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Internet of Things based Applications using Mobile Computing

Miss. Priyanka S. Padwal[1], Dr. Mrs. Neeta A. Deshpande[2]

ME Scholar, Dept. of Computer Engineering, D Y Patil College of Engineering, Akurdi, Pune, MH, India[1]
Associate Professor, Dept. of Computer Engineering, D Y Patil College of Engineering, Akurdi, Pune, MH, India[2]

Abstract: *As the Internet of Things and the Web of Things are becoming a phenomenon, their interconnection with mobile phone computing is expanding. Mobile phone integrated sensors offer advanced services, which when combined with web-enabled real-world devices located near the mobile user (e.g. body area networks, RFID tags, energy monitors, environmental sensors etc.), have the potential of upgrading the overall user knowledge, perception and experience, encouraging major informed choices and better decisions. This paper serves as a survey of the most significant work performed in the area of mobile phone computing combined with the Internet/Web of Things. A selection of over 50 papers is presented, which constitute the most significant work in the field up to date, categorizing these papers into different domains, according to the area of application (i.e. sports, gaming), the nature of interaction (i.e. participatory sensing, eco-feedback) or the communicating actors involved (i.e. things, people). Open issues and research challenges are identified, analyzed and discussed.*

Keywords*: Mobile computing, Internet of Things, Web of Things, Sensors, Survey.*

I. INTRODUCTION

Technologies such as wireless sensor networks, short-range wireless communications and radio-frequency identification (RFID) have allowed the Internet to penetrate in embedded computing [1], [2]. The Internet of Things (IoT) [3] is becoming reality, as everyday physical objects are becoming equipped with sensors and actuators, being (uniquely) addressable and interconnected, allowing the interaction with them through the Internet. Porting the IP stack on embedded devices was a successful effort [4], [5] and, together with the introduction of IPv6 (which provides extremely large addressing capabilities), facilitate the merging of the physical and the digital world, enabling the IoT to grow faster. Building upon the notion of the IoT, the Web of Things (WoT) [6], [7], [8] reuses well-defined Web techniques to interconnect this new generation of Internet-enabled physical devices. While the IoT focuses on interconnecting heteroge-neous devices at the network layer, the WoT can be seen as a promising practice to achieve interoperability at the application layer. It is about taking the Web as we know it and extending it so that anyone can plug devices into it. The rise of multi-sensory mobile phones with Internet connectivity has helped to reduce the barriers for associating mobile computing with the IoT/WoT. Mobile phone integrated sensors offer advanced capabilities such as measuring prox-imity, acceleration and location or record audio/noise, sense electromagnetism or capture images and videos [9]. These sensing services, when combined with web-enabled physical entities located near the user, have the potential of enhancing the overall user knowledge and experience, helping the user to take more informed choices [10], [11]. Although there exist several survey papers focusing on advances related to the IoT/WoT [12], [13], [14], [15], not any papers -as far as we can ascertain- have yet surveyed the growing interconnection between mobile computing and the IoT/WoT.

II. METHODOLOGY

Before describing the important work in the field, the methodology in collecting this information is explained, this involved three steps: a) collection of the state of the art work, b) clustering of related work, and c) analysis of related work. In the first step, a keyword-based search for conference papers and articles in well-known scientific databases (e.g. IEEE Xplore, ACM, DBLP, ScienceDirect, CiteSeerX) and search engines was performed. Various keywords were used such as ”mobile computing”, ”internet”, ”web”, ”web of things” and combinations of them. Existing surveys on the IoT/WoT and mobile sensing [12], [13], [14], [16], [15], [9] were also studied for relevant efforts. The focus was to pick only papers which followed the main concepts and a design principle of the IoT/WoT [6], [7], excluding papers that used proprietary protocols and in which vendor lock-in was evident. This means that some popular papers in mobile pervasive computing might have been excluded from our survey. Also, some cutting-edge research papers related to the exciting domain of feature- and depth-based identification, tracking of and interaction with the physical world have also been excluded, as these works have not yet become (widely) applied on mobile devices, due to their large processing requirements. Thus, 68 papers in total were firstly identified, performing then a depth search on their most relevant references, increasing the list of papers to 102. In the second step, related work was categorized in clusters according to their topic/area of application. Ten clusters were created, in which the papers were placed with respect to their relevance to each cluster. These clusters are explained in detail in the next section. It is noted that these clusters were aimed to cover more or less the whole spectrum of combining mobile computing with the IoT/WoT. Some clusters had more studies performed than others while some other clusters involved also business cases (not only research efforts). In the final step, each cluster was examined carefully, studying and analyzing each paper sep-arately, recording its summary, contribution and impact to the community, and its overall novelty and importance. After this procedure, at most 8-12 more significant works per cluster were selected, which are described in the next section. Hence, the rest of this survey is based on the analysis performed on the selected papers, as organized in the ten clusters.

