows and toys of different shapes and forms, some of which have breathing, warming and lighting effects (Fig. 5).

The concept was named as 'Live' toy. It was an idea that actually came out from another idea of having only one pillow that works as the SENSING and the ACTUATING at the same time, for example, a pillow that gives haptic feedback like heartbeat or just can 'breath' based on real heartbeat of a baby.

3 Evaluation

Since the target user group may have multicultural backgrounds, we hope these concepts can be evaluated by the users living in different countries. Therefore, video prototypes were considered to be the best choice for the evaluation. To do that we created and showed to our users a video with the concepts and asked them in the form of an online survey to give their feedback about the ideas. This approach could help us to get already in advance insights from potential users and show more or less if the idea actually looks promising for the market in the future.

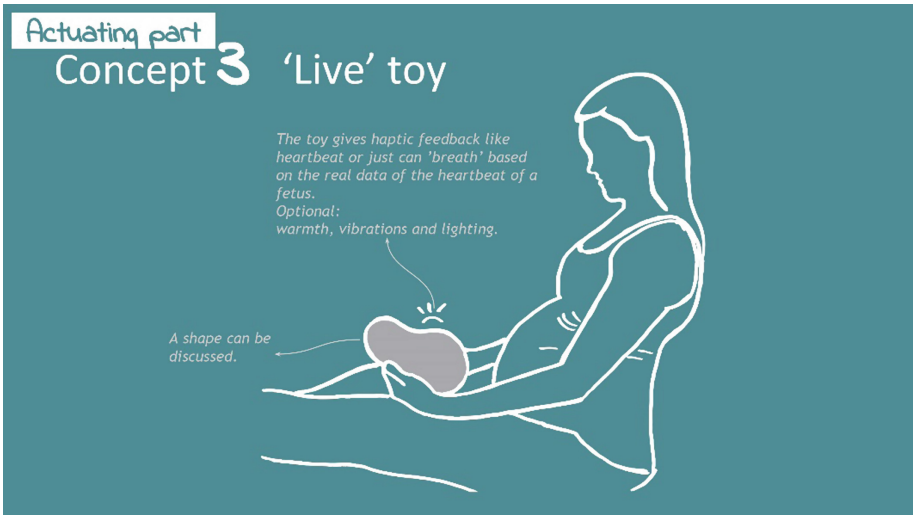

Fig. 5.

3.1 Process

First of all, a video with the concepts was created. The idea was to show in the video the all 3 pillows (C, D and Double D shapes) with an explanation that they are actually 'smart' version of the existing maternity pillows with the pressure sensors embedded inside that help the pillows detect fetal heartbeat. In the video after showing the pillows all 3 ideas of the ACTUATING were shown – 'Smart' bracelet, 'Creature' on a phone and 'Live' toy as they were prepared. The idea of the 'Creature' on a phone for the Online User tests was renamed to a simple Visualization on a mobile phone. Since it was not possible to record a video with the prototypes we made with any pregnant woman in the home context with the pillows, for the video some part of the existing videos of the maternity pillows C, D and Double D shapes were used.

When the video was ready, a short survey was created by using the platform TypeForm. The survey had a link to the video with the concepts and several questions according to the video, such as:

- Would the participants like to have at home a 'Smart' pillow that can 'read' fetal heartbeat?
- Which pillow from the video the participants like the most and would like to use at home?
- Which actuating from the video the participants like the most?

The initial version of the video and questions were prepared in English, then two more versions were prepared in Chinese and Russian languages based on the English version. The both Chinese and Russian versions were as duplicates of the English version with literal translation of the questions. In the Chinese and Russian versions, the same video was used with the same voice-over, but with the subtitles in Chinese and in Russian respectively.

All 3 versions of the Online survey were shared as links within colleagues, relatives and friends and posted in social medias and special forums for pregnant. In the Online survey could participate not only pregnant women, but also women who had just delivered their baby 0–12 month ago, what was mentioned on the main page of the surveys.

3.2 Results

After 3 weeks following amount responses were received:

