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Challenges in Wearable Devices based Pervasive Wellbeing Monitoring

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***Abstract*— This paper presents an open discussion about current achievements and remaining challenges in the general adoption of wearable monitoring devices among the general population. To understand the open issues we present some background of Internet of Things (IoT) systems for pervasive wellbeing monitoring, including a brief taxonomy of wearable monitoring devices and possible application domains. We also classify and explain key possible influencing factors related to use, adherence and attrition in wearable monitoring solutions. Finally, we have conducted a survey where we analyzed the user perspective of long term wearable device usage. We asked about 16 issues, organized in three categories: the practical daily use, data and measurement procedures, and user experience with the device and supporting software. Preliminary findings indicate that most of the issues are perceived as highly relevant or relevant for the users and that roughly half of them have already personally experienced these problems. Based in the findings of the survey we provide some insights about possible solutions.**

Keywords*— *wearable devices, monitoring, user experience, challenges, IoT, mHealth, survey

I. Introduction

Personal devices and mobile applications that enable pervasive self-monitoring of various parameters and aspects of the life are becoming increasingly popular. They emerge in various forms, ranging from tiny wearable gadgets equipped with sensors and communication interfaces, to mobile applications benefiting from the sensor and communication capabilities readily embedded in a modern smartphone. Smartphone apps or web applications provide data storage, analytics and visualization to foster self-reflection for insight gaining. Self-monitoring solutions can be applied in several application domains, including health, wellbeing, sports and tourism.

However, numerous reports as well as personal experience of authors have indicated low adherence to regular and long term application of wearable devices. Despite available solutions and promising application domains, many users abandon personal self-monitoring only after a couple of months, if not additional objectives to use it are provided [1]. This indicates that the positioning of pervasive wellbeing self-monitoring and finding its' (real) value for the users is still a challenge. Some scientific reviews [2], [3] tried to systematically indicate actual or possible issues in using and benefiting from wearable technologies. In addition, frequent online news, brief reports and forum discussions point to particular problems experienced by the users of wearable devices, including e.g. poor device autonomy [4], data validity and robustness [5], allergy problems [6] or even life threatening security issues [7], [8], [9].

The primary motivation of this paper is to classify, analyze and understand better various issues, related to use, adherence and attrition in wearable monitoring solutions. We are convinced that these issues may not be limited to enabling technologies in wearable monitoring (e.g. procedures for big data analysis and intelligent support for cognitive action), but have also to refer to user experience with the device and supporting software and problems in daily use.

Our contribution is in presenting and analyzing possible reasons for high attrition in using wearable tracking devices. Such an understanding is of key importance for future device, application and advanced service developers and could lead them to design and development of even more successful monitoring solutions in e-health, wellbeing or sports. To understand users' personal attitudes and experiences in using wearable trackers, we created and executed an online survey to collect these inputs.

In chapter 2 we provide brief technical background of wearable monitoring solutions, typical system architectures and common implementation approaches, along with possible application domains for these solutions. In chapter 3 we present and classify key challenges in long-term user engagement and factors that influence perceived value of pervasive wellbeing monitoring. Chapter 4 presents the methodology, results and findings of the online survey we carried out, in order to analyze these challenges in a group of wearable monitoring users. Chapter 5 concludes the paper and highlights future research and survey avenues that originate mostly from the feedback collected from the respondents in the survey.

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II. WEARABLE MONITORING CONCEPTS

Pervasive self-monitoring systems share the key technology trends of other Internet of things (IoT) solutions and can be thus regarded as an incarnation of the IoT principle, particularly addressing problems related to ageing, health and daily living. A very systematic reference architecture of IoT was presented in [10]. It enables derivation of concrete architectures, which meet functional and interoperability requirements and facilitates their implementation based on common functional blocks. For our needs we provide a much simplified architecture depiction, merely to explain the technical background of pervasive self-monitoring. There can be four key physical entities involved: a sensor device, an intermediate gateway device, and server or cloud-based backend. The fourth are end-user interfaces (computers, smartphones, tablets, etc.). These devices have to enable following functional components: sensing i.e. data acquisition, pre-processing of the sensory data, temporary or permanent storage, analytics, and visualization or user feedback. The functional components can be spread among various physical entities, so there are body/personal area and wide area communications required to interconnect them. On the other hand one physical device can facilitate several functional components. A smartphone can e.g. serve as the gateway and enable temporary storage, some analytics and visualization of monitoring results [11].

