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Mobile Participatory Sensing Systems: A Comprehensive Review

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Abstract

Mobile Participatory Sensing Systems have the potential to improve different services through monitoring of the urban landscape using mobile devices based on the collaboration of thousands of mobile users. Many articles have been recently published related to mobile participatory systems where data collected from thousands of mobile users are analyzed to extract vital community information and a spatiotemporal interpretation of the phenomenon of interest is built. The purpose of this paper is to assess the state-of-the-art mobile participatory sensing systems to classify key practical requirements of such systems and related challenges. The Kitchenham method has been used to conduct this review. A selection of 24 articles out of 590 articles related to mobile participatory sensing frameworks have been made between the period of 2013 to 2018 from the IEEE Xplore Digital Library and ACM library for assessment. A detailed review has been conducted through the classification of mobile participatory sensing systems and a critical evaluation is carried out. Potential opportunities and challenges for modern mobile participatory sensing systems are also discussed. This paper provides researchers in the field with a comprehensive and up-to-date review of mobile participatory sensing systems

Keywords: Wireless Systems, Mobile Crowdsourcing, Crowdsourcing frameworks, Participatory Crowdsourcing systems, Mobile participatory systems.

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1. Introduction

Several participatory systems have emerged in recent years for different domains such as traffic monitoring and air pollution monitoring in urban spaces [1]. There are also people-centric applications where sensors are used to monitor personal health [12]. Additionally, there are numerous challenges in these real-time monitoring systems such as data privacy, completeness of data, cost-effectiveness, user trust, incentives to encourage the participation of users, and many more. Since data are collected from numerous users in participatory systems and analyzed in real-time,

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trustworthiness and reliability are important challenges among others to be considered.

In recent times, mobile phones have certainly shaped various breakthroughs in different domains of socio-economic activities. This modern wave of Internet-enabled, sensor-rich, smart mobile devices such as Apple, Samsung, and many more have unlocked the door for an innovative paradigm known as participatory sensing. Participatory sensing allows monitoring the urban landscape using mobile devices based on the collaboration of thousands of mobile users. Using this paradigm, mobile users gather multi-level statistics information from the external surrounding environment using their mobile devices. Therefore, they can share the data through an existing communication infrastructure. Nowadays most of the mobile phones are equipped with sensors and various applications are dependent on the data being generated by these sensors. This data collection from thousands of mobile users is commonly known as mobile crowdsourcing. The collected data are analyzed to extract vital community information and a spatiotemporal assessment of the phenomenon of interest can be constructed [6, 22]. Given the widespread of smartphones and the mass of people in the urban area, a participatory sensing application can accomplish an extraordinary level of granularity both in time and space for events of interest in metropolitan spaces [12].

The aim of the paper is to provide a systematic literature review in Mobile participatory sensing systems to classify key practical requirements of such systems and related challenges using the Kitchenham method. It consist of three stages namely, planning, conducting, and reporting. Therefore, it provides researchers in the field with a comprehensive and up-to-date review of mobile participatory sensing systems. The relevance of the paper is to conduct an in-depth investigation of the limitations and benefits of mobile participatory crowdsourcing. A detailed review has been conducted through the classification of mobile participatory sensing systems and a critical evaluation is carried out.

This paper is organized as follows, first, the research method used to conduct this study is presented. Secondly, the outcomes are reported after grouping the 24 selected frameworks and thirdly, the result are discussed. Thus, the paper is planned as follows: Section 1 presents the research methodology, based on Kitchenham, which was used to review articles from the IEEE and ACM library. Section 2 presents the inclusion and exclusion criteria. Section 3 is an overview of the steps conducted to perform the review. Section 4 discusses the 24 Mobile Participatory Sensing Systems using five criteria namely accuracy, reliability, real-time, trustworthiness, and scalability. Section 5 presents possible research challenges and opportunities. Last, but not the least, section 6 presents a summary and conclusions of the paper.

2. Research Method

A systematic detailed literature review has been directed from 2013 to 2018 to evaluate, assessed, and interpret all existing research related to the subject area “Mobile Participatory Sensing Systems”. Thus, the literature review is an important step to evaluates and to better understand the challenges that exist in this area. Additionally, a research gap analysis has been conducted to have a clear and precise direction for future research work. The paper is based on the Kitchenham guidelines and is conducted using three stages namely, planning, conducting, and reporting. Therefore, the systematic review aims to direct future research by identifying gaps and open challenges in the mobile participatory sensing domain.

2.1. Planning the Review

A well-established procedure is used to define a suitable approach for the review, consisting of three phases. Firstly, the data source (inclusive of conference and journal events). Secondly, the domain area dependency (expressions to search). Thirdly, the inclusion and exclusion criteria consisting of the information sources to be investigated (counting databases, specific conferences, and journal proceedings).

