

Smart Cities using Crowdsensing and Geofenced Notifications

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Abstract. As the internet and the Internet of Things continue to expand, the idea of Smart Cities has begun to take hold. Smart Cities use connected devices and data to improve the environment and quality of life of their citizens. Technologies such as crowdsensing and geofencing allow citizens to contribute to initiatives and receive notifications when near areas of interest, respectively. This paper presents a systematic review of past works on the implementation of crowdsensing and geofencing technologies in Smart Cities, with the goal of identifying their purpose, strategies, and tools. The review examines seventeen relevant papers identified through the Scopus citation and abstract database.

Keywords: Internet of Things · Smart Cities · Geofences · Crowdsensing · Crowdsourcing · Smart Notifications · Location-based Notifications.

1 Introduction

As urban populations grow, the need to modernize cities and give essential services to communities has become increasingly important. This has led to the rise of Smart Cities, where technology and infrastructure are combined to enhance the quality of life in a sustainable and transparent way [11, 1, 23].

Smart Cities are increasingly dependent on the Internet of Things and its domains, as these technologies evolve and gain attention, from not only the academic community but also from industry and civil societies [14].

For many years, Smart Cities has been an area of interest and progress, but the initial phase of research was focused purely on its technical aspects. Emphasis has recently widened to include a more comprehensive approach to the information systems that support Smart Cities [13]. Nowadays, the focus is on enhancing citizen quality of life and assessing how smart technologies affect it, as well as on the social, economic, and environmental sustainability of cities [10].

One of the areas that has seen particular development is crowdsensing, as it enables to take advantage of the large amount of personal mobile devices and

their sensors to collect and process information in a distributed and collaborative way, without more burden to the management or administrative entities [22].

Crowdsensing is a highly diverse field that has seen large growth and change. One aspect of its development involves integrating the sensory data collection through users' mobile devices, allowing citizens to contribute to the collective via their devices. Another aspect is providing personalized, intelligent information to each citizen, enabling them to leverage the collective [16].

Regarding citizens taking advantage of the collective, some work and developments of interest have begun to appear most recently, with key technology for most these works being geofences, which consist of the notion of a virtual perimeter for a real geographical region. Devices and applications can use geofences to give useful information to citizens when they're near an area of interest [8]. The implementation of geofences for the incorporation of citizens into intelligent environments through personalized information that's sensitive to each citizen's context, either through a mobile application or notifications, are goals for both the development and implementation of Smart Cities, as well as the expansion of crowdsensing users.

The goal of this systematic review is to identify recent scientific publications that provide an overview of the current state of development in the areas of crowdsensing in smart cities. To this end, three research question were formulated:

- **RQ1:** What is the role and purpose of crowdsensing and crowdsourcing, namely geofences and location-based notifications, in smart cities?
- **RQ2:** What existing strategies and tools were utilized to incorporate crowdsensing and crowdsourcing into smart cities?
- **RQ3:** How can crowdsensing implementations improve citizens' lives in a smart city, and how make them active contributors?

The following document is structured in five Sections: Introduction, Methodology, Results, Discussion, and Conclusion. This section's goal is to present a contextualization and framing of the work, the main motivation, main objectives, and the document's structure. Section two describes the research and review process, taking into account its main steps, i.e., selection of data sources, search strategy, selection criteria, and results. On sections 3 and 4, the obtained results are discussed, as well as relevant articles and documents are presented. The last section of this document aims to summarise and present the main conclusions and contributions obtained through the review, including recommendations for future work.

2 Methodology

This research approach was guided by the PRISMA³ (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement and checklist, widely ac-

³ <http://www.prisma-statement.org>

cepted by the scientific community in the fields of computer science and engineering [15]. The steps taken into account include:

1. Identification of the study's research questions and relevant keywords;
2. Creation of the research query;
3. Definition of the eligibility criteria to filter and reduce the articles sample;
4. Analysis of the resultant set of studies and papers;
5. Presentation and discussion of the results.

On February 8, 2023, preliminary research was conducted using Scopus⁴ from Elsevier as the data source. The reasons for this choice were Scopus' large abstract and citation database, quality assurance, and advanced search capabilities.