The sensor device employs one or more different sensors along with (at least) some basic pre-processing and local storage of the collected sensor data. If the sensor device incorporates short range communication technologies (e.g. Bluetooth) only, additional intermediate gateway device enables synchronization of collected data with cloud-based Internet backend systems. Such a gateway is often implemented as a mobile phone or PC with a desktop application. Synchronization usually requires no or very little user intervention. The server side backend system (i.e. Big Data and Cloud technologies) stores, processes, analyses and visualizes the collected data, and creates information based on it. The backend systems generally provide an application programming interface (API) for the interchange of data with similar or complementary online systems. This API is commonly based on HTTP using web services (RESTful). In this way mashup applications can be built, that combine IoT provided data from various devices, with e.g. location information, or publically available data sources (e.g. current weather information).

In practice several exceptions to the described composition can be found. There are self-monitoring systems that have no server-side storage or processing. User applies e.g. a wearable device and analytics (if any), storage and visualization are implemented on a smartphone. Similarly, the sensory part can be based entirely on sensors readily available in the smartphone. So a smartphone becomes the platform that provides all the required functional components. Wearable sensor devices can provide an embedded user interface and thus an immediate insight into the collected data, too. Due to battery limitation these are frequently in form of LED indicators, small LED screens or embedded vibrators.

Active living is becoming an important component of healthy and responsible lifestyles. It involves physical exercise and management of stress, diet and sleep. Such activities can be motivated by various and at least to some extent overlapping aspirations. These could be health, wellbeing, sports, leisure or tourism. Pervasive wellbeing monitoring systems can contribute to any of these aspirations. Besides providing an instant and elaborated insight into the monitored parameters, important and broader mind-changing impacts can be expected. These include raised awareness about positive habits, more systematic and frequent physical activity, better self-awareness and proprioception, and motivation to keep up with positive changes.

Self-monitoring [12] for non-medical purposes reflects the desire of knowing more and better about oneself. A form of this movement is known as quantified self (QS) [13]. But for many wellbeing self-monitoring systems the initial objective is more humble and encompasses increased motivation, including social dimension of application usage, along with integration of gaming dynamics in wellbeing applications.

In the domain of sports [14] self-monitoring has a clearer objective. So the solutions oriented towards planning, executing and monitoring the training process in almost every available sport discipline.

Application of ICT in health [15], [16], including pervasive monitoring of vital signs [17] and physiological parameters [13] has resulted in numerous e-health solutions. Self-monitoring with wearable devices is of crucial importance in chronic disease management [18], [19]. With ageing population and their increased demand for medical services, older adults are another segment with immense application possibilities [20]. Long term vision of e-health as seen by some researchers [21], [22] envisages an integrated database that includes genomic data, traditional (electronic) medical or health records and data from wearable devices. These should provide a basis for more precise interpretation of patient, disease and interventions. Currently, the medical and wellbeing information systems are not tightly integrated, neither at the operational level (data formats, exchange of data) and even less in the holistic understanding of human being.

III. USER EXPERIENCE, INFLUENCING FACTORS AND OPEN CHALLENGES

The technology push and user pull in wearable monitoring are striving to establish a productive balance. Technology trends like IoT, wearable user interfaces and even m-health are positioned close to the peak of inflated expectations in the technology readiness cycle and are five or more years from the plateau of productivity. But despite that, there are numerous products and applications available. As the price for basic tracking devices is affordable, self-monitoring is a rapidly growing market (about 10% US population has acquired e.g. a wearable activity tracker) [1]. But the real value for the users, which would naturally create a sound user pull and long-term user appeal, is still a mayor issue for this industry.

According to the literature, various objective and subjective influencing factors contribute to the situation, where users frequently abandon the usage self-monitoring solutions. They range from vague long-term benefits and related lack of clear cognitive action [23] to quality of experience (QoE) related challenges [24], which limit usefulness and effectiveness of the solutions. We analyze three groups of influencing factors:

- Wearable tracking devices, in particular issues related to their daily use;
- Data measurement procedures, and quality, validity and integrability of the collected data;
- User experience based on information analytics, user interfaces, feedback, and user empowerment.

A. Daily use of wearable tracking devices

Operation autonomy of wearable devices is limited by the size and capacity of embedded batteries with respect to the device energy consumption. High energy consumption is usually a consequence of larger and capable screens and intensive communication requirements. Practically, the recharging period is a couple of days or longer, but can be as low as every day. There is also no seamless charging method for wearable devices.

As a consequence, the functionalities of the devices are limited to prolong the battery duration, otherwise frequent (e.g. every night) recharging is needed, which results in long non-recording periods and challenges the objective of persistence in monitoring.

Ruggedness of implementation in terms of water, shock, temperature or dust and dirt resistance is required for the device that are supposed to be worn in any daily situation.

If high requirements are not met, the devices can be damaged. If the user detaches the device to protect it from unwanted impacts during his regular daily activities, the continuity of measurement is lost temporarily or even permanently, if the device remains forgotten for a longer period.

Robustness of data measurements with e.g. an optical heart rate sensor, can be strongly affected by proper placement of the wearable device, body hair, vibrations or external light sources.

This can impact data validity to an extent where the measurement becomes useless.

In daily usage **style and hygiene** strongly shape user experience, too. Wearable monitoring devices are perceived as fashion accessories. The design has to meet practical hygiene requirements as well. If not met, this can make the usage uncomfortable or even present a health risks. In similar manner, a personal tracking device can create a form of stigma. Its usage can be perceived as sign of weakness or illness, resulting in deteriorated social image.

These factors can affect the tiny line between persistently using and abandoning a personal tracking device.

B. Measurement procedures and data quality, validity and integrability

Data accuracy and quality are a major issue in personal wellbeing and eHealth. Body composition analyzers, stress monitors or even simple pedometers often suffer from inappropriate positioning of sensor and apply data (pre)processing algorithms that do not necessarily share same and comparable scientific backgrounds. Some researchers in wellbeing and medical measurements expect the high data volumes, which can be acquired with persistent personal monitoring, along with advanced data mining algorithms.

If the devices was subjected to e.g. systematic medical certification, these factors can result in poor quality and repeatability of measurements (even to the extent where results become senseless and invalid), and impaired interoperability at the data level, where various tracking devices provide data inputs. Data accuracy is the key limiting factor for a closer integration of wellbeing related measurements into medical health system and for augmenting medical analyses with a set of wellbeing data that reflects one's state and condition in a broader and more holistic manner.

Data might be accurate, but is not necessarily **valid.** Automated and persistent measurements can indeed provide a rich set of data. But without standardized data capture procedures and with lacking context, such a measurement might be unrelated to the problem, which we are solving.

A serious consequence of inappropriate data validity is that users receive information or indications that are not properly related to their objectives. Even if most of the invalid wellbeing related measurements cannot result in direct damage to the user, this may not be the excuse to honestly face data validity deficits. Poor data validity, similarly as meager accuracy, impairs interoperability and data exchange, since the measurements are incomparable in e.g. frequency, precision or structure.

Integration and interoperability refer to interchange of personal monitoring result among devices, applications, systems, and application domains. The interoperability requires harmonized data formats and common communication protocols for exchange. Widely recognized eHealth communication and information recommendations and standards (e.g., HL7, IEEE 11073, OpenEHR) can leverage this challenge in eHealth systems, but their practical implementation is demanding. The wellbeing oriented systems can bypass some of the strict eHealth related requirements about certification, privacy, security, standardization and common business procedures. These solutions rely on more general Web oriented mash-up approaches. But despite these mitigations, wellbeing system struggle in providing simple and efficient interoperability, too. Seamless exchange of measurements from e.g. one particular backend system to another cannot be simply anticipated. Similarly, a particular mobile application that visualizes user measurements usually supports just one or a couple of selected backend platforms, although the others store and provide equivalent measurement results (e.g. daily activity). There are several platforms available, even some from the most prominent players in Internet and mobile application markets, but at the moment none seems to be dominant in addressing the challenges properly.

This not only limits the users' choice of wellbeing monitoring solutions. Even more importantly it limits simple integration of various data sources for a particular individual, prevents unlimited application of big-data principles to these diverse resources, and leads to additional reluctance in integration of e eHealth and wellbeing system.

C. User experience

User interfaces in mobile and Web applications for review and analysis of monitored parameters frequently experiment with design and user experience (UX) concepts. The motivation for this is in distinguishing their application from competitive ones. But most of the solutions focus more on providing information (e.g. visualization of measurements) than supporting users' ability to act towards his or her clear objectives. Interface design for wellbeing monitoring is becoming even more challenging with alternative physical interfaces (glasses, vibrations, car displays, etc) [25].

Current situation leaves users frequently puzzled in review of the results and inapt to act in desired direction.

Supporting software relates to user interfaces, but involves also data analytics and application scenarios. It too strongly affects user experience. The underlying analytics has to focus on usage objectives (and not data as such), and application logic design needs to provide motivational aspects, as well. Serious gaming approaches, common challenges and social dimension in wellbeing monitoring could be the key distinguishing factors among common and winning concepts.

In user centric application design **scope and goal** of an application are shaped by the user needs. For wellbeing monitoring segmentation of target users does not necessarily reflect in application adaptations. Needs and scopes of a sportsman are different from those of a housewife trying to manage her body weight, although they might be using similar or the same sensor devices and measuring the same parameters.