2.2. Data Sources

Mobile participatory systems have gained a high level of popularity and interest in the research community over the past decade. Several databases were explored to conduct searches where relevant papers were found in IEEE Explore Digital Library and ACM Library. Thus, these two mentioned libraries were selected for the systematic review. The most noteworthy importance of indexed papers was found in IEEE Xplore Digital Library after exploring some databases. Thus, the selected library for this review is IEEE Xplore Digital Library.

2.3. Search Terms

To narrow down the selection process of the publications, a custom range is applied to journals. The exploration term (mobile participatory) AND (sensing applications) were used. The review was conducted over the last 5 years, ranging from 2013 to 2018. A complete sketch of the approach for mining articles is presented in section 2.4.

2.4. Inclusion and Exclusion Standards

The inclusion and exclusion criteria that were used to accept the relevant articles to assess the state-of-the-art mobile participatory sensing systems are presented in this section.

For an article to be reviewed, the following features and characteristics need to be demonstrated:

1. Use of mobile devices and wireless communication
2. Crowdsourcing systems or participatory systems
3. Articles available from 2013 to 2018

Systems that exhibited the following features and characteristics are excluded from the review.

1. Articles that do not contribute to original research
2. Articles that provide the flaw of mobile participatory systems without proposing a solution.
3. Any work in the form of, master's and doctoral dissertations, guest editorials, article summaries, and unpublished working papers.

3. Conducting the Review

In this section, the planning phase is discussed. The planning phase consists mainly of a selection and analysis stage. Mendeley along with Excel was used for classifying the documents. Additionally, data mining and analysis were conducted on the selected works.

3.1. Selection Process

The Kitchenham multistage procedure model was used as the selection process. A total of 590 non-copied articles were recovered and retained. Once the exclusion criteria were applied, only 35 articles were retained. As a final point, after combining the exclusion criteria to that of the inclusion measures, 24 relevant research articles were retained. Table 1 shows an overview of the 24 selected papers.

Table 1. An overview of the 24 papers identified

Cite	Description
Chen, H *et al.* (2014)	CrowdPic: An interactive and Selective Picture Collection Framework for Participatory Sensing Systems
Szabó, r., *et a*l (2014)	Framework for Smart City Applications Based on Participatory Sensing
Restuccia, f. *et al*. (2014)	FIDES: A Trust-based Framework for Secure User Incentivization in Participatory Sensing
Wu, F.J. et *al* (2014)	A Generic Participatory Sensing Framework for Multi-modal Datasets
Dong, Z., *et al* (2014)	REPC: Reliable and Efficient Participatory Computing for Mobile Devices
Moraes, A.L.D. *et al* (2014)	A Meta-Model for Crowdsourcing Platforms in Data Collection and Participatory Sensing
Zaman, J. et *al* (2015)	DisCoPar: Distributed Components for Participatory Campaigning
Gupte, S *et al* (2015)	Participatory-sensing-enabled Efficient Parking Management in Modern Cities
Wu, F.J. *et al* (2015)	Infrastructureless Signal Source Localization using Crowdsourced Data for Smart-City Applications
Mrazovic, P. and Matskin, M., (2015)	MobiCS: Mobile Platform for Combining Crowdsourcing and Participatory Sensing
Alswailim, M.A., *et al* (2016)	A Reputation System to Evaluate Participants for Participatory Sensing
Zhang, B. *et al* (2016)	Energy-Efficient Software-Defined Data Collection by Participatory Sensing
Chifor, B.C. (2016)	A Participatory Verification Security Scheme for the Internet of Things
Sei, Y. and Ohsuga, A (2016)	Privacy Preservation for Participatory Sensing Applications
Saremi, F. and Abdelzaher, T. (2016)	Slow Start Transition in Participatory Sensing Applications
Cheny, J. and Zhao, D (2016)	A Quality-Aware Attribute-based Filtering Scheme for Participatory Sensing
Zhang, B. *et al* (2016)	Robots-Aided Participatory Crowdsourcing with Limited Task Budget
Tefera, M.K., and Xiaolong, Y. (2017)	Trust and Privacy in Mobile Participatory Sensing: Current Trends and Future Challenges
Melo, G *et al* (2017)	Towards an Observatory for Mobile Participatory Sensing Applications
Mousa, H *et al* (2017)	A Reputation System Resilient Against Colluding and Malicious Adversaries in Mobile Participatory Sensing Applications
Ji, X et al (2017)	Exploring Diversified Incentive Strategies for Long-term Participatory Sensing Data Collections
Khoi, N.M (2017)	Citizense - A generic user-oriented participatory sensing framework
Jadoo, S. and Nagowah, L (2017)	A Hybrid Approach to Cater for Identity and Location Challenges in Crowdsourcing Applications
Krishna, M.B (2018)	Group-based Incentive and Penalizing Schemes for Proactive Participatory Data Sensing in IoT Networks

3.2. Data Analysis

In this section, the results of the data analysis are displayed. The results were useful to spot the requirements and core features of participatory sensing systems. The systems were reviewed into three major categories of participatory sensing systems. They are as follows, environmental participatory sensing systems, people-oriented participatory sensing systems, and task-oriented participatory sensing systems. The second segment consists of a comprehensive analysis of the systems based on the following criteria: accuracy, reliability, real-time, trustworthiness, and scalability within each of the three categories.

The above-stated categories are identified for data analysis as per the number of applications being developed, contributions of researchers, and the widespread of these applications. Nowadays there are special reasons for thinking about the problems of cities in terms of creativity or lack of it. Factors that once shaped city development were transport, infrastructure, and the different types of pollution. However, there is a need to give special attention to elder people. Common users of these systems are aged care service providers with an exceptional focus on health-related issues, which is the people-oriented part. Additionally, using a proper platform, people can report environmental issues or provide appropriate services on environmental changes. On the other hand, access to resources, data, and information is restricted due to the geographical landscape. Thus, in a disaster situation, authorities may be helpless even possessing the best hardware and manpower. Therefore, there is a need for a task-oriented analysis.

4. Reporting the Review

After investigation of the designated articles, the mobile participatory sensing systems are grouped as per three categories namely environmental, people-oriented, and task-oriented. The following sections present the outcomes and classification of the mobile participatory sensing systems by analysing the 24 papers in Table 1.

4.1 Environmental Participatory Sensing Systems

The main aim of an environmental system is to provide real-time information to the authorities. Services provided can be air monitoring, water monitoring, or sound monitoring. Some frameworks send instructions to the nodes to extract data, whereas others allow participants to send information in a participative way. The mobility of participants can largely affect the server's decision or process. Nowadays environmental processes vary dramatically in time and space. Thus, the system needs to work with a wide range of data. The environment is a shared space for resources and services which activate entities to provide functionalities such as traffic monitoring, among others. When participants are collecting data and send them to the server, the system should be able to classify the data to the corresponding services. In some systems, different rules can be defined in entities. It can be in the form of a visual check. In other systems, the services provided can be directly linked to the format of data being collected. One example could be that all traffic services can be stored in a picture format. Therefore, the server can track the format of data collected to provide adequate services.

Other systems can define a communication protocol such that the different types and formats can be forwarded to the server by one participant. Data and resources can be identified, generated, modified, or used by the participants. The extent to which the participants can access a specific service may depend on several factors as the system should have a proper level of abstraction. If traffic checking is considered, the street quality will, in general, be adaptable, with potholes and uneven streets being natural. Vehicles types are also very diverse, going from 2-wheelers (e.g., bikes and motorbikes) and 3-wheelers (e.g., auto-carts) to 4-wheelers (e.g., vehicles) and bigger vehicles (e.g., transports). Table 2 is derived from table 1 where all environmental-oriented participatory sensing systems are analyzed.

Table 2. Environmental Participatory Sensing Systems

Cite	Description	Contributions	Strengths	Limitations
Chen, H *et al.* (2014)	CrowdPic: An interactive and Selective Picture Collection Framework for Participatory Sensing Systems	Reduce the client-server communication cost. Elimination of redundant image	Checking and removal of the redundant image	The algorithm does not address the short life span of data collection in participatory sensing systems.
Szabó, r., *et al* (2014)	Framework for Smart City Applications Based on Participatory Sensing	Provides an efficient framework for travel planning	Check for trustworthiness and reliability of data	The system does not cater for third party application
Zaman, J. *et al* (2015)	DisCoPar: Distributed Components for Participatory Campaigning	Collection of data to propose a new citizen observation. Ability to reused and reconfigured different levels of participatory systems	Uses real-time data collection using the concept of data aggregation	Data cannot be assessed to ensure trustworthiness
Gupte, S *et al* (2015)	Participatory-sensing-enabled Efficient Parking Management in Modern Cities	Collection of data to find, monitor, and regulate parking.	Uses real-time data collection	The system is highly dependent on the number of participants.
Alswailim, M.A., *et al* (2016)	A Reputation System to Evaluate Participants for Participatory Sensing	Participant are group based on the contribution and then rates them to provides accuracy	Data accuracy has been implemented	The trustworthiness of data among participants has not been implemented due to low level of participants
Zhang, B. *et al* (2016)	Energy-Efficient Software-Defined Data Collection by Participatory Sensing	The framework proposed handle multi-role based participatory sensing through coordination among role assigned to the participant	Data privacy has been preserved	The experiment has been done via simulation not real data processing and has not catered for the reliability of participants.
Chifor, B.C. (2016)	A Participatory Verification Security Scheme for the Internet of Things	The system verifies the device before further processing to provide adequate services	The framework is checking the validity of the trusted device	The system does not cater for data reliability
Sei, Y. and Ohsuga, A (2016)	Privacy Preservation for Participatory Sensing Applications	The proposed framework is to provide a desirable level of privacy based on data distribution	Real-time latency has been estimated and existing methods have been analyzed	Part of the experiment has been based on simulation, not giving a real-time response
Saremi, F. and Abdelzaher, T. (2016)	Slow Start Transition in Participatory Sensing Applications	The time modelling approach has been used to ensure service reliability	The system has a bounding modelling error to predict fuel consumption of vehicles	The system does not cater for real-time latency
Tefera, M.K., and Xiaolong, Y. (2017)	Trust and Privacy in Mobile Participatory Sensing: Current Trends and Future Challenges	The survey is used to assess the threats to user privacy and trust of data	The trustworthiness of data has been implemented	The system does not cater for real-time latency
Melo, G *et al* (2017)	Towards an Observatory for Mobile Participatory Sensing Applications	Classification of crowdsensing application in different ontological categories	The researcher has adopted a participative approach	Research does not address trustworthiness problem

4.2. People-Oriented Participatory Sensing Systems

The smart city is a label where the city is aggressively chasing the use of technology to upturn the quality of life. Some systems are helping to reduce the C02 emissions, waste, improving public and private sector services while others are optimizing energy consumptions by building efficiency and renewable energy productions. Technology is not the only driving force in a smart city, citizen's experiences can help to develop better services and solutions. To reduce failure, one can listen to citizens' potential problems at an early stage. People can help in collecting data that detected noise and ozone pollution as they lived their regular lives, and the result can be displayed over a mapping engine. These frameworks can help in decision-making processes and also build sustainable local communities where individuals care for one another. Having a people-oriented approach can aim to foster more informed, educated, and socialized citizens. It is also an initiative to allow followers of a city to contribute to the management and governance of a city. It also helps to become an active user. Interest and coordinated effort between government, residents, and associations are viewed as fundamental in the improvement of smart communities. Some of the activities (parks and recreation, community development, and planning) typically involved in smart city projects can benefit greatly from citizen participation. A recent study [13] demonstrates an association between cities' acceptance and application of sustainability strategies as well as public contribution in policy formulation.

Some cities have already developed participatory sensing systems that help to better understand human behavior and to obtain real-time information about environmental conditions and traffic. Counties such as Chicago who has been implementing the Array of [15] since 2014 to monitor air quality component. For example, in urban spaces, many participants can collect and transmit information about air quality. Thus, people and local authorities can be aware of the level of pollution at different locations. This information can be vital for those who have health issues such as asthma and therefore avoiding any risky areas. Louisville [28] has proposed an innovative approach since 2012 and uses GPS gadgets installed in inhalers to gather information on where and when individuals with asthma are especially affected. The concept of this pattern is to allow the city to forecast possible events and take precautionary measures. Each city's community requests the implementation of such a system that permits residents to report problems that they are facing. It can be in the form of broken streetlights, unlawful stopping, water spill, and so on. Participatory sensing tools will allow these organizations to initiate data collection that likewise connect people to the preparation of their environments. Researchers [21] defines a GIS-based noise preparation tool made for the city of Belo Horizonte in Brazil. Such systems method allows citizens to collect and share basic information on ambient sound at regular intervals. This application could join a data-collection campaign to document noise levels in a community. Table 3 is derived from table 1 where all people-oriented participatory sensing systems are analyzed.

Table 3. People-Oriented Participatory Sensing Systems

Cite	Description	Contributions	Strengths	Limitations
Restuccia, f. *et al.* (2014)	FIDES: A Trust-based Framework for Secure User Incentivization in Participatory Sensing	Define a set of attacks aimed at declining existing reward systems. Trust-based frameworks, and location-verification systems.	Check for trustworthiness and reliability of data	The mobile security agent requires intensive computing power and slow down communication within the network
Wu, F.J. *et al* (2014)	A Generic Participatory Sensing Framework for Multi-modal Datasets	Providing incentives to attract high-quality data collection. Extensibility of datasets	Incentive and extensibility motivating participants to contribute high-quality data from different data types.	The system does not address the short life span of data collection in participatory sensing systems.
Wu, F.J. *et al* (2015)	Infrastructureless Signal Source Localization using Crowdsourced Data for Smart-City Applications	The framework that solves the localization technique by filtering noise	Help to increase accuracy up to 50% in the range of 1-16 meters	Data cannot be assessed to check the trustworthiness
Mousa, H *et al* (2017)	A Reputation System Resilient Against Colluding and Malicious Adversaries in Mobile Participatory Sensing Applications	The system can defend against the corruption of data.	Proposed frameworks enhance data accuracy	When data is captured, real-time latency is not assessed
Ji, X *et al* (2017)	Exploring Diversified Incentive Strategies for Long-term Participatory Sensing Data Collections	The system caters for data collection and incentive strategies.	Incentive provided	Data accuracy and trustworthiness has not been assessed
Khoi, N.M (2017)	Citizense - A generic user-oriented participatory sensing framework	A generic system that can be implemented in the different domain area	Data accuracy has been addressed	Trustworthiness among data collected has not been addressed