III. PARTICIPATORY SENSING

Participatory sensing involves the tasking of mobile de-vices to form interactive, participatory systems that enable individuals in the general public to gather, analyze and share local information, towards the co-creation of knowledge or addressing environmental challenges [17]. The MetroSense project [18] aims at transforming the mobile device into a social sensing platform. It is based on a three stage framework which involves sensing, learning and sharing. In the sense stage, MetroSense leverages mobility-enabled interactions between human-carried mobile sensors, static sensors embedded in the civic infrastructure and wireless access nodes providing a gateway to the Internet, to support the delivery of application requests to the mobile devices and the delivery of sampled data back to the application.

Figure1. Sound exposure through the Noise Tube project

Goldman et al. [19] show the significance of participatory sensing for our daily lives, namely its impact on climatic change. GPS-equipped mobile phones are used to photograph diesel trucks, in order to understand community exposure to air pollution. Odourmap [20] is a communication platform on which citizens and authorities can be involved into the odour management process. Portolan [21] builds signal cov-erage maps performing network monitoring based on crowd sourcing. In NoiseTube [22], mobile phones are used as noise sensors, to measure the personal exposure to noise of citizens, in their everyday environment. Figure 2 presents the sound exposure of a user during a walk in Paris through the NoiseTube project.

The Common Sense project [23] derives design principles for describing data collection and knowledge generation from remote air quality data. In [24], a case study is performed, involving sensors deployed in public areas, shared by different communities. Users get informed of environmental conditions directly from these sensors. The findings indicate sensitivity to environmental factors from the people involved.

Furthermore, participatory sensing can be extended to the health domain. A very nice example is about smartphone applications for melanoma detection [25]. Users use their phones' camera to record unusual spots on their body, and then share with the online community, patients and generalist clinician users who provide feedback and informal diagnosis.

Related work indicates that mobile sensing, both participa-tory and remote, is beneficial to the users and engages them in sustainable actions that improve their community [19], [24]. Mobile users become active members of their communities and raise their awareness towards their surroundings, while barriers for delivering large-scale environmental campaigns are reduced [17]. It constitutes an excellent approach for co-creating advanced knowledge based on a participatory scheme, and it could be used even for medical advice [25]. We need to comment however that these positive effects are often transient and only persist as long as users engage actively with the application. The evolution of participatory sensing is mobile crowd sensing for large-scale sensing [26], [27], which enables a broad range of applications including urban dynamics mining, public safety, traffic planning and environment monitoring.

IV. ECO-FEEDBACK

Eco-feedback mobile applications provide feedback to the users about their impact on the physical environment, such as their personal energy footprint (water, electricity, driving habits etc.) or useful information and knowledge about the existing local environmental conditions. Regarding eco-feedback on personal consumption, Ener-gyLife [28] developed a mobile application to provide electric-ity consumption feedback about domestic electrical appliances and conservation tips. In UbiLense [10], users can utilize their mobile phones as magic lenses to view the energy consumption of their home devices just by pointing on them with the phone's camera. Ambient meter [29] is a mobile device that displays the level of energy consumption of the place it is currently located in, by changing its color from green (i.e. the amount of energy consumed in the room is low) to red (i.e. a lot of energy is consumed).

Figure2. The eMeter system

Moreover, the eMeter system [30] allows users to interac-tively monitor, measure, and compare their energy consump-tion at a household and device level, by making use of a smart electricity meter and getting consumers ”into the loop” of energy monitoring, as displayed in Figure 3. Disaggregation of the electrical consumption of individual appliances within a household by means of a mobile application is discussed in [31], with accuracy rates of 87%.

Social Electricity [32] is a mobile application that allows people to compare their energy consumption with their online friends, neighbors, similar peers etc., in order to perceive whether their footprint is high. In this case, the application assists the user to reduce his/her consumption through person-alized tips and educational material. OPOWER is a US com-pany that offers similar services through mobile phones [33]. PowerPedia [34] enables users to identify and compare the consumption of their residential appliances to those of others through a mobile application that uploads the measured data to a community platform. It thus helps users to better assess their electricity consumption and draw effective measures to save electricity. Furthermore, products such as CubeSensors combine sensors and a mobile application to help people understand how their home or office is affecting their health, comfort and productivity. LoseIt [36] is an example of a nutri-tion tracking tool, which offers a barcode scanner for providing information on various processed food options available at the supermarkets.

Eco-feedback through mobile phones can also help to mitigate the negative effects of the increasing urbanism, to the people and the city as a whole. Urbanism implies that traffic is increased, levels of pollution are rising, some areas become dirty and polluted while health and security are compromised. To address some of the challenges implied by increasing urbanism, UrbanRadar [11] is a location-based application that discovers and interacts with environmental services offered by Web-enabled urban sensors. UrbanRadar allows the user to create urban mashups, defined as opportunistic web mashups that integrate real-world services, validated only when the local environmental conditions support the sensor-based Web services defined by these mashups. An example urban mashup is displayed in Figure 4. In this example, a sensor measuring levels of noise, a pollution sensor and a street camera combine their services to infer the traffic conditions existing at a city center. Air quality and pollution is studied in [37], using specialized sensors embedded in prototype mobile phones. By means of UrbanRadar, the work in [38] investigates and discusses the acceptance, influence, usefulness and potential of these services to mobile users, towards the vision of a real-time digital city. This case study suggested eleven design principles, which the author considers important for future mobile applications that deal with remote sensing of the physical and urban environment.

Timely eco-feedback can influence residents to reduce their consumption by a fraction of 5-15%, through more informed choices and better energy management [39]. It is important however to consider the fact that the positive effect might not be persistent for long time [40]. Mobile applications make the eco-feedback experience more personal, effective and convenient. Mobile applications on urban remote sensing can contribute toward the active involvement of citizens with their urban landscape.

V. SPORTS

Sports and recreational activities constitute one of the most rapidly growing areas of personal and consumer-oriented IoT and WoT technologies [41]. WoT-enabled mobile applications focusing on sports include various physical sensors, installed usually on the body or the clothes of the user, and which are used during sport activities to record various metrics and help to improve the user's performance. The mobile phone in these cases records the measurements of the sensors and shares this information to the web. A typical example is the BikeNet application [42], which aims to give a holistic picture of the cyclist experience, not only by measuring various metrics (speed, distance traveled, calories burned, heart rate etc.) but also by sharing this information within the online cycling community. A snapshot of the web portal of BikeNet is illustrated in Figure 5.

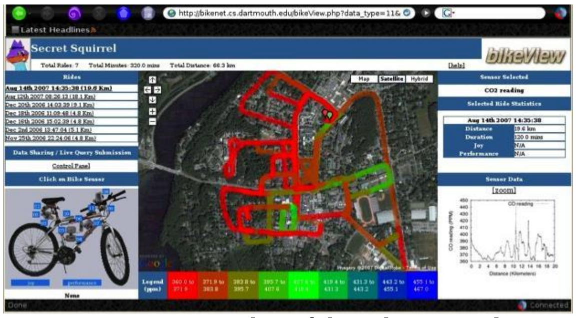

Figure 3. Snapshot of the BikeNet application

Also, measuring physical activity and promoting an active way of life is a subject of research. Mobile Teen [43] uses the mobile phone's built-in motion sensor to automatically detect likely sedentary behavior. Fit Buddy [44] helps users track their personal fitness statistics focusing on step counting from both walking and running using a smartphone. Commercial solutions also exist, such as the Nike+ Sports Sensor [45], which puts a super smart sensor in shoes and uses pressure data in combination with an accelerometer to calculate movement. This information can then be recorded by smart watches and mobile phones and then shared through the web, to challenge online friends and other online users, set personal goals, train smarter, improve performance etc. Apple Watch [46] has an excellent design and co-exists with the user's mobile device to track daily activity, encouraging the user to keep moving for health and fitness. Similar products and services are offered by other large companies such as Garmin [47] and Samsung [48] (smart watches), as well as Suunto [49] (sports watches, dive computers and precision instruments). The aforementioned mobile applications make the sports experience more entertaining and fun for the user, helping him/her to improve performance through competitions and comparisons with friends, similar peers and the online community, encouraging a more active way of living. This community can create new useful knowledge, as for example the sharing of nice cycling pathways [42] recently discovered.

CONCLUSION

This paper performed a survey on the most significant efforts in the area of mobile computing combined with the IoT/WoT, an exciting research domain in which mobile phone applications exploit the sensing of the real world through internet/web technologies for providing better information and more advanced knowledge to the user, helping him/her to take more informed decisions during everyday life.

More than 100 papers have been identified, analyzed and divided in ten different categories, which represent either the area of application (i.e. health, sports, gaming, transportation, agriculture), the nature of interaction (i.e. participatory sensing, eco-feedback, actuation and control) or the communicating actors involved (i.e. things, people). Open issues and research challenges at this research domain have been identified and discussed. Summing up, the practice of combining mobile computing and the IoT/WoT seems to offer tremendous new opportunities in many real-life domains, enabling the seamless integration of devices, services and information that can create advanced knowledge, more informed reasoning and decision-making, as well as encouraging big data analysis, more use of persuasive and engagement techniques, emotions analysis and personalization. However, this openness comes together with various risks in privacy, security and reliability of information, and also various challenges such as search and discovery of devices, services and information on the fly, which is still an open issue in the WoT world. Finally, the most critical element seems to be a need for large business cases which could prove the market value of mobile computing and the IoT/WoT, and which could eventually lead to wide-scale adoption of this practice, inspiring even more research and development in satisfying the risks and challenges at this field.

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