Challenges that still have to be met in any of the three mentioned areas reduce the perceived value, which user needs for a long term engagement.

IV. SURVEY

A. Methodology

We have carried out a study, in the form of an anonymous online survey, regarding the experience of using wearable devices in long periods of time. We were querying about three key areas. First, we collected a minimum set of demographic information (age, gender), second, we asked about their use of ICT (computers, smartphones, tablets), and third about their objective for using a wearable monitoring device and the form factor of the device they use.

The core of the survey was split in three subsections, including practical aspects of daily use of wearable devices, issues related to data and measurement, and user experience with the device and supporting software. Based on literature review we selected a set of possible issues for every subsection and verified personal attitudes and personal experience with wearable trackers in relation to each issue. The questions were closed-ended and the levels of relevance were queried with Likert scale ranging from 1 to 4. We deliberately selected an even scale, so that a respondent had to take a positive or negative stand, without having an option to select indecisive middle value. Finally, we verified level and reasons for attrition.

The survey was distributed among people from Spain and Slovenia and a set of 33 complete responses were collected. Since one of the requirements to participate in the study was to already being familiar with at least one wearable device, the number of responses seems reasonable.

B. Survey results

In the survey we collected 33 complete responses. 29 of 33 respondents were between 26-45 years old. There were 26 men and 7 women. All of them were very regular users of and expressed strong self-efficacy to use personal computers/laptops and smartphones. The use of tablets was less frequent, but still 13 used it on daily basis. The respondents evaluated self-efficacy to use ICT on a four point discrete Likert scale, with 1 presenting "Not confident at all" and 4 "Very confident", these results are given in Table 1.

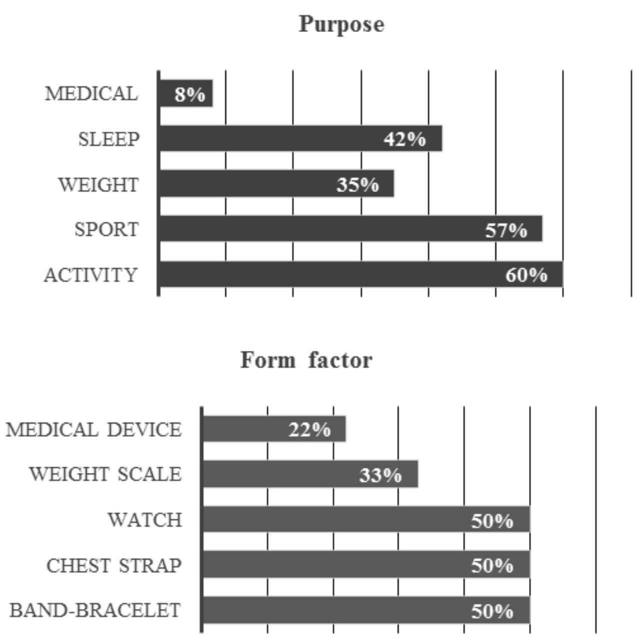
TABLE I. EXPRESSED SELF-EFFICACY TO USE ICT

Confidence in ICT	*Mean*	*Var*
Personal computer	3.9	0.08
Smartphone	3.79	0.17
Tablet	3.36	0.96

28 respondents were or had been using some form of wearable trackers themselves. Among the remaining ones, 4 have never used it and 1 had used a smartphone only for monitoring purposes. The dominant forms of devices in use were watches (16), chest straps (16), and bands or bracelets (14), closely followed by weight scales (12). Head-worn devices and smart textile were not mentioned. 7 used medical devices (e.g. blood-pressure meter, glucometer),

too. The most frequent reason for wearable tracking was monitoring of activity level (20) and sports (19), closely followed by sleep (14) and body-weight (12) monitoring. Stress monitoring was not selected at all. 4 respondents were monitoring certain health conditions, and surprisingly stress was not mentioned at all.

TABLE II. SHARE OF RESPONDENTS BY OBJECTIVE FOR USING A WEARABLE TRACKING DEVICE AND THE FORM FACTOR OF THE DEVICE THEY USE



We investigated 16 potential issues, which are grouped in three categories: (i) practical daily use, (ii) data and measurement procedures, and (iii) user experience with the device and supporting software. For each potential issue respondents estimated its perceived relevance on a four point discrete Likert scale, with 1 presenting "Not really relevant" and 4 "Very relevant". Respondents also reported if they had experienced the particular issue themselves. The results for this part are given in Table 3. The values present number of selected responses. Columns *Relevance 1+2* and *Relevance 3+4* present sums of responses with values 1 or 2 and 3 or 4. These two sums present respondents with tendency of an issue being not (that) relevant or being relevant. Mean value and variance for each were calculated. In the Table 3, we highlighted items which somehow stand out from the rest. In green we marked high mean values ≥3.5 and low variance ≤0.3, and in red low mean values ≤2.5 and high variance ≥0.95.