4.3. Task-Oriented Participatory Sensing system

Task-Oriented participatory sensing applications can be defined as an application area for multi-robot teams. It consists of task-oriented missions, in which possibly heterogeneous robots must solve several individual tasks. There is a high demand for these types of applications. The arranged robot needs to adapt to non-critical failure. Task-oriented can also be applicable to help users with a disability. For example, a task-oriented system could assist a blind person to follow a specific route. Such a person must have some perception or plan of that route. Thus, the traveler can learn the direction while being directed by a sighted escort or may only have verbal instructions. When a path has been practiced, a user can distinguish and avoid obstacles. Additionally, the traveler can follow the course to know their position, direction, and make fundamental revisions. In disaster situations or mountainous landscapes, a versatile participatory framework should be able to process complex resource-intensive tasks. Due to the restricted access to resources, services, and multimedia, acquiring distributed information for emergency responses is a critical factor. Relevant research disciplines such as in-network processing, service discovery, and service composition help to better manage restricted areas. In a disaster situation, authorities may be helpless, even having the best hardware and manpower. When the participants have already collected and sent data, the server will be able to monitor the changes or the frequency of data being pushed from a region or a service. The server can then apply a priority mechanism to task processing. Thus, a task-oriented will help to give better information on how to plan, manage, and execute an action before, during, and after a disaster situation.

In complex systems such as robotics, human errors can be disastrous and are beyond our expectations. Thus, to avoid this, a task-oriented system can be used. Many structures, such as a crawler, a legged robot, a manipulator, or other robotic shapes, can be assembled by the arrangement of (identical) modules. This kind of rigidity is extremely desired for robotic systems used in unpredictable and unstructured environments. It can operate as a rescue operation in earthquake-stricken areas or deep-sea and space exploration. An alternative advantage of self-reconfiguration is self-repair by changing broken modules. Thus, the system is not down waiting to be repaired where human intervention latency could prove to be disastrous. An example would be in a nuclear plant where task-orientation is extremely important. Table 4 is derived from table 1 where all task-oriented participatory sensing systems are analyzed.

Table 4. Task-Oriented Participatory Sensing Systems

Cite	Description	Contributions	Strengths	Limitations
Dong, Z., *et al* (2014)	REPC: Reliable and Efficient Participatory Computing for Mobile Devices	Effective randomized task assignment framework. Minimize the number of tasks to be executed by individual devices	Achieved reliable participatory computing with very low system overhead in various system settings.	No real-time decision from the task manager. The system does not address the short life span of data collection in participatory sensing systems.
Moraes, A.L.D. *et al* (2014)	A Meta-Model for Crowdsourcing Platforms in Data Collection and Participatory Sensing	Provides a multi-model to fit generic solutions	Data collected and participatory sensing help to better understand Environmental issues	The trustworthiness of data cannot be identified.
Mrazovic, P. and Matskin, M., (2015)	MobiCS: Mobile Platform for Combining Crowdsourcing and Participatory Sensing	Proposed an architecture that takes different nodes of mobile sensing to treat carriers as intelligent problem solvers	Trustworthiness and quality control were implemented	Task allocation was not a complete success due to the accuracy problem
Cheny, J. and Zhao, D (2016)	A Quality-Aware Attribute-based Filtering Scheme for Participatory Sensing	Data quality has been ensured to encourage more participant to contribute to the sensing framework	The server will assess participant whose data satisfies the quality policy by ensuring confidentiality and accuracy	Accuracy has been preserved by data latency has not been addressed
Zhang, B. *et al* (2016)	Robots-Aided Participatory Crowdsourcing with Limited Task Budget	The system caters data to be processed by the robots-aided system	The system provides additional services to existing Participatory sensing framework	The system does not cater for reliability and trustworthiness of data
Jadoo, S. and Nagowah, L (2017)	A Hybrid Approach to Cater for Identity and Location Challenges in Crowdsourcing Applications	Privacy of users has been applied using encryption and encoding	Hashing technique has been used to protect against Data privacy	The system proposed does not cater for different levels of attacks
Krishna, M.B (2018)	Group-based Incentive and Penalizing Schemes for Proactive Participatory Data Sensing in IoT Networks	The proposed system defines incentive and penalizing factors	Data accuracy, reliability, and consistency has been implemented in the framework.	The system has a limited amount of user involved

5. General Results

In this section, the 24 mobile participatory sensing systems are evaluated against the five criteria which are accuracy, reliability, real-time, trustworthiness, and scalability.

5.1. Accuracy

In a participatory sensing application, providing a service will largely depend on how accurate the data has been captured. Accuracy is a requirement that is desired before any processing to provide adequate services in a participatory application. Over the years, many researchers [1, 12] have largely contributed to the participatory sensing systems. At the end of this section is an analysis of the impact of "accuracy" in those systems. Accuracy can be defined as the acceptable level of measurement with an accepted standard.

5.2. Real-time Latency

A machine cannot act on something, such as providing a service instantaneously, and the amount of waiting time between an input and its output is called latency. In a participatory system, to preserve delay between input and output such that it is non-existent, the latency must be low, that is the system must react in real-time. Consistent latency is the most desirable requirement in a system. The amount of data being collected or pushed from participants, and the constantly changing environment data should be relatively low.

5.3. Reliability

In a participatory system, when data is sent for processing, it is important to check if the captured data is still relevant. For example, if a participant has captured data and is disconnected from the network, it is important to check the reliability of the data. When the user will connect to communicate the data to the server, the relapsing of the data has changed. As such reliability can be defined as the ratio of data being collected that produces correct output to the total number of participants in a participatory sensing system.

5.4. Trustworthiness

It will check whether a malicious person will send irrelevant data to the server. Often while capturing data, several types of noise adversely affect the collected data and when this data is sent to the server to map an environmental change, the system reports inaccurate data to the users. Thus, the application server must have the necessary mechanisms to assess the trustworthiness of the collected data so that malicious contributions, corrupted, and incomplete data can be detected.

5.5 Scalability

It is described as the capability of a process, network, software, or association to develop and manage increased demand. A system or software that is labeled as accessible has a benefit because it is more flexible to the varying needs or demands of its users. Scalability is the property of systems to deal with a developing measure of work by adding assets to the systems. In a participatory system, the number of participants is not fixed, instead, it varies, and to handle the constant change of participants, the system must be scalable.

Table 5 presents the evaluation of the 24 mobile participatory sensing systems against the five criteria. Three benchmarks are used as the level of acceptance which is: low, average, and critical. A rating analysis is performed based on the following details:

- Low → 0 or 1
- Average → 2 or 3
- Critical → 4 or 5

Table 5. Evaluating the Participatory Sensing Systems

Cite	Accuracy	Real-time latency	Reliability	Trustworthiness	Scalability	RATING
			Environmental Participatory Sensing Systems			
Chen, H *et al*. (2014)	Average: 3	Critical: 4	Critical: 4	Critical: 4	Low: 0	15
Szabó, r., *et al* (2014)	Average: 3	Critical: 5	Critical: 4	Critical: 4	Low: 0	16
Zaman, J. *et al* (2015)	Low: 1	Low: 1	Critical: 4	Critical: 4	Low: 0	10
Gupte, S *et al* (2015)	Critical: 4	Critical: 4	Critical: 4	Critical: 4	Average: 3	19
Alswailim, M.A., *et al* (2016)	Critical: 4	Average: 3	Critical: 4	Critical: 4	Low: 0	15
Zhang, B. *et al* (2016)	Critical: 4	Average: 3	Critical: 4	Critical: 4	Critical: 4	19
Chifor, B.C. (2016)	Critical: 5	Average: 3	Low: 1	Critical: 4	Low: 0	13
Sei, Y. and Ohsuga, A (2016)	Average: 3	Average: 3	Low: 1	Low: 1	Low: 0	8
Saremi, F. and Abdelzaher, T. (2016)	Low: 1	Low: 1	Critical: 4	Critical: 4	Low: 0	10
Tefera, M.K. and Xiaolong, Y. (2017)	Average: 3	Average: 3	Critical: 4	Critical: 4	Low: 0	14
Melo, G *et al* (2017)	Average: 3	Critical: 4	Critical: 4	Critical: 4	Average: 3	18
Total per Column	**34**	**34**	**38**	**41**	**10**	**157**
			People-Oriented Participatory Sensing Systems			
Restuccia, f. *et al.* (2014)	Low:1	Low: 1	Critical: 4	Critical: 4	Critical: 4	14
Wu, F.J. *et al* (2014)	Critical: 4	Average: 3:	Critical: 4	Critical: 4	Average: 3	18
Wu, F.J. *et al* (2015)	Average: 3	Average: 3	Critical: 4	Critical: 4	Average: 3	17
Mousa, H *et al* (2017)	Critical: 4	Average: 3	Critical: 4	Critical: 4	Average: 3	18
Ji, X *et al* (2017)	Low: 1	Low: 1	Critical: 4	Critical: 4	Low: 0	10
Khoi, N.M (2017)	Critical: 4	Critical: 4	Critical: 4	Critical: 4	Low: 0	16
Total per Column	**17**	**15**	**24**	**24**	**13**	**93**
			Task-Oriented Participatory Sensing Systems			
Dong, Z., *et al* (2014)	Critical: 4	Critical: 4	Critical: 4	Critical: 4	Low: 0	16
Moraes, A.L.D. *et al* (2014)	Average: 3	Average: 3	Critical: 4	Critical: 4	Average: 3	17
Mrazovic, P. and Matskin, M., (2015)	Average: 3	Critical: 4	Critical: 4	Critical: 4	Low: 0	15
Cheny, J. and Zhao, D (2016)	Average: 3	Critical: 4	Critical: 4	Critical: 4	Average: 3	18
Zhang, B. *et al* (2016)	Low: 1	Low: 1	Critical: 4	Critical: 4	Low: 0	10
Jadoo, S. and Nagowah, L (2017)	Average: 3	Critical: 4	Critical: 4	Critical: 4	Low: 1	16
Krishna, M.B (2018)	Critical: 4	Critical: 4	Critical: 4	Critical: 4	Low: 1	17
Total per Column	**21**	**24**	**28**	**28**	**8**	**109**

6. Discussion

In this section, the 24 mobile participatory sensing systems are discussed as per the categories identified in section 4 and section 5. Potential challenges are identified and discussed.

6.1. Environmental Participatory Sensing System Challenges

The environmental participatory sensing system has a high impact on our daily life. From the 24 systems stated above, 11 systems have been identified as an environmental participatory sensing system and the overall rating is 157. Different systems such as traffic monitoring, air monitoring, water monitoring, or sound monitoring have contributed hugely to this category and there is an increasing demand for such systems. Some researchers [27] have shown how critical such applications are now. It has also been noticed that these systems are limited in terms of users' participation, that is, the rate at which users are entering or leaving the networks. Researchers are investing a lot of effort into how to propose an alternative to issues rather than consolidating existing systems. Below is a representation of the five criteria's assessment within the environmental category:

- Accuracy → 34
- Real-Time → 35
- Reliability → 37
- Trustworthiness → 41
- Scalability → 10

6.2. People-Oriented Participatory Sensing system challenges

The technological recognition of users is important for the positive acceptance of People-Oriented Participatory Sensing systems. For this category, 6 systems have been identified as people-oriented systems with a rating of 93. Yet, it is crucial to explore these systems with diverse groups of participants since each user has an altered kind of contact with the systems. Some researchers [13] have given proof of the importance of such systems, with direct response abilities. Therefore, there is a great necessity to perform research. Most of the services provided are restricted to regions, developed countries, or the performance of devices. No proper research has been conducted to see how these services can integrate existing platforms or to monitor a trial version in developing countries. Below is a representation of the five criteria's assessment:

- Accuracy → 17
- Real-Time → 15
- Reliability → 24
- Trustworthiness → 24
- Scalability → 13

6.3. Task-Oriented Participatory Sensing System Challenges

Nowadays, the adoption and development of Task-Oriented Participatory Sensing systems are becoming fundamental in participatory sensing systems. 7 systems identified in table 4 represent task-oriented systems, with a rating of 109. These structures can function in a multidisciplinary location and be technology autonomous. Some researchers [33] have shown the interoperability and the immense opportunities of such systems. There is an apprehension among employees of being replaced by these systems to cut costs. This is due because researchers are focusing on how technology can increase productivity while decreasing cost and death rather than proposing how humans can interact with these systems to increase efficiency. Below is a representation of the five criteria's assessment:

- Accuracy → 21
- Real-Time → 24
- Reliability → 28
- Trustworthiness → 28
- Scalability → 8

From this review, it has been noticed there is an important consideration for environmental systems. The reliability and trustworthiness of data remain critical criteria for the participatory sensing systems. One criterion that demand further attention is scalability. Most of the systems identified have either a limited number of participants during testing or participants are not willing to join and share information over the network. Table 6 shows a classification of the five criteria as per the priority of the systems.

Table 6. General evaluation of Participatory Sensing Systems

Criteria	Environmental	People-Oriented	Task-Oriented
Accuracy	34	17	21
Real-Time	34	15	24
Reliability	38	24	28
Scalability	10	13	8
Trustworthiness	41	24	28
Grand Total	**157**	**93**	**109**

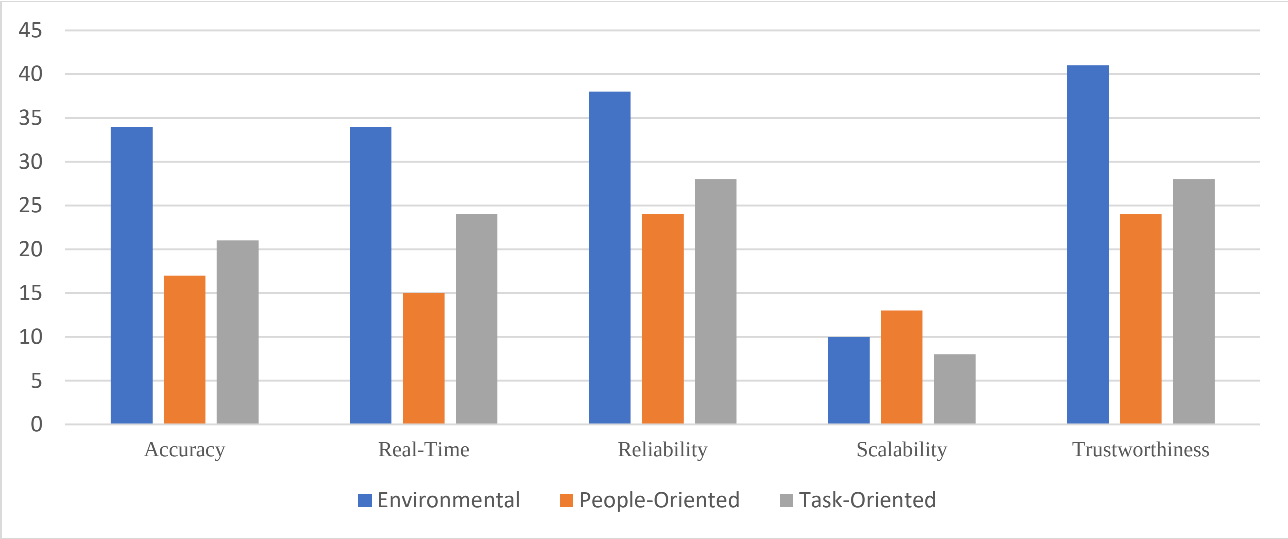

Figure 1. General evaluation of Participatory Sensing Systems

6.4. Open Research Challenges

Mobile participatory sensing systems possess immense opportunities in different spheres of socio-economic activities. There are numerous challenges in these real-time monitoring systems such as data privacy, completeness of data, cost-effectiveness, user trust, incentives to encourage the participation of users, and many more. Since data are collected from numerous users in participatory systems, two important challenges are to ensure the reliability and trustworthiness of the data. Data from participatory systems are sensed, analyzed in real-time and actions are taken accordingly. Therefore, reliability and trustworthiness are of utmost importance. Many research challenges are still open due to these complexities. These are discussed in the following section and are interpreted as scalability, user participation, efficiency/power consumption, and interoperability.

Interpretation of Results

From table 6, a detailed analysis has been performed from the 5 criteria which showed where there is a need for future research and what is the ongoing domain interest. Scalability is a domain where improvement is required due to the increasing number of devices and users. On the other hand, trustworthiness and reliability are the areas where researchers are exploring and contributing heavily.

Scalability

Mobile participatory sensing systems should be able to define the maximum number of users and devices. In an environmental system, the targeted audience should be on a larger scale due to the constant changes of data. Therefore, scalability will focus mainly on the number of users participating in the system as it is difficult to give an exact amount of users in such systems. For a task-oriented system, it must harness a greater set of processors. Therefore, it must scale to a higher amount of processors compatred to the existing multiprocessor systems, such as networks of workstations. Thus, scalability will have a different behavior depending on the category targeted.

User Participation

The number of participants is a critical characteristic to ensure proper service. Users are expecting to have accurate and reliable services from the system, else participants will not be willing to use and participate. Thus, there should be a proper mechanism, architecture, or protocol to increase the participation of users. Some researchers [16] have proposed incentives depending on the user's participation while others have proposed a reputation model [16]. Nevertheless, there is a big challenge to encourage the users to capture, send data, and to use the services.

Efficiency/Power Consumption

Data should be continuously sensed and captured to prove a real-time service. This addresses the limited power resources which mobile devices and sensor nodes possesses. Futher research should be conducted to provide a "dormant-active" state of sensing devices or optimization algorithms [8]. The in depth research could apply to a limited degree to report mobile participatory sensing systems topics such as node localization, optimal deployment, and data aggregation.

Interoperability

A mobile participatory system is highly desirable to interact with different technologies. To guarantee a general data format, interoperability, and conventions can be used. In a mobile participatory sensing architecture, different types of devices and different types of OS are communicating. Diverse protocols and software are also used to address the topic of interoperability. Therefore, the widespread use of mobile can be used to report the characteristic of interoperability in such systems.

7. Conclusion

This paper presented a review in the state-of-art mobile participatory sensing systems and categorized the systems as environmental, people, and task-oriented with a specific focus on topics and experiments related to mobile participatory sensing systems. Nowadays most of the mobile phones are equipped with sensors and various applications are dependent on the data being generated by these sensors. Researchers have started and are exploring this technological solution to enhance the provision in the different categories. In this paper, 24 mobile participatory sensing systems from 2013 to 2018 are evaluated to improve ongoing research/systems and various prominent problems are defined. From the results, it is seen that there is a demand for mobile participatory sensing systems, especially environmental systems. Moreover, people-oriented, and task-oriented participatory sensing systems appear to be gaining in popularity and there are a number of pressing challenges that needs to be overcome. Researchers have shown how critical data reliability and trustworthiness of data is, without neglecting the other criteria identified in this paper. However, as pointed out in this paper, several challenges remain to be addressed to attain an almost flawless mobile participatory sensing systems. In the near future, the evolution of mobile participatory sensing systems can significantly improve the day to day life of people. The main challenges in such systems were outlined, and areas that researchers should investigate futher for motivating users to participate were discussed.

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