To carry out the bibliographic research, keywords were identified and organized into two groups which were combined with a conjunction. To further refine the search, keywords in each group were combined with a disjunction. This ensured that documents containing at least one keyword from each group were selected, thus achieving the desired outcome. The research topic of "Smart Cities", "Crowdsensing", "Smart Notifications" and "Location-based Notifications" comprises the first group of areas and technical subjects, while the second group focuses on broader areas of technology such as "Information Communication Technology", "Information Systems" and "Mobile Computing" in order to better pinpoint results within the context of information systems and agents.

As a result of applying the strategy described above, the following research query emerged:

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1 ( TITLE-ABS-KEY ( smart AND cities )
2 OR TITLE-ABS-KEY ( crowdsensing )
3 OR TITLE-ABS-KEY ( smart AND "notifications" )
4 OR TITLE-ABS-KEY ( location AND based AND "notifications" )
5 AND
6 ( TITLE-ABS-KEY ( information AND communication AND technology
  ↪ )
7 OR TITLE-ABS-KEY ( information AND systems )
8 OR TITLE-ABS-KEY ( mobile AND computing ) ) )

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Some eligibility criteria were defined in the form of exclusion criteria to screen the articles and studies collected, and all documents that met any of these criteria were excluded:

1. : Publications that aren't accessible in Open Access.
2. : Publications that were not produced in the last 5 years (from 2018) or have not yet been fully published..
3. : Publications that aren't from the fields of Computer Science or Engineering.
4. : Publications that aren't Articles or Reviews/Surveys and aren't written in English.

⁴ <https://www.scopus.com>

5. : Publications that don't focus on the variables studied or are out of context.
6. : Publications that are not in accordance with the European Union's General Data Protection Regulation (GDPR).

3 Results

The initial bibliographic research identified 14,840 studies, which were then subject to the defined eligibility criteria. The first five criteria were applied using Scopus's filtering system, resulting in a subset of engineering and computer science articles or reviews that were freely accessible, written in English, and had relevant authors or citations in the last five years. Of the 575 studies, 526 were excluded due to not meeting the European Union's standards for data extraction, manipulation, privacy, and data protection. The remaining 49 were fully read, with seventeen meeting the criteria of being related to crowdsensing and crowdsourcing applications in smart cities, namely, through geofences and location-based notifications, and not developed in an enterprise context. Thus, 32 studies were excluded.

Next, a summary of the results found in the review to answer the research questions will be presented.

Ande et al. [3] made an overview and reference guide for IoT systems, particularly considering security issues. The authors show in this study that the Internet of Things is the result of improvements in computing, communication technologies, and the Internet, all which are combined with the human desire to better our quality of life.

Amaxilatis et al. [2] present a solution for deploying and managing crowdsensing campaigns and experiments across cities federated in the OrganiCity facility. As a result, the authors concluded that the system allows developers to reverse course if they notice that their campaign design is underperforming through the system.

Cheng et al. [5] propose a collaborative geofence site selection (CGSS) method for city management to designate geofence sites for dock-less shared bikes in the city. In this scenario, geofences are used to determine the best sites for renting bicycles and scooters to maximize user satisfaction with the service's availability and coverage for the city's expansion.

Pánek [19] describes the timeline of development and deployment of an emotional mapping approach, a methodology that allows individuals to initiate a map-based dialogue concerning the current and future state of public space, relying solely on their experiences. The author concluded that emotional maps, as a tool for crowdsourcing, provide an easy-to-use setting for social participation while fostering a sense of belonging to a specific social group or community.

Fernandes et al. [6] developed a platform to be used via a mobile application that allows its users to obtain information regarding the current and future status of the city, as well as the provision of smart notifications with useful information taking into account the context of each user.

In their paper, Foschini et al. [7] introduced ParticipAct, a mobile crowdsensing technology that uses edge nodes to calculate potentially hazardous crowd situations. This system requires users to have a sensing client application installed on their phone, and when sensing campaigns created by researchers or platform administrators are initiated, the collected data are sent to a centralized cloud server.

Kousiouris et al. [12] leveraged social network data to find large crowd concentration (LCC) events. In this approach, the user data, coming from a Smart Transportation platform, is linked with social network activity peaks to identify large crowd concentration events that might affect the user journey. The authors concluded that this kind of mechanism can be used, for example, by the caregivers of a disabled user to alter the planned journey to avoid congestion, confusion and limited mobility circumstances.

Roman et al. [20] suggested a mobile on-street parking spot identification system that is scalable and manageable when compared to a stationary sensor method. A supervised learning system that analyses the structure of the sonar trace to distinguish parked automobiles from road clutter, transmits this information to a central server that generates a map of parking occupation. The authors claim this mobile sensor system could be a crowdsourcing approach in the future, where members of the public can install sensors on their vehicles and collect data, with appropriate compensation in the form of reduced parking costs or simply free access to the parking apps.

Picaut et al. [17] propose a crowdsourcing-based alternative method for assessing the noise environment. A smartphone application and a data infrastructure have been developed specifically for gathering physical and perceptual information about the sound environment. Each contributor's data feeds a community database, which allows for a more detailed representation of the sound environment in space and over time than by using traditional numerical modelling methodologies.

Kirimtat et al. [11] overviewed smart city projects by examining key concepts and data management strategies. The authors concluded that based on current developments in scientific studies, there is still a lack of scientific reports on smart floating cities, which seems to be good candidates for future smart cities.

Pilloni et al. [18] presented the main aspects related to Industry 4.0. The authors explore the effects, advantages and challenges that IoT, crowdsourcing and crowdsensing, big data and other technologies will have on industrial processes.

Yang et al. [25] present a perspective which displays crowdsensing as a technique in which a significant number of people using mobile devices with sensors share sensory data to measure, analyse, or infer any issue of common interest.

Shahrour and Xie [21] present and discuss the role of the IoT and crowdsourcing in constructing smart cities by emphasizing the role of data in smart city solutions, and the use of IoT and mobile crowdsourcing in smart city applications. The authors concluded that smart city development still needed more collaboration between smart city technology-centred research, which is primar-

ily based on the IoT, and smart city citizen-centred research, which is primarily based on crowdsourcing.

Wang et al. [24] focused on citizen recruiting through social network. Citizen engagement is vital to any crowdsensing project's success, and it has become a key study area.

In a study by Ismagilova et al. [10], the implications of Information Systems in smart cities are explored. The article covers a variety of topics, such as smart mobility, smart living, smart environment, smart citizens, smart government, and smart architecture, while also examining associated technologies and concepts. Shortcomings in existing research are revealed along with potential future developments.

Nizetic et al [14] conducted a comprehensive analysis of the Internet of Things (IoT) and its potential, difficulties, and worries in the context of a smart and sustainable future. Through their review, the authors improved the knowledge of existing technological advancements in IoT application areas, as well as the ecological ramifications of enlarging IoT product use. Ultimately, they ascertained that this study was beneficial in furthering understanding of the topic.

4 Discussion

This section explores and discusses the findings of the review against the research questions. The first subsection addresses the first research question and discusses the role and purpose of crowdsourcing, namely geofences and location-based notifications, in smart cities. The second presents the strategies and tools that have already been developed and used to implement and integrate mechanisms of crowdsourcing in smart cities. The last is related to how crowdsensing implementations can improve citizens' lives in a smart city, and how to make citizens active contributors.

4.1 Role and purpose of crowdsensing and crowdsourcing, namely geofences and location-based notifications, in smart cities

According to Pilloni et al., MCS includes both mobile crowdsensing and mobile crowdsourcing [18]. The author states that "mobile crowdsensing makes use of mobile sensors to collect data from a crowd of different sources", and that "in mobile crowdsourcing, users are required to complete a task, usually consisting of providing feedback". MCS has been widely adopted in smart cities, personal health care, and environment monitor areas [9].

Crowdsensing is a technique in which a large number of people using mobile devices with sensors share sensory data to measure, analyse, or infer any issue of common interest [25]. In fact, in recent years, mobile crowdsensing has emerged as one of the most popular paradigms for urban sensing, "allowing the collection and sharing of great amounts of data and the monitoring/detection of citizenship habits and movements in urban environments" [7]. In smart cities, crowdsourcing initiatives enable citizens' active and passive engagement in data

collection about the city’s functioning, services, quality of life, and environment. Mobile crowdsourcing relies on human sensing capacity, which combines sensors with human feedback and analysis. This is particularly valuable when users are assessing urban concerns such as the quality of urban services and the impact of decisions on users’ quality of life [21].

Shahrour and Xie [21] claim that crowdsourcing contributes to three key success factors of smart city projects. The first is related to data collection, as mobile crowdsourcing enables the development of cost-effective and high-quality monitoring systems for urban infrastructures, services, and the environment. Furthermore, user feedback based on sensor data is essential for capturing people’s demands and preferences, as well as determining the true impact of smart city projects on inhabitants’ quality of life. The second factor concerns citizens’ involvement in local development and activities, as local governments can get citizens’ ideas and feelings about smart city projects and their real-world impact using mobile crowdsourcing. The third factor involves the creation of smart applications based on crowdsourcing, like smart navigation, real-time public transportation, carpooling, risk warnings, emergency operations, and disturbance alerts. By developing crowdsourcing-based and cost-effective monitoring systems as an alternative to traditional smart city monitoring systems, mobile crowdsourcing could help speed up the deployment of smart city projects.

According to Amaxilatis et al. [2], the use of IoT devices together with smartphone apps is a crucial enabler for the creation and consolidation of innovative ecosystems within cities, as it allows users to validate and embrace new services. The authors concluded that because people carry and utilise their smartphones daily, creating a significant potential for researchers to collect complex and intelligent observations of an urban environment.

To summarize, the research suggests that mobile crowdsensing and mobile crowdsourcing have been widely adopted in smart cities, personal health care, and monitor areas. Crowdsensing allows for the collection and sharing of sensory data to measure, analyze, or infer any issue of interest. Crowdsourcing contributes to key success factors of smart city projects related to data collection and citizens’ involvement. The use of IoT devices with smartphone apps is also seen as a crucial enabler for the creation and consolidation of innovative ecosystems within cities.

4.2 Strategies and tools that have already been developed and used to implement and integrate mechanisms of crowdsensing and crowdsourcing in smart cities

Amaxilatis et al. [2] present a solution for deploying and managing crowdsensing campaigns and experiments across cities federated in the OrganiCity facility. The authors present a tool to help those planning crowdsensing campaigns define more exactly what they want as input from those taking part in such activities, as well as extra feedback that allows them to characterize their success numerically and qualitatively. Experimenters can see if participants’ contributions stick to the spatiotemporal limits they set, and participants can follow their contributions.

As a result, the authors concluded that the system allows developers to reverse course if they notice that their campaign design is underperforming through the system.

Cheng et al. [5] propose a collaborative geofence site selection (CGSS) method for city management to designate geofence sites for dock-less shared bikes in the city. It initially selects hotspots using a density-based and collaboration-inspired algorithm, and then assigns geofence sites to the highest-ranking hotspots. In this scenario, geofences are used to determine the best sites for renting bicycles and scooters to maximize user satisfaction with the service’s availability and coverage for the city’s expansion.

Fernandes et al. [6] developed a platform to be used via an application mobile device that allows its users to obtain a set of information regarding the current status and future of the city, as well as the provision of smart notifications with useful information taking into account the context of each user. The platform also has a gamification mechanism that includes the subjective perception, evaluation and satisfaction of each user concerning the city in which they live, to promote the continued use of the platform in question.

In 2021, Foschini et al. introduced ParticipAct, a mobile crowdsensing platform utilizing edge nodes to identify potential hazardous crowd scenarios [7]. This platform is especially helpful in emergency scenarios, such as the COVID-19 pandemic, enabling people to avoid dangerous crowd situations, and suggesting people safer routes or places. In ParticipAct the users have a sensing client application installed on their smartphones and they send collected information to a centralized cloud server, based on targeted sensing campaigns created by researchers and platform administrators.

In smart city applications, Kousiouris et al. [12] leveraged social network data to find large crowd concentration (LCC) events. In this approach, the user data, in the form of planned routes and locations, coming from a Smart Transportation platform, is linked with social network activity peaks to identify large crowd concentration events that might affect the user journey. For this project, the public bus transport authority has implemented Route Monitoring of individuals with special needs when they are taking buses throughout the city. If a large gathering of people is detected, the caregivers will be notified. Thus, the caregivers may alter the planned journey of the user to avoid congestion, confusion and limited mobility circumstances.

Roman et al. [20] proposed a mobile on-street parking space detection system that is scalable and manageable when comparing its performance with a fixed sensing solution. Ultrasonic sensors are installed on the passenger side of a car to determine the distance between the vehicle and the next roadside object. A supervised learning system that analyses the structure of the sonar trace to distinguish parked automobiles from road clutter, transmits this information to a central server, which creates a parking occupancy map. This mobile sensor system could be a crowdsourcing approach in the future, where members of the public can install sensors on their vehicles and collect data, with appropriate

compensation in the form of reduced parking costs or simply free access to the parking apps.

Picaut et al. [17] propose a crowdsourcing-based alternative method for assessing the noise environment. To collect physical and perceptual data on the sound environment, a smartphone application and a spatial data infrastructure have been designed specifically for this purpose. Each contributor's data feeds a community database, which should allow for a more detailed representation of the sound environment in space and over time than those obtained conventionally by using traditional numerical modelling methodologies.

This research has identified various crowdsourcing methods in smart cities, including deploying and managing crowdsensing campaigns and experiments, collaborative geofence site selection for bike sharing, emotional mapping for public space dialogue, a mobile platform for obtaining city information and user satisfaction, edge-enabled mobile crowdsensing for dangerous crowd situations, leveraging social network data for large crowd concentration events, mobile on-street parking space detection, and crowdsourcing-based noise environment assessment. These methods utilize a combination of mobile devices, sensors, and community engagement to collect and analyse data for smart city applications.

4.3 Improvement of citizens' lives in a smart city through crowdsensing and strategies to make citizens active contributors

At first, smart cities were simply cities with economic development objectives; later, the notion expanded to encompass the usage of information and communications technology (ICT) within city infrastructures, and finally, the concept became more citizen-centric. Today, smart cities incorporate technology into their infrastructures, allowing them to better serve their citizens by providing more efficient services to citizens, monitoring and optimizing existing infrastructure, increasing collaboration among various economic actors, and encouraging innovative business models in both the private and public sectors [3].

Mobile crowdsensing (MCS) has the potential to significantly improve citizens' daily lives while also providing urban civilizations with new perspectives. Furthermore, the IoT paradigm is a suitable solution for a wide deployment of sensing infrastructure that enables smart city applications [4, 14]. In smart cities, citizens can not only interact and engage with services but also provide data for these services via crowdsensing [10]. MCS makes use of human intelligence, which has a better awareness of context than typical sensor networks. As a result, citizens' active participation can improve the spatial coverage of existing deployed sensing systems without requiring further investments, according to Capponi et al. [4].

MCS has the potential to improve the living conditions of a smart city through numerous applications, such as emergency management and prevention, environmental monitoring, health care and wellbeing, e-commerce, indoor localization, intelligent transportation systems, mobile social networks, public safety, unmanned vehicles, urban planning, waste management, and Wi-Fi characteri-

zation. Capponi et al. [4] have identified these domains as the most promising for the use of MCS.

The success of any crowdsensing implementation depends on citizen engagement and contribution [24, 4, 7]. Gathering more data leads to more thorough outcomes and, consequently, better quality data sets [7]. In this way, citizen recruitment and data contribution incentives are critical to the success of MCS programs and how to attract a big group of citizens as active contributors has become a major research topic [24, 4].

A common strategy for increasing and reinforcing participation is through a gamification technique. In this way, the adoption of reward programs encourages and stimulates the users to complete the task, augmenting the quantity and the quality of the gathered information [7].

Many strategies have been proposed to stimulate participation and make citizens active contributors, and they can be classified into three categories, according to Capponi et al. [4]: entertainment, service, and money. The first category considers methods that stimulate participation by turning sensing tasks into games. The service category consists of providing services to the users in exchange for their data. Finally, monetary incentives reward users for their contributions with money. The authors concluded that these strategies are highly dependent on the type of application and that, in general, rewards should be based on the quality of contributed data and determined by the demand-supply relationship.

Hu et al. [9] created a three-stage Stackelberg game to keep the number of participants constant by viewing the MCS situation as a sensory data market. Players in the three-stage Stackelberg game are divided into two groups: monthly-pay participants and instant-pay participