People as Sensors and Collective Sensing-Contextual Observations Complementing Geo-Sensor Network Measurements

Bernd Resch

Abstract Ubiquitous sensor networks and Location-based Services can potentially assist in taking decisions in near real time in a variety of application areas such as public safety, traffic management, environmental monitoring or in public health. Yet, analysing our surroundings in real time is still a major challenge due to sparsely available data sources for real-time monitoring. The innovative concept of People as Sensors defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but in which also humans can contribute their individual 'measurements' such as their subjective sensations, current perceptions or personal observations. This chapter contains a disambiguation between the terms People as Sensors (people contributing subjective observations), Collective Sensing (analysing aggregated anonymised data coming from collective networks) and Citizen Science (exploiting and elevating expertise of citizens and their personal, local experiences). Then, the particular significance of integrating the People as Sensors concept with established LBS, data analysis and visualisation systems is elaborated. Finally, the paper discusses current challenges, points out possible solutions, and pin-points directions for future research areas.

Keywords People as sensors · Human observations · Collective sensing · Location-based services · Privacy

B. Resch (✉)
SENSEable City Lab, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
e-mail: bernd.resch@geog.uni-heidelberg.de

B. Resch
Institute of Geography–GIScience, University of Heidelberg,
Berliner Street 48, 69120 Heidelberg, Germany

B. Resch
Institute for Geoinformatics and Remote Sensing, University of Osnabrück,
Barbara Street 22b, 49076 Osnabrück, Germany

J. M. Krisp (ed.), *Progress in Location-Based Services*,
Lecture Notes in Geoinformation and Cartography, DOI: 10.1007/978-3-642-34203-5_22,

1 Introduction

Ubiquitous sensor networks can potentially assist in taking decisions in near real time in a variety of application areas such as public safety, traffic management, environmental monitoring or in public health (Resch et al. 2010a) Yet, analysing our surroundings in real time is still a major challenge due to sparsely available data sources for real-time monitoring.

The same issue applies to Location-based Services (LBS). LBS' potential economic value has been estimated around 20 billion US Dollars in 2010. But neither LBS nor smartphone-based apps could fulfil those enormous expectations. According to Beinat et al. (2007), reasons for this development comprise uncertainties in smartphone positioning, lacking usability, uncontrolled growth of non-standardised semantic models, and particularly a lack of personalised contextual information.

On the data analysis side, a significant limiting factor is that Geographic Information Systems (GIS) and GIS-based Spatial Decision Support Systems (SDSS) are often not—or only conditionally—suitable for the integration of measurement data in real time. Current systems are primarily designed for integrating quasi-static data without high spatio-temporal fluctuations (Resch et al. 2010a). This is partly due to the fact that geo-data is per definition historic and so far, geospatial processing has focused on analysing static data, with low temporal fluctuations.

These deficiencies have prevented the realisation of the comprehensive vision of *'People as Sensors'* up to now, which is currently being advanced in a number of academic and corporate research projects, for instance Nokia's 'Wearable Eco-Sensor' concept (Nokia 2012), On Line Disaster Response Community (Laituri and Kodrich 2008), or Lift Lab (Girardin et al. 2008).

People as Sensors defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but in which also humans can contribute their subjective 'measurements' such as their individual sensations, current perceptions or personal observations. These human sensors can thus complement—or in some cases even replace—specialised and expensive sensor networks. Throughout recent literature, the term *'People as Sensors'* is used interchangeably with 'Citizens as Sensors' (Goodchild 2007) or 'Humans as Sensors' (Forrest 2010). This chapter also aims to establish a clear disambiguation between the terms *'People as Sensors'* , 'Collective Sensing' and 'Citizen Science' in Sect. 2 of this chapter.

One driver towards the vision of *People as Sensors* and ubiquitous LBS is the diminishing digital divide on a global scale. The digital divide is basically explained by two factors: (1) that access to Internet and other information and communication technologies (ICT) is unevenly distributed throughout the world and also within countries; and (2) that this imbalance has profound societal effects in that people with access to modern communication technologies have higher chances for social and economic development. While the digital divide within countries is still strongly affecting the degree of access to information and knowledge, the global digital divide is decreasing due to the fast rise of ICT markets in China, India, South-East Asia, South America and Africa. Mobile phone penetration has been at 76.2 % of the world's population in 2010, where it is at 94.1 % in the Americas and at 131.5 % in CIS (Commonwealth of Independent States) (International Telecommunication Union 2010). The two fastest growing mobile phone markets China and India are currently facing penetration rates of 64 and 70 %, which makes a total number of 1.69 billion subscribers.

Another supporting factor for the concept of *People as Sensors* is the exponential growth of the number of Internet users. Prognoses state that the number of people who use the Internet will drastically increase between 2010 and 2020—from 2 billion Internet users in 2010 to more than 50 billion connected devices in 2020. This potential is a strong driving force towards the realisation of the concept of *People as Sensors*.

The remainder of this chapter, which partly builds upon previous research (Resch et al. 2011), is structured as follows. After this introduction, Sect. 2 comprises a disambiguation on the terms of*'People as Sensors'* , 'Collective Sensing' and 'Citizen Science'. The subsequent section contains the conceptual and technical description of a particular implementation called OpenSensTracker. Thereafter, the broader significance of *People as Sensors* is discussed, and challenges and future research avenues are laid out before the chapter ends with a short conclusion.

2 A Disambiguation: People as Sensors, Collective Sensing and Citizen Science

As mentioned in the introductory section of this chapter, the term ***People as Sensors*** can basically be used interchangeably with Humans as Sensors and Citizens as Sensors. *People as Sensors* describes a measurement model, in which people act as non-technical sensors with contextual intelligence and comprehensive knowledge. Like this, measurements are not created absolutely reproducibly by calibrated sensors, but through personal and subjective observations. Such observations could be air quality impressions, street damages, weather observations, or statements on public safety, submitted via dedicated mobile or web applications (including e.g. Twitter). Figure 1 shows a screenshot of Waze (Waze 2012), a smartphone app allowing people to send their personal traffic reports, which are directly used in other persons' routing requests.

The central advantage of this approach is that no cost-intensive physical sensor networks have to be deployed, but people can use their everyday's devices (smartphones, desktop computers, tablet PCs etc.) to enter their observations into a specialised application or data warehouse. The essential drawbacks of the People of Sensors concept are limited comparability and interpretability of the 'sensed' data. As semantics research has shown, academic solutions cannot be imposed on

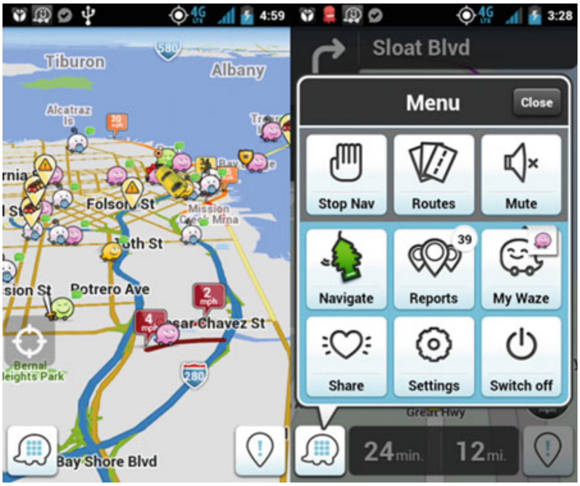

Fig. 1 Waze map (*left*) and input interface (*right*). (Waze 2012)

specific communities. Hence, other semantic models have to be found to extract information from human observations. These are discussed in the Sect. 5.

Consequently, the *People as Sensors* approach will not be able to replace current sensor network developments in the short term, but only complement them. This can be useful in a variety of application domains, in which objective measurements by sensors are highly expensive and highest measurement accuracy is not an absolute requirement. Here, the term ‘observation’ seems more suitable than ‘measurement’.

One example, in which this kind of volunteered data was of invaluable importance, was the earthquake including the following tsunami in Japan in March 2011. In this case, the Tweet-o-Meter (UCL Centre for Advanced Spatial Analysis 2012) application has been used to find anomalies in Twitter activity. Right after the earthquake, people started to post status reports, video streams, and conditions of destroyed houses and cities, which could be interpreted in near real time as an indicator for an extraordinary event. Furthermore, information could be semantically extracted from personal comments and posts.

A related concept is *Participatory Sensing*, in which a number of persons with a common goal in a geographically limited area contribute geo-referenced data via their end user devices such as smartphones (Zacharias et al. 2012). From this definition it is evident that the term Participatory Sensing is highly similar to *People as Sensors*, but its definition is a little bit more restricted in terms of input devices, data acquisition and information processing.

Secondly, we are currently witnessing a fast rise of **Collective Sensing** approaches. This methodology tries not to exploit a single person’s measurements and data. Thus, it is similar to User-generated Content (UGC) based and crowdsourcing approaches. However, Collective Sensing analyses aggregated anonymised data coming from collective networks, such as Flickr, Twitter, Foursquare or the mobile phone network. Like this, we can gain a coarse picture of the situation in our environment without involving personal data of single persons.

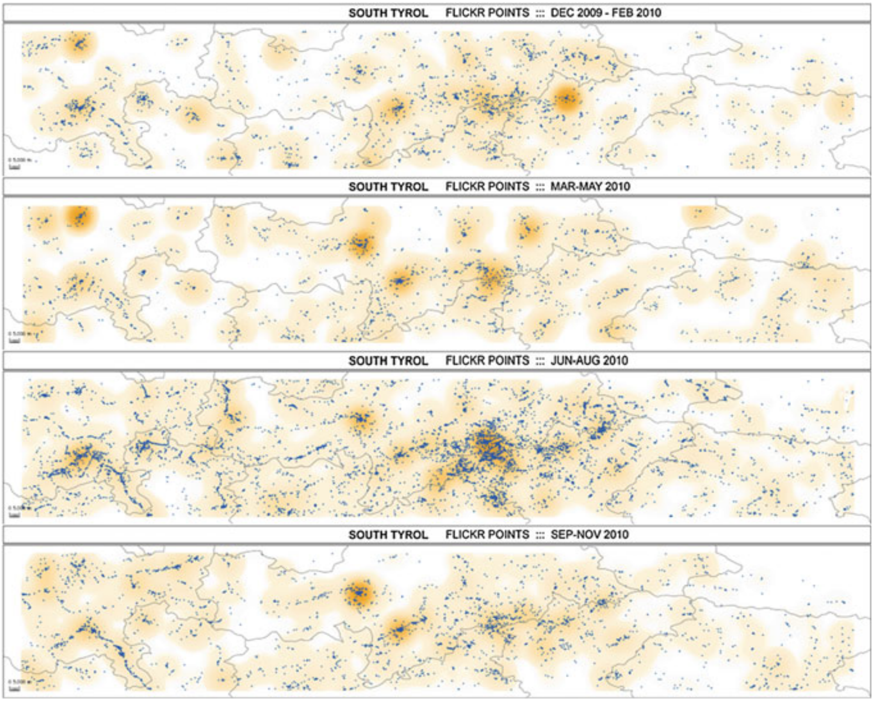

Fig. 2 Location-based tourist dynamics analysis using collective sensing technologies. (Sagl et al. 2012)

In contrast to *People as Sensors*, Collective Sensing is an infrastructure-based approach, which tries to leverage existing ICT networks to generate contextual information. Unlike smartphone-based or specialised web apps, which examine single input data sets, Collective Sensing holistically analyses events and processes in a network. For instance, increased traffic in the mobile phone network might be an indicator for the presence of a dense crowd of people (Reades et al. 2007). This information is generated without having to use a single person's data and their personal details.

Examples for exploiting collective information include using data from mobile phone networks to sense and influence urban dynamics (Reades et al. 2007; González et al. 2008), or leveraging Flickr photos to assess seasonal tourist behaviour (Sagl et al. 2012), which is depicted in Fig. 2 for the region of South Tyrol in Italy.

Finally, the term **Citizen Science** plays a key role in the context of *People as Sensors*. Citizen Science basically states that 'through the use of sensors paired with personal mobile phones, everyday people are invited to participate in collecting and sharing measurements of their everyday environment that matter to them' (Paulos et al. 2008). In other words, citizens augment their role, becoming agents of change by uncovering, visualising, and sharing real-time measurements from their own everyday environment by exploiting and elevating their expertise

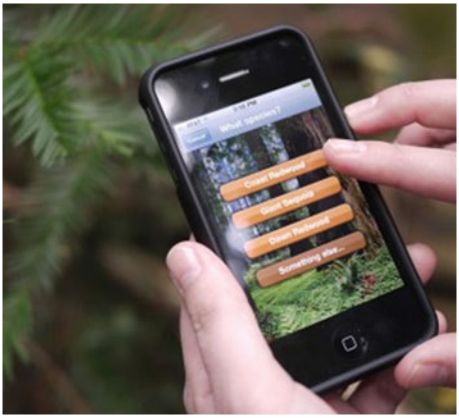

Fig. 3 Redwood watch application to monitor redwood forests (Save the Redwoods League 2010)

and their personal, local experiences. An example for promoting the Citizen Science concept is the 'Citizen Science—Community Involvement Today and in the Future' grant programme by the US Environmental Protection Agency (EPA) (US EPA 2012), which aims to encourage individuals and community groups in New York City to collect information on air and water pollution in their communities, and seek solutions to environmental and public health problems.

In consequence, researchers hope that public understandings of science and environmental issues will be improved and can have access to larger and more detailed data sets coupled with local knowledge. This access to environmental data of the city also becomes a tool to raise the citizen awareness of the state of their environment. Figure 3 shows the 'Redwood Watch' location-based application, which exploits Citizen Science to predict the growth of redwood forests (Save the Redwoods League 2010).