TABLE III. SURVEY RESULTS: PRACTICAL DAILY USE, DATA AND MEASUREMENT PROCEDURES, AND USER EXPERIENCE WITH THE DEVICE AND SUPPORTING SOFTWARE

		Relevance								Past experience
	ID	**1**	**2**	**3**	**4**	**1+2**	**3+4**	**Mean**	**Var**	**[yes]**
Practical daily use										
Obtrusiveness	**Q1**	0	1	6	26	**1**	**32**	3.76	0.24	14
Autonomy	**Q2**	0	1	9	23	**1**	**32**	3.67	0.28	17
Robustness	**Q3**	0	4	7	22	**4**	**29**	3.57	0.49	11
Styling	**Q4**	3	10	14	6	**13**	**20**	2.70	0.76	7
Hygiene	**Q5**	0	2	12	19	**2**	**31**	3.52	0.37	4
Data and measurement procedures										
Robustness of measurements	**Q6**	0	2	11	20	**2**	**31**	3.55	0.37	14
Data accuracy	**Q7**	0	2	13	18	**2**	**31**	3.48	0.37	18
Pairing	**Q8**	0	1	7	25	**1**	**32**	3.72	0.26	18
Synchrnonization	**Q9**	0	1	13	19	**1**	**32**	3.55	0.31	16
Exporting	**Q10**	0	8	14	11	**8**	**25**	3.09	0.57	17
Security and privacy	**Q11**	2	7	6	18	**9**	**24**	3.21	0.96	2
User experience										
Desing of UI	**Q12**	0	4	13	16	**4**	**29**	3.36	0.47	21
Interaction with applications	**Q13**	0	2	15	16	**2**	**31**	3.42	0.37	19
Raw data	**Q14**	7	9	11	6	**16**	**17**	2.48	1.04	9
Feedback not clear	**Q15**	0	4	17	12	**4**	**29**	3.24	0.43	11
Motivation provided	**Q16**	7	12	8	6	**19**	**14**	2.39	1.03	12

At the end we investigated adherence in use of wearable trackers. 6 respondents did not use them anymore or had not used them at all, 20 used wearable devices, but had also stopped using some of them in the past, and 7 were only using them. Respondent could select one or more among 20 different reasons for stopping using these device in the past. The possible reasons addressed all issues included in the survey, as well as some additional ones focusing on purpose or meaning of using such a device. The most frequent reason was obtaining a new device which replaced a previous one (16). Two other causes pointed out as well: limited battery duration or autonomy (13), and lack of meaning. The later was addressed in to possible answers, which marked 11 and 9 votes. A frequent reason was mobile application replacing the function of separate wearable device (9), a fact that device had broken (8), it was uncomfortable (8) or complicated for use (7). All the other options scored 4 or less votes, hygiene and allergy issues was the only one not being selected even once. Finally, respondents had to estimate on a 1 to 4 scale how hard it was for them to see a clear purpose and long term value to regularly use a wearable device. Most of them had no major problem (19) or no problem at all (7).

C. *Survey findings*

1) *Demographics*

The survey addressed active population and respondents who are highly familiar with use of various information and communication technologies - ICT. We can state that their attitudes and experiences towards wearable technologies are not biased by lack of competence of efficacy in ICT. We expect that to be different if the target group comprised of e.g. older adults, with different attitudes towards ICT.

The dominant forms of devices (watches (16), chest straps (16), bands or bracelets (14), weight scales (12)) are correlated with the most frequent reason for wearable monitoring (activity level (20), sports (19), sleep (14) and body-weight (12) monitoring). It is evident that the respondents use the devices mostly for sports and wellbeing, and not for medical purposes. This results are also related to the demographic characteristic of the study subjects. Therefore, our results by no means indicates an overall situation in application of wearable devices, but merely the fact, that most of respondents were active persons, some of them even engaged in fitness industry.

2) Practical daily use

Five potential issues of practical daily use of wearable devices were investigated. All issues are dominantly perceived as relevant or highly relevant. Obtrusiveness while wearing, autonomy or battery duration, and hygiene and allergy issues were not marked as relevant or highly relevant only by 1-2 respondents. It seem that the obtrusiveness is of special importance, because it was marked as highly relevant in 26 cases. Still clearly relevant (29) was robustness of implementation. In practical daily use only styling and appearance seems to have a bit lower perception of relevance. It was issue in this category that was most frequently perceived as less relevant (13), and marked as highly relevant only by 6.

The practical experience of these issues is more diverse. 17 respondents have experienced battery duration or autonomy related problems, 14 obtrusiveness while wearing, and 11 problems with robustness, to these are the issues that are occurring most frequently. Experiencing styling and appearance related (7) was less frequent, which is in accordance with its lower relevance. However, the hygiene and allergy issues have been experienced least commonly (4), but 3 of 4 respondents with this issues experience it frequently or very frequently and have marked it as at least inconvenient. The high perceived relevance of hygiene and allergy seems not to be biased by actual negative experience. The respondents seem to be aware of potentially very inconvenient consequences this issue can result in.

Consequently, since obtrusiveness is very important for the users, and many of the users experienced issues on this matter with their devices, we think that this is one of the key aspects that device makers should address. The same occurs to battery life, which is the second aspect that device manufactures should address and robustness which also seems to be a problem yet. These problems are perhaps related to the need to constrain the price of the device, so that it can be purchased by most of the people. On the other hand, hygiene and allergy issues already seem to be properly handled by manufacturers.

We additionally analyzed what the acceptable autonomy of wearable device would be. For the majority of 19 responses it was in range of 1-2 weeks. Autonomy of 2-3 days was acceptable only for 2, and 1 day for no one. This clearly indicates that user have different expectations in terms of autonomy for wearable devices and for smartphones. Smart watches, as relatively new form of wearable devices, will have problems in this respect. But the positive message could be that users got somehow tolerant to limited autonomy. Although this was most frequently experienced issue, only 1 respondent among them marked is as very inconvenient.

Since most of the test subjects admitted using the smartphone regularly and those people have got used to the one day battery life of these devices, it is possible that the results may be biased by this reason.

3) Data and measurement procedures

Six issues related to data and measurement procedures were taken into account. All issues are dominantly perceived as relevant or highly relevant. Robustness of data measurements, data accuracy and validity, connecting/pairing the wearable devices, and synchronization with mobile phone or Internet were marked as relevant or highly relevant by 31-32 respondents, but there is a high variance on the responses. Additionally, more than 40% of the subjects experienced issues in this subject, although not frequently. Issues with connecting or pairing the wearable devices with smartphones or computes seem to be of special relevance, because 25 (the highest score in this category) mark it as very relevant. This could be also due to the fact, that many respondents (18) had practical experience with it. The remaining two issues are still mostly perceived as relevant, but number of those who find it less relevant is importantly higher, i.e. 8 for exporting of data among various systems and 9 for security and privacy. Exporting of data is to some extent an add-on feature that is no absolutely required for meaningful and successful use of wearable devices, according to the survey results. The predominant selection of being relevant to some extent (14) over being highly relevant (11) is in line with this, too. This could explain the deviation in this issues.

A surprising result is the lowest score in this category for perceived relevance of security and privacy issues (24). But among these 24, 18 respondents mark it a highly relevant. It seems that in terms of privacy and security we deal with two types of users, those who don't care about it much, and those who care a lot. The latter could be excused to some extent, because the dominant reasons for wearable monitoring was monitoring of activity level and sports, followed by sleep and body-weight monitoring. These are not real medical data (i.e. not directly revealing some personal »weakness«, which would otherwise remain secret), and are therefore likely to be considered less sensitive in this sense.

Even more surprising is the actual experience with security and privacy issues. Only 2 respondents report this experience. However, the far dominant answer among the rest is that "*they do not know of having such issue*". The practical experience of all other issues in this category is rather coherent. 14 to 18 respondents report having such experiences.

4) User experience

We analyzed six issues related to usability and user experience with the device and supporting software, including feedback and information provided to the user. In scope of our analysis this category of issues shows the most diverse outcomes. Interaction with supporting web pages or applications is perceived as the most relevant. It slightly outscores the unclear feedback and the design of user interfaces despite the fact, that the latter was the most frequently experienced issue (21) among all in our survey. These results indicate that the respondents are able to distinguish between aesthetic design of user interface and interaction usability issues. On the other hand, none of the issues in this category scored more than half votes (maximum was 16) for being very relevant, which is quite the opposite from responses in the remaining two categories, namely practical daily use, and data and measurement procedures. Correspondingly, number of less decisive answers (i.e. not being highly relevant or highly irrelevant), is higher, too. We could relate this with two facts. First that dealing with various kinds of user interfaces (Web, mobile, computer operating system), including all possible positive and negative aspects of such experience, is common and frequent. This seems to build a kind of resistance among users. And second, design and operation of ICT user interfaces has been studied thoroughly in the past and is addressed with concern by many application developers. Supporting software for wearable devices benefits from positive findings about user experience with software in other domains.