- English version – 27
- Chinese version – 2
- Russian version – 19

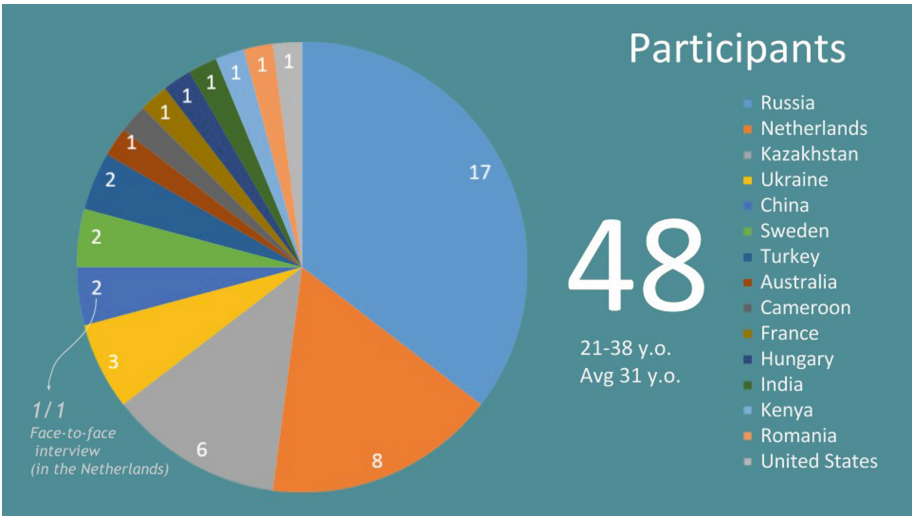

Fig. 6.

In total 48 women from 15 countries at the time of deriving the data were involved in the Online User tests with the age range 21–38 years old in different pregnancy stages and also who had just delivered their baby (Fig. 6):

- 1st Trimester – 4
- 2nd Trimester – 5
- 3rd Trimester – 17
- Gave birth (0–12 month ago) – 22

Many positive expressions from the participants about the ideas presented in the video were received, such as:

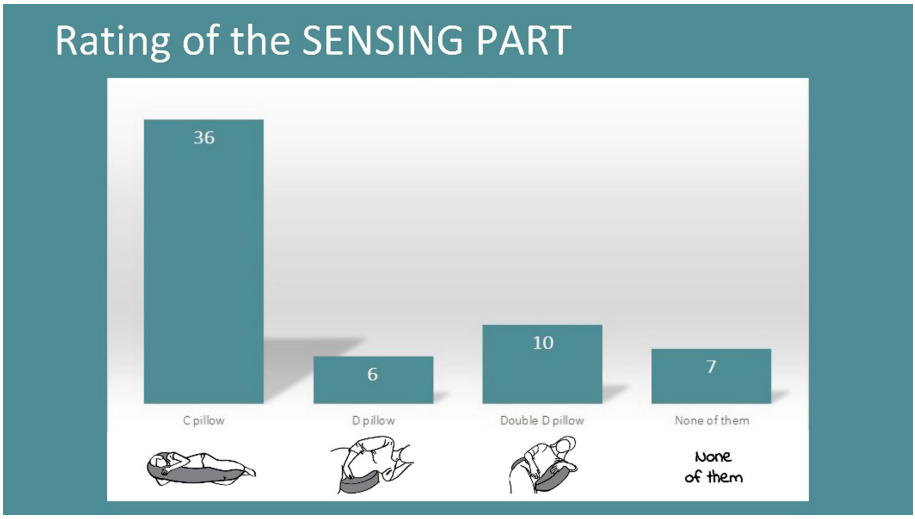

Fig. 7.

> "It's a nice idea", "Good idea", "I like everything!", "Nice concept!" "I wished this be exist when I was pregnant!", "It takes away some fear when you don't feel your baby", "I like the idea with fetal heartbeat detection. It would be super nice to know how my baby is doing in my belly".

Couple of the participants pointed that the ideas are good especially for the first pregnancy:

> "I think it will be interesting especially during the first pregnancy!", "Really good ideas, especially for those who pregnant first time and don't have experience".

Couple of the women commented that they would prefer to have the sensor, which monitors the fetal heartbeat, not only when using the pillows:

> "It would be great if I would have this kind of sensor always with me and not only on a horizontal position only by using the pillow", "It's pity that the sensors only in the pillows. I think that it would be good if you can monitor constantly the heartbeat of a baby. For example, a comfortable belt with the sensors for everyday usage would be good".

29/48 (60%) women mentioned that they would like to have a 'smart' pillow that can detect fetal heartbeat at home. All the participants, regardless of their answer if they would like or would not like to have a 'smart' pillow at home, could make their choice which ideas they like from the video – which pillow and which idea of the visualization/representation.

As a result, the C pillow became a winner from the all pillows presented in the video according to the votes (36 women) (Fig. 7).

Plenty of positive feedback was received about the initial idea about the 'smart' maternity pillows that can detect fetal heartbeat:

> "I like that it is integrated in something I already use (the pillow)"
> "It's a good idea to create such pillows which can calm down the always worried mommy"

"I love the idea of pregnancy pillow with heartbeat detector!!"
"Awesome idea to use pillows! It's very necessary for a pregnant woman. But the greatest here that using the pillow you can not only rest, but also get a heartbeat of your baby! Very interesting!"
"I like your idea with the pillow very much. Most of the pregnant women use special pillows to sleep and rest comfortably. But if such pillows combine more functions it is even better! You don't need to purchase a number of things - you have your pillow and it is multifunctional"
"The idea of the smart pillows that can detect fetal heartbeat is very interesting! Somehow it gives you a kind of control and calm… I could listen to the heartbeat of my baby and know other things only when I was visiting my doctor. And with this new product I would know everything by myself"
"I'm using C maternity pillow even after my baby was born. Very comfortable. I'm sure that the functional pillow will be even better!"

At the same time there were some participants who expressed their skeptical opinions about the ideas:

"I'm … not sure if I need such a pillow on my second half of pregnancy as I constantly feel my fetus movement so that I know that everything is OK. I would probably prefer cheaper, but non-smart pillow for my comfort"
"Why do you want to measure the heartbeat with the pillow when there are so many compact technologies present in the market? I don't see a reason why I would prefer this one over others. Moreover, it only measures the heartbeat" "I've never felt concern over my fetal heartbeat. I trust my body is doing what it needs to do and I rely on my midwife to tell me otherwise. I think this is an unnecessary item playing into people with stressful personalities"

One of the women expressed her doubts by comparing the 'smart' pillow with a Doppler she currently uses:

"I own a doppler which can be used much earlier than the pillow (I imagine)… I cannot imagine it to be nearly as accurate as a doppler".

Also, different concerns were expressed from the participants about situations if something can be wrong, what we should definitely take into account:

"I would worry if… something goes wrong with technology. This results in stress and that is not a good thing"
"What if something will go wrong with the system and panic will happen? I had a situation when before the labor doctors checked the heartbeat of my baby. Something went wrong with a device, all values were shown not correctly, everyone started to panic"

Different opinions were received about the ideas of the visualization/representation of the fetal heartbeat data. There were participants who liked different ideas:

"I like the idea with the bracelet"
"I prefer the smartphone as a main device to connect to the pillow"

Since in the video very simple prototypes were shown, we can assume that the visualization style might have effect on the opinion of the participants.

Couple of the women seems specifically did not like the visual and representation:

"I don't like the idea of representation as blinking butterfly/fish etc. I'd better prefer to see the fetal heartbeat rate"
"I'd like not to compare my child to an animal (fish or cat or whoever). Baby is a baby. I am waiting for Baby, not for butterfly or a flower"

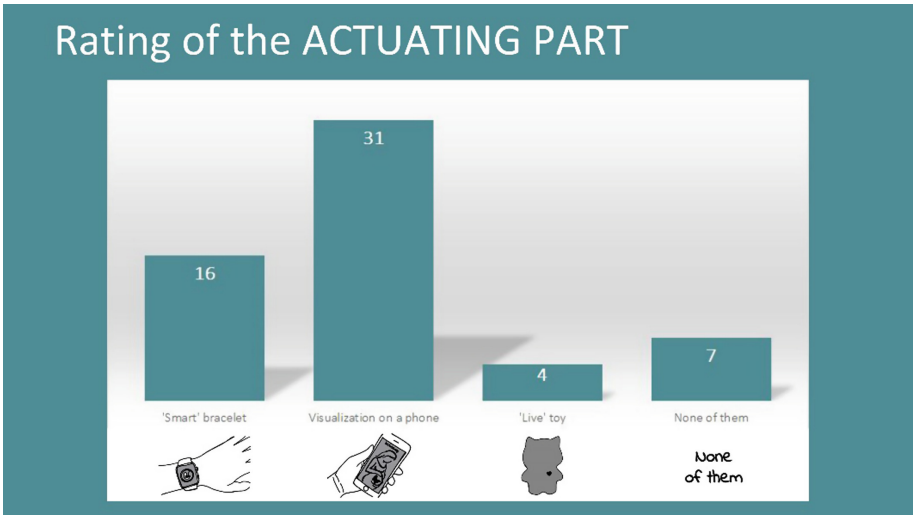

Fig. 8.

"I don't like a toy… Looks like for a kinder garden"

One woman expressed the idea about representation of the fetal heartbeat in the same pillow:

"I think there is enough to have kind of indicator on the pillows C and D shapes looks like a small heart which will be beating based on your fetal heartbeat. And you don't need any additional stuff".

Some of the concerns from the participants about the idea of the 'Smart' bracelet mostly was about the fact that it is an extra thing that they need to buy and wear, or because they just do not like it:

"I would like it to be cost efficient. I won't buy a smart watch just for this case" "I don't really like the smart bracelet. While being pregnant for example I didn't really like anything on my wrists"
"I don't like smart watches"
"I don't wear a watch, and wouldn't want to start wearing one during pregnancy".

Among all ideas the idea of the Visualization on a mobile phone got the most number of votes (31 women) (Fig. 8). Most of the opinions were that it is the best idea:

"I think that the App is the best!", "The app is the best variant!", "For the functional inspection, I think, the mobile would be the best!", "The phone is the most accessible for me", "As about visualization I prefer a mobile phone. Mobile phone is always with me and no needed to buy and carry new devices".

Only 4 women have chosen the 'Live' toy idea. Some of them commented:

"Toy I don't mind because it is something cute and maybe useful for the baby later on?", "The idea of the toy is cute!".

The low number of votes for this idea could be probably because the initial idea could not be shown clear in the video and participants did not get sense that the pillows and the toy actually match each other. Or maybe the prototype was not good enough. This fact we should take into account by performing following user tests in the future.

The women, with whom a face-to-face interview was conducted, mentioned that she liked actually all ideas, but she prefers to have a mobile phone as a main device. But the bracelet and the toy could be only as additional and extra things, because the last ones "give less data for this monitoring". Moreover, she told that from the mobile visualization she expects more "for example, some data or more history record".

It seemed that except for visualization of the heartbeat of a baby in metaphors women really want to see practical data:

> "An interesting idea, but there is also needed to show information about the normal heartbeat of a baby, because a pregnant woman can have concerns about if the heartbeat of her baby is too fast or slow"
> "And give more advice like… for example, I'm on the 5th month of the pregnancy… on this stage… what range of heartbeat is normal… Give me more detailed inspection and I feel more professional on this device".

One of the comment was about expecting from the ACTUATING a medical suggestion based on collected data:

> "For example, the data… some medical suggestion. For example, on the late stage if the heartbeat is really quick or really slow is abnormal… it can pop out some warning or this kind of reminder 'Mother, you should be careful. Maybe you need to visit a doctor or have more rest…' Things that actually help me to protect my baby"

Some women wanted to be able to see more data from a baby and not only heartbeat:

> "Would be great if it can detect the hiccups and imitate the different movements also", "Also it would be nice to know if the baby is sleeping or no".

By performing the Online user tests with a video with the concepts we could get preliminary feedback from the potential users if the ideas are actually attractive for them. Of course, for the real user tests women need to try the prototypes in live – check how comfortable the pillows are with the sensor inside, and at the same time test how usable the ACTUATING prototypes.

Overall, the results from the Online User tests are quite positive, which show that the idea of the 'Smart' maternity pillows seem attractive for the potential users. The question is only to see which product as the ACTUATING actually will be the best in the real context of using the pillows, by taking into account not only practical matters, but also possibility of playful and emotional interactions.

4 Conclusion and Recommendations for Future Development

In this project, we come up with the design of a new 'smart' product for pregnant women which consists two parts as the SENSING – a 'Smart' maternity pillow with the pressure sensors embedded to collect the fetal heartbeat data, and as the ACTUATING – several

different concepts of representation and visualization of real data such as 'Smart' bracelet, 'Creature' on a phone (Visualization on a mobile phone) and 'Live' toy.

Just by using approaches as Prototyping and Online User tests by showing a video with the concepts we could quickly check the ideas with our potential users and get some positive insights and feedback from them. The results show that the main idea of making existing maternity pillows 'smart' by embedding the pressure sensor inside for baby's heartbeat monitoring looks quite attractive for our potential users. The ideas of the 'Creature' on a phone (Visualization on a mobile phone) and 'Smart' bracelet seem more promising for representation and visualization of the real data.

To turn the prototypes into useable devices, a series of technical tests specifically of the SENSING prototypes are needed. Special schemes should be prepared with explanation how to perform the technical tests and how to adapt the inner materials of the pillows if needed in case of trying out to get a better signal.

References

1. Babu, I.: Piezoelectric composites. Design, fabrication and performance analysis. Eindhoven University of Technology (2013)
2. Fanelli, A., Ferrario, M., Piccini, L., et al.: Prototype of a wearable system for remote fetal monitoring during pregnancy. In: 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC 2010, pp. 5815–5818 (2010)
3. Jose, S., Shambharkar, C., Chunkath, J.: HRV analysis using ballistocardiogram with LabVIEW. In: Proceedings of the International Conference on Computing and Communications Technologies, ICCCT 2015, pp. 128–132 (2015)
4. Karki, J.: Signal conditioning piezoelectric sensors. Application report, Sensors Peterborough NH, 48, pp. 1–6 (2000)
5. Maas, J.: Mother & fetus: the start of a relationship. Tilburg University (2013)
6. Nassit, M., Berbia, H.: On the fetal heart rate diagnostic technologies. In: 2015 10th International Conference on Intelligent Systems: Theories and Applications, SITA 2015 (2015)
7. Sato, H., Yoshimura, K., Nakamoto, H., et al.: 19.2 cm^3 flexible fetal heart rate sensor for improved quality of pregnancy life. In: Proceedings of the 2016 IEEE Biomedical Circuits and Systems Conference, BioCAS 2016, pp. 140–143 (2017)
8. http://www.lisawatch.com
9. http://www.redbookmag.com/body/pregnancy-fertility/news/a48938/fibo-bracelet-men-pregnancy/