Concluding, Citizen Science can be considered a sub-part of *People as Sensors* in that users (citizen scientists) need to have some knowledge in a certain area—ranging from bird sighting to air pollution reports or wild animal classification. In effect, citizen science aims to exploit and elevate the local expertise of citizens and their personal, local experiences across their lives.

Table 1 summarises the comparison of the discussed concepts of *People as Sensors*, Collective Sensing and Citizen Science according to the following criteria.

- *Voluntary/Involuntary*: whether contributing people voluntarily (dedicatedly) share their data for further (geospatial) analysis or decision-making
- *Content*: type of data, which are contributed
- *A Priori Knowledge*: required knowledge of the user
- *Contextual Data*: whether the contributed data contain harvest contextual intelligence, for instance a person's local knowledge
- *Reliability*: quality level of the generated data and contributors' trustworthiness
- *Analysed Datasets*: whether single (individual) datasets are analysed or spatially and temporally aggregated (anonymised) data are used
- *Specific Infrastructure*: whether additional dedicated infrastructure is necessary to collect data

Table 1 Comparison of concepts

	People as sensors	Collective sensing	Citizen Science
Voluntary/ Involuntary	Voluntary	Involuntary	Voluntary
Content	Layman Observations	Raw geo-data (images, tags,…)	Semi-professional Observations
A priori knowledge	Medium	Low/none	High
Contextual data	Yes	Yes	Yes
Reliability	Medium	Mediocre	Good
Analysed datasets	Individual	Aggregated	Individual
Specific infrastructure	No	No	No

A number of applications have been developed in the area of *People as Sensors* throughout the last years. On the one hand, these are specialised applications and technologies to allow people to transmit their sensations; on the other hand, we see a number of data mining-like approaches that try to exploit existing ICT infrastructure data. One central issue with most existing systems is their implementation in singular mobile apps or monolithic and use-case-centred mobile applications.

3 OpenSensTracker: Concept, Implementation and Use Cases

OpenSensTracker is a concrete realisation in the area of *People as Sensors*. Similarly to the concept of Volunteered Geographic Information (VGI) (Goodchild 2007), the application allows people to send geo-referenced data to a data analysis and visualisation system via their smartphone (Resch et al. 2011). Like this, location data can be transmitted along with subjective 'measurements' (human observations) to a central server directly from a person's smartphone via a mobile network, e.g. the cellular network or a Wi-Fi network.

The OpenSensTracker application is characterised through the design of a very simple, easily usable and intuitive interface to minimise usage requirements and technical capabilities on the user's side. The smartphone application allows people to send their personal observations and sensations to a spatial decision support system using pre-defined classes—e.g. to submit air quality data on a traffic light based classification system (green = good, yellow = medium, red = bad). Figure 4 shows the user interface for sending observations and configuring the application.

The establishment of pre-defined classes is basically a trade-off between giving the user the opportunity to freely insert their observations and simplifying the generation of information from the 'sensed' data. Naturally, the restriction to predefined classes results in a certain fuzziness of the observations. This compromise will be discussed in Sect. 5.

Fig. 4 Mobile *people as sensors* application using pre-defined classes

A central advantage of the OpenSensTracker application is its modular structure and its broad reliance on design templates. This allows for simple adaptability of the app to a variety of application domains by just chaining the frontend. Application areas comprise public health (biometric surveillance of endangered patients), environmental monitoring (citizen information about local air quality), urban planning (feedback about street damage) or tourism (rating of slope conditions or service on skiing huts). Furthermore, this kind of user-generated content (UGC) is rapidly gaining importance in the area of disaster management, e.g. for the assessment of status data (severity of people's injuries, houses' degree of damage etc.) or for geo-tagging (current location of injured persons).

4 Adding Value: Integrating Human Measurements Into Geo-Service Infrastructures

The actual value of location-based *People as Sensors* applications is the integration of subjective observations into established analysis systems, their combination with sensor measurements and subsequent information provision to different users and user groups. Figure 5 illustrates such a system, the Live Geography infrastructure (Resch et al. 2010a) that provides components for data acquisition, sensor data access, sensor fusion, process modelling, real-time data analysis and information visualisation based on open (geospatial) standards.

The integration of human observations into comprehensive infrastructures for data analysis and decision support opens up wholly new possibilities for creating

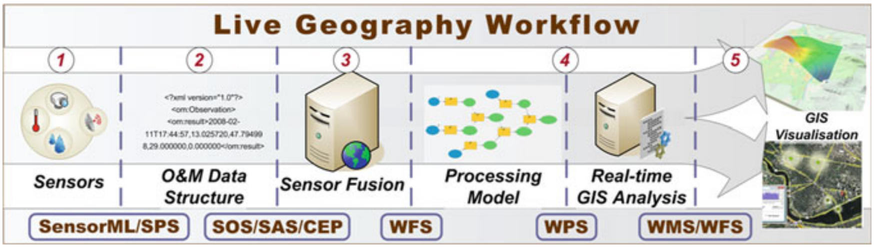

Fig. 5 Live geography workflow for the integration of measurements in real time

situational awareness. Particularly the use of open standards such as the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS) allows for simple integration of user-generated observations into geospatial data analysis and visualisation systems.

From a technical viewpoint, this integration can happen via pull-based mechanisms (OGC SOS, Keyhole Markup Language—KML or GeoRSS) or via push-based alerting services (OGC Sensor Alert Service—SAS, OGC Sensor Event Service—SES or Common Alerting Protocol—CAP).

This approach allows for the integration of human observations in real time and offers a number of advantages:

- Direct on-the-fly integration in GI systems without interim storage
- Mitigation of the risk of a performance bottleneck caused by too large data volumes
- No ‘single point of failure’ through a federated service-based sensor architecture
- No need for a use case motivated web portal for sensor data provision (but the use of standardised sensor services)

Figure 6 shows the basic workflow for integrating human observations and providing them via a variety of standardised interfaces. Currently, data are sent to the Geo-Tracking & Fusion Server by a simple HTTP GET request containing the measurements as GET key-value pairs. The next step will be to integrate those data via a transactional instance of the Sensor Observation Service (SOS-T).

5 Challenges and Future Research Avenues

As the concepts of *People as Sensors* and LBS are comprehensive in terms of technologies, semantic consistency, data integration and workflow integration, a number of research challenges and future research avenues can be identified. These can be divided into technical and technological, methodological, and privacy and legislation issues.

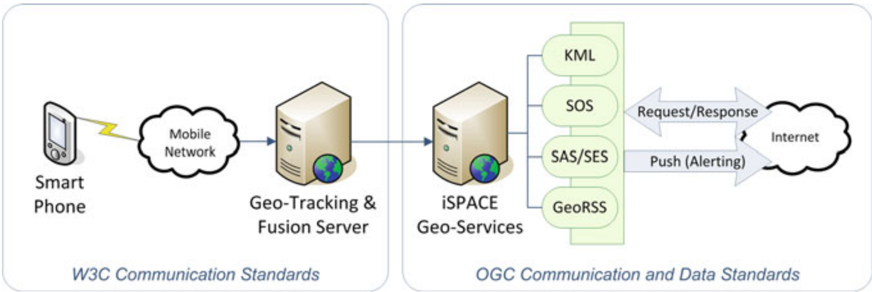

Fig. 6 Integration of human observations into analysis and visualisation systems

5.1 Technical and Technological Aspects

As mentioned above **Volunteered Geographic Information** (VGI) plays a key role in the context of *People as Sensors*. We are currently witnessing an overwhelming willingness of people to share their impressions, personal observations and emotional states in (semi-) public comments. These range from Facebook posts or Twitter tweets to commented geo-referenced image uploads onto Flickr. As elaborated above, this kind of contextual location-based information can potentially build a strong basis for operational real-time strategies in areas such as public safety, dynamic traffic management systems or urban planning. Yet, we are currently facing technical challenges in terms of connectivity, real-time integration of observations, sensor fusion and semantic models. The latter aspect will be discussed in the following sub-section.

In terms of integrating human observations with existing sensor and analysis systems, the creation of a **standardised measurement infrastructure** using well-conceived data and service standards is a major technical challenge. An essential factor will be the integration of new developments with existing community projects such as Ushahidi or Twitter to create new possibilities for qualitative information fusion. This will potentially result in increased LBS-driven situational awareness and enhanced Common Operational Pictures (COP). Furthermore, this development supports infrastructure-oriented approaches and directives such as Global Monitoring for Environment and Security (GMES), Infrastructure for Spatial Information in Europe (INSPIRE) and the Shared Environmental Information Space (SEIS).

5.2 Methodology: Semantic Models, Quality Assurance and VGI

A central issue in the integration of human observations with existing measurement systems is the definition of **consistent semantic encodings**. This requires standardisation on two levels—firstly on sensor data level (encodings for measurements) and secondly on phenomenon level (measurand encodings). Current research comprises 'Human Observations' (Förster et al. 2010) on data level and the Sensor Observable Registry (SOR) on phenomenon level. These top-down standardisation approaches can potentially build the basis for further development and distribution of community-based integration platforms such as *Crowd-Map* (http://www.crowdmap.org), *Singapore Live*! (http://senseable.mit.edu/singaporelive) or *GeigerCrowd* (http://www.geigercrowd.org).