The presentation of raw data is perceived evidently less relevant that any other issue discussed so far. Most (20) response are gathered around the neutral middle position of the scale. We see to reasons for such a result. On one hand among most frequent reasons for using the wearable device was sports (e.g. measuring heartrate) or weight management, where raw data is actually of key importance. Second could be, that the question was not formulated clear enough and the respondents did not fully comprehend what the alternative to raw data would be.

Finally, perspective on issues related to motivation provided for regular and long term use, were most noticeably different from all the other. It was the only issue perceived more as less relevant than relevant (19 vs. 14). As most of our respondents are regular users of wearable trackers and some of them even engaged in fitness industry, only reason to explain this is, that they find motivation for use elsewhere and do not expect supporting applications to do that for them.

5) Adherence and attrition

Results about adherence and attrition are more challenging to be interpreted. It is clear, that getting a new gadget was the most frequent reason for dropping an older one, since 20 of 33 users have had experience with more than one device. Autonomy was mentioned as a frequently experienced issue in daily use, and it seem really to be a major issue for wearable device, since it can lead to adherence, too. Other responses can be summarized in following statements. Next most relevant reason is related to inadequate perceived value of using such a device. Poor robustness and obtrusiveness of the device are important reason for stopping using it. Data and measurement procedures are recognized as a reason, but not a major one. Usability of the device and even more supporting software seem not to be an important reason. The same is true for security and privacy issues.

V. CONCLUSION

Our research provided us an interesting insight into user engagement and factors that influence perceived value of the pervasive wellbeing monitoring. We are aware that in the next step we need to verify statistical reliability and validity of the current results, and fine-tune the survey. We expect to extend the target group and to collect additional survey completions, if needed, to investigate to which extent the results can be statistically generalized to our and other target groups. But even the analysis at this stage shows, that the most of the foreseen issues are perceived as very relevant to the users, and that many of them have had personal experience with these problems, which in addition provides some paths for the manufacturers of wearable devices and software developers in order to foster the general adoption of wearable devices.

Among our future research questions we see e.g. the issues related to security and privacy, the motivational aspects, and the forms of presenting and communicating the results in health and wellbeing monitoring. Based on the feedback on this paper, which we expect to gather during its' presentation, we will try to define a more precise research hypothesis.

As the most promising and influential research and development directions in wearable monitoring we see user interfaces that present information in an efficient way which leads to insights and promotes conscious actions towards an improvement of wellbeing. Complex data analysis procedures could lead to integration of various data sources to provide combined estimations of the required high-level parameters (e.g. activity, stress), to increase data accuracy and persistence, to assure user and usage context along with the measurements, and to sensibly interpret results for application of wellbeing monitoring in blended daily life, e-health and wellbeing applications. In a higher level of abstraction this automatic data analysis may be combined with recommendation engines which could lead to virtual wellbeing coaches.

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REFERENCES

[1] Ledger, D., McCaffrey, D. (2014). Inside Wearables - How the Science of Human Behavior Change Offers the Secret to Long-Term Engagement. Retrieved 7.7.2015 from

http://endeavourpartners.net/assets/Wearables-and-the-Science-of-Human-Behavior-Change-EP4.pdf.

[2] Zheng, Y.L.., et.al. (2014). Unobtrusive Sensing and Wearable Devices for Health Informatics. IEEE Transactions on Biomedical Engineering, 61(5), 1538-1554.

[3] Pantelopoulos, A. and Bourbakis, N.G. (2010). A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis. IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews, 40(1) pp.1-12.

[4] Dolan, B. (2015). Was Apple Watch's health sensor team held back by battery concerns?. Retrieved 7.7.2015 from http://mobihealthnews.com/36454/was-apple-watchs-health-sensor-team-held-back-by-battery-concerns/.

[5] Comstock, J. (2015). Report: Accuracy concerns led Apple to cut advanced health features from Apple Watch. Retrieved 7.7.2015 from http://mobihealthnews.com/40610/report-accuracy-concerns-led-apple-to-cut-advanced-health-features-from-apple-watch/.

[6] Stables, J. (2015). Fitbit Charge skin irritation complaints still plague company. Retrieved 7.7.2015 from http://www.wareable.com/fitbit/fitbit-charge-skin-irritation-complaints-593.

[7] Zetter. K. (2015). Hacker Can Send Fatal Dose to Hospital Drug Pumps. Retrieved 7.7.2015 from http://www.wired.com/2015/06/hackers-can-send-fatal-doses-hospital-drug-pumps/.

[8] Cherry. S. (2013). Hacking Pacemakers. Retrieved 7.7.2015 from http://spectrum.ieee.org/podcast/biomedical/devices/hacking-pacemakers.

[9] Schneier. B. (2008). Hacking Medical Devices. Retrieved 7.7.2015 from https://www.schneier.com/blog/archives/2008/03/hacking_medical_1.html.

[10] Bassi, A., Bauer, M., Fiedler, M., Kramp, T., Kranenburg, R., Lange, S., Meissner, S. (2013). Enabling Things to Talk - Designing IoT solutions with the IoT Architectural Reference Model. Springer Verlag. 7.7.2015. DOI 10.1007/978-3-642-40403-0.

[11] Gravenhorst, F., Muaremi, A., Bardram, J., Grünerbl, A., Mayora, O., Wurzer, G., Frost, M., Osmani, V., Arnrich, B., Lukowicz, P. and Tröster, G. (2015). Mobile phones as medical devices in mental disorder treatment: an overview. Personal and Ubiquitous Computing. 19(2). 335-353.

[12] Christophides, V. and Palpanas, T. (2015), Report on the First International Workshop on Personal Data Analytics in the Internet of Things (PDA@IOT 2014). Retrieved 7.7.2015 from http://www.sigmod.org/publications/sigmod-record/1503/pdfs/11_reports_Christophides.pdf.

[13] Smarr, L. (2011). Quantified Health: A 10-Year Detective Story of Digitally Enabled Genomic Medicine. Strategic News Service Newsletter. Volume 14 (36), 1-28. Retrived 7.7.2015 from http://lsmarr.calit2.net/repository/092811_Special_Letter,_Smarr.final.pdf.

[14] Xu, Y. (2015). Swot Analysis of Domestic Market of Wearable Sports Equipment Based on Internet of Things Technology. International Conference on Artificial Intelligence and Industrial Engineering (AIIE 2015). Retrieved 7.7.2015 from http://www.atlantis-press.com/php/download_paper.php?id=22086.

[15] Ya-Li, Z., Xiao-Rong, D. and Poon, C.C.Y. (2014). Unobtrusive Sensing and Wearable Devices for Health Informatics. IEEE Transactions on Biomedical Engineering. 61(5).

[16] WHO Global Observatory for eHealth. (2011). mHealth - New horizons for health through mobile technologies. Retrieved 7.7.2015 from http://www.who.int/goe/publications/goe_mhealth_web.pdf.

[17] Baig, M.M. and Gholamhosseini, H. (2013). Smart Health Monitoring Systems: An Overview of Design and Modeling. Journal of Medical Systems. 37(2):9898.

[18] ElHelw, M., Pansiot, J., McIlwraith, D., Ali, R., Lo, B.; and Atallah, L. (2009). An integrated multi-sensing framework for pervasive healthcare monitoring. Pervasive Computing Technologies for Healthcare, 2009. PervasiveHealth 2009. pp.1-7.

[19] Mata, P., Chamney, A., Viner, G., Archibald, D. and Peyton, L. (2015). A development framework for mobile healthcare monitoring apps. Personal and Ubiquitous Computing. 19(3-4). 623-633.

[20] Huh, J., Le, T., Reeder, B., Thompson, H.J. and Demiris, G. (2013). Perspectives on wellness self-monitoring tools for older adults. International Journal of Medical Informatics, 82(11), 1092-1103.

[21] CATCH. (2012). Center for assessment of technology and Continuous Health. Retrieved 7.7.2015 from http://www.catch-health.org/.

[22] Shaywitz. (2014). Do Data From Wearables Belong In The Medical Record?. Retrieved 7.7.2015 from http://onforb.es/1tDkS0O.

[23] Davenport, T. (2015). Running on data: Activity trackers and the Internet of Things. Retrived 7.7.2015 from https://www.linkedin.com/pulse/running-data-activity-trackers-internet-things-tom-davenport.

[24] Skorin-Kapov, L., Dobrijevic, O. & Piplica, D. (2012). Evaluating QoE of RPM services: Considering usability aspects. Retrieved 7.7.2015 from http://www.fer.unizg.hr/images/50008067/IJMHCI14-Towards_Evaluating_QoE_of_RPM_Services.pdf.

[25] Martin, T., Kim, K., Forsyth, J., McNair, L., Coupey E. and Dorsa, E. (2013). Discipline-based instruction to promote interdisciplinary design of wearable and pervasive computing products. Personal and Ubiquitous Computing. 17(3). 465-47.