A connected methodological issue in the field of semantics is **representativeness in VGI**. This question probably has to be tackled by a combined bottom-up/top-down approach. In bottom-up approaches, user groups and communities define their own semantic objects and interrelations between these in separate taxonomies. In contrast, top-down approaches try to define semantic rules and ontological relations as generically as possible—mostly before actual applications exist and decoupled from real-world use cases. Only the combination of those approaches can result in trans-domain semantic models, which are linked via object relations.

In these research areas of semantic encodings and representativeness of VGI, new and innovative approaches have to be found as previous ontology research has not kept its promises because these developments are too inflexible, ambiguous and bound to a specific community. Seminal approaches comprise **Linked Data** (for trans-domain definition of semantic rules and for flexible and generic definition of ontological relations), and **semantic search** (for natural language based search portals).

Furthermore, the requirement of high-quality information seems to be self-evident, but has not been tackled thoroughly for real-time geo-sensor networks and *People as Sensors* based approaches. Those systems, including the OpenSensTracker implementation, make use of pre-defined classes (categories), as described above. One disadvantage of this approach is the resulting **uncertainty** in the observed phenomenon, which emerges from different perceptions of every 'sensor' through people's subjective views of their environment. This issue can be solved by the definition of standardised uncertainty factors to qualitatively describe phenomena and their observations, which guarantees objectivity and lowers usage barriers for specialised *People as Sensors* applications.

If this development of increasing availability of user-based information generation continues, we will soon face a vast amount of data contributed by a variety of different data producers—mostly non-quality assured data stemming from private observations or sensor networks. Although we experience quickly increasing awareness of the opportunities of digital mobile communication and LBS, the question arises how we can dedicatedly **engage people** to contribute actively being 'human data sources'. This is necessary in order to leverage user-generated information in areas such as environmental monitoring, emergency management, traffic monitoring, or e-tourism. An important but yet poorly research issue is the use of incentive schemes to encourage people to contribute their data. Current approaches mostly comprise 'feedback' and 'gamification', but their practical suitability has not been fully proven yet.

The concept of *People as Sensors* naturally raises the question of trustworthiness of these data. Thus, automated **quality assurance** mechanisms have to be developed for uncertainty estimation, dynamic error detection, correction and prevention. In this research area, we are currently seeing different approaches in development including Complex Event Processing (CEP) (Resch et al. 2010b) for error detection, standardisation efforts for representing uncertainty in sensor data (e.g. Uncertainty Markup Language–UncertML) (Williams et al. 2008), or proprietary profiles to define validity ranges for particular observations. Only when these questions are solved, reliability and completeness of recommendations can be ensured.

Up to now quality analysis on VGI (e.g. Zielstra and Zipf 2010; Helbich et al. 2010) focused on completeness as well as geometrical and semantic accuracy, but considered only few timeslots and neglected the (near) real-time requirement of many sensor-based applications. Apart from the creation real-time sensor fusion mechanisms, VGI can also be used to improve the data quality through **intelligent algorithms**, as Hagenauer and Helbich (2012) show.

Another critical issue in the area of *People as Sensors* is the integration of user-contributed observations with established **decision-making workflows**. Research has to be performed on how to combine these data with analysis and visualisation tools and algorithms while preserving the working structures of professionals in a variety of areas. This requires development of task-oriented, user-tailored and transparent data integration and (sensor) fusion mechanisms.

5.3 Protecting People's Privacy

A crucial question in the context of *People as Sensors* and LBS is how we can **preserve people's privacy** dealing with user-generated information and partly personal data. In terms of privacy, the claim might arise that we need to be aware of our personal and private data *before* we share them. This also raises the need to discuss the concept of U-VGI, i.e. Un-Volunteered Geographic Information, in contrast to VGI. For instance, collective sensing approaches exploit anonymised data from digital networks (e.g. by deducing crowd movements from traffic distribution in the cell phone network) even though people have not intended to share their data in this way.

The essential question in this context, however, is *how* we can raise awareness of ways to deal with that matter. Terms and conditions of digital services and technology are mostly hardly understandable to non tech-experts. Thus, more simple and binding ways of communicating this kind of information have to be found.

Another central issue in deploying human observation based monitoring systems is the personal impact of fine-grained urban sensing, as terms like 'air quality' or 'pollutant dispersion' are only surrogates for a much wider and more **direct influence** on people, such as life expectation, respiratory diseases or quality of life. This raises the demand of finding the right level of information provision. More

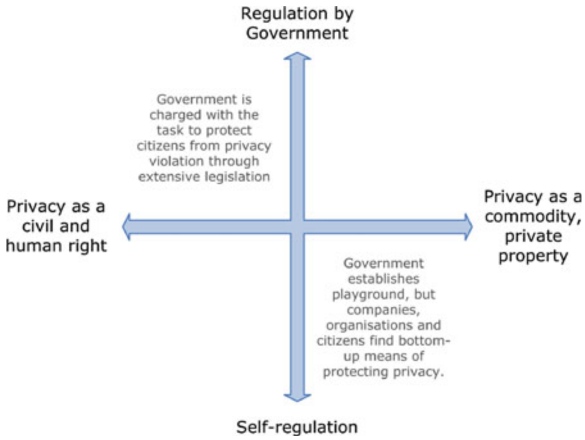

Fig. 7 Understanding of privacy versus the government's role in regulation

accurate, finer-grained or more complete information might in many cases not necessarily be worthwhile having, as this could allow for drawing conclusions on a very small scale, in extreme cases even on the individual. This again could entail a dramatic impact in a very wide range of areas like health care, the insurance sector, housing markets or urban planning and management.

As *People as Sensors* based systems and LBS are oftentimes dealing with personal or individually significant data, **legal frameworks** have to be developed on national, trans-national and global levels to protect those data. The largest limiting factor in this regard is the varying interpretation of 'privacy' in different parts of the world. For instance, privacy can be traded like an economic good by its owner in the USA, whereas it is protected by law in the European Union. This means that supra-national legislation bodies and initiatives are called upon to set up appropriate world-wide regulations. As shown in Fig. 7, legislation and governments play a highly different role in these two settings.

This also includes the critical question of **data ownership**—who owns the data: the data producers (i.e. the citizens or a mobile phone network operator), the institutions that host a system to collect data, or the data providers? Furthermore, if sensitive data is analysed to produce anonymised information layers, who is responsible if decisions that are based on this information are wrong due to lacking quality of the base data? In conclusion, the issues of privacy, data ownership, accessibility, integrity and liability have to be tackled thoroughly all at once and not separately from each other.

In case of tracking applications or services, in which personal data are involved, people should have an **opt-in/opt-out** possibility. This means that users can decide themselves whether they want to use the application—and also withdraw their consent—being aware of the type and amount of data that is collected and transmitted.

6 Conclusion

Ubiquitous sensor networks and LBS can potentially assist in taking decisions in near real time in a variety of application areas such as public safety, traffic management, environmental monitoring or in public health (Resch et al. 2010a). Yet, analysing our surroundings in real time is still a major challenge due to sparsely available data sources for real-time monitoring.

The innovative concept of *People as Sensors* defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but in which also humans can contribute their individual 'measurements' such as their subjective sensations, current perceptions or personal observations. These human sensors can thus complement—or in some cases even replace—specialised and expensive sensor networks. Throughout recent literature, the term *'People as Sensors'* is used interchangeably with 'Citizens as Sensors' (Goodchild 2007) or 'Humans as Sensors' (Forrest 2010).

This chapter tries to establish a distinct disambiguation between the terms *People as Sensors* (people contributing subjective observations), *Collective Sensing* (analysing aggregated anonymised data coming from collective networks) and *Citizen Science* (exploiting and elevating expertise of citizens and their personal, local experiences).

Furthermore, the particular significance of integrating the *People as Sensors* concept with established LBS, data analysis and visualisation systems is elaborated. Therefore, a special smartphone-based application called OpenSensTracker has been developed, which allows transmission of location data along with subjective 'measurements' (human observations) to a processing service directly from a person's smartphone via a mobile network.

In the course of the presented research, three main research challenges in the area of *People as Sensors* have been identified: methodological issues, technical/technological problems, as well as privacy and legislative questions. This chapter discussed these challenges, pointed out possible solutions, and pin-pointed ideas for future research areas.

Concluding, it can be stated that *People as Sensors* can potentially play a complementary key role in supporting decisions and holistically assessing our environment in a broad variety of application areas. Yet, a number of research questions are to be solved including semantic information extraction, privacy preservation, engaging people and uncertainty modelling.

Acknowledgments The author would like to thank all involved researchers and external contributors, from which the publication Resch et al. (2011) originated. This was a strong foundation for the presented research. Furthermore, a particular 'thanks' goes to all people at University of Osnabrück, Research Studios Austria, Massachusetts Institute of Technology and Salzburg University of Applied Sciences who offered their valuable thoughts.

References

Beinat E, Steenbruggen J, Wagtendonk A (2007) Location awareness 2020—A foresight study on location and sensor services. Report E-07/09, Vrije Universiteit Amsterdam, Spatial Information Laboratory, May 2007

Forrest B (2010) Humans as sensors. LBX J. http://www.lbxjournal.com/articles/humans-sensors/260057. Accesed on 21 March 2012

Förster T, Jirka S, Stasch C, Pross B, Everding T, Bröring A, Jürrens E (2010) Integrating human observations and sensor observations—the example of a noise mapping community. In: Towards digital earth workshop at future internet symposium 2010 (CEUR proceedings 640), 20 Sep 2010, Berlin, Germany

Girardin F, Calabrese F, Dalfiore F, Ratti C, Blat J (2008) Digital foot-printing: uncovering tourists with user-generated content. IEEE Pervasive Comput 7(4):36–43

González MC, Hidalgo CA, Barabási A-L (2008) Understanding individual human mobility patterns. Nature 453:779–782

Goodchild MF (2007) Citizens as sensors: the world of volunteered geography. GeoJournal 69(4):211–221

Hagenauer J, Helbich M (2012) Mining urban land use patterns from volunteered geographic information using genetic algorithms and artificial neural networks. Int J Geograph Inf Sci (IJGIS) 26(6):963–982

Helbich M, Amelunxen C, Neis P, Zipf A (2010) Investigations on locational accuracy of volunteered geographic information using OpenStreetMap data. In: GIScience 2010 Workshop, Zurich, Switzerland, 14–17 Sep 2010

International Telecommunication Union (2010) Key global telecom indicators for the world telecommunication service sector. http://www.itu.int, 21 Oct 2010 (17 Sep 2011)

Laituri M, Kodrich K (2008) On line disaster response community: people as sensors of high magnitude disasters using internet GIS. Sensors 8:3037–3055

Nokia (2012) Nokia–eco sensor concept–future concepts–devices and accessories–devices and services–environment. http://www.nokia.com, April 2011 (15 March 2012)

Paulos E, Honicky R, Hooker B (2008) Citizen science: enabling participatory urbanism. In: Handbook of research on urban informatics: the practice and promise of the real-time city. p 506, ISBN 9781605661520, IGI Global, Hershey PA, USA, 2009

Reades J, Calabrese F, Sevtsuk A, Ratti C (2007) Cellular census: explorations in urban data collection. IEEE Pervasive Comput 6(3):30–38

Resch B, Blaschke T, Mittlboeck M (2010a) 2010A: Live geography–interoperable geo-sensor webs facilitating the vision of digital earth. Int J Adv Netw Serv 3(3&4):323–332

Resch B, Lippautz M, Mittlboeck M (2010b) Pervasive monitoring–a standardised sensor web approach for intelligent sensing infrastructures. Sensors–special issue 'intelligent sensors 2010', vol 10(12), pp 11440–11467

Resch B, Mittlboeck M, Kranzer S, Sagl G, Heistracher T, Blaschke T (2011) People as sensors mittels personaliserten geo-trackings. In: Strobl J, Blaschke T, Griesebner G (eds) Angewandte geoinformatik 2011. Wichmann, Heidelberg, pp 682–687

Sagl G, Resch B, Hawelka B, Beinat E (2012) From social sensor data to collective human behaviour patterns: analysing and visualising spatio-temporal dynamics in selected environments. In: Proceedings of the GI_Forum 2012 conference, 03–06 July 2012, Salzburg, Austria

Save the Redwoods League (2010) Redwood watch|redwoods and climate change initiative|save the redwoods league. http://rcci.savetheredwoods.org/action/redwoodwatch.shtml. Accessed on 03 April 2012

UCL Centre for Advanced Spatial Analysis (2012) Tweet-o-meter–giving you an insight into twitter activity from around the world!. http://www.casa.ucl.ac.uk/tom. Accessed on 12 March 2012

US EPA (2012) Citizen science—community involvement today and in the future. http://www.epa.gov/region02/grants/CITIZEN-SCIENCE-RFA-2012-v6a.pdf. Accesed on 04 April 2012

WAZE (2012) Free GPS navigation with turn by turn—waze. http://world.waze.com. Accesed on 04 April 2012

Williams M, Cornford D, Bastin L, Pebesma E (2008) Uncertainty markup language (UncertML). OGC Discussion Paper 08-122r2, Version 0.6, 8 Apr 2009 (14 Aug 2011)

Zacharias V, de Melo Borges J, Abecker A (2012) Anforderungen an eine Technologie für Participatory Sensing Anwendungen. In: Proceedings of the geoinformatik 2012 conference, 28–30 March 2012. Braunschweig, Germany, pp 311–318

Zielstra D, Zipf A (2010) A comparative study of proprietary geodata and volunteered geographic information for Germany. In: 13th AGILE international conference on geographic information science, Guimarães, Portugal, 10–14 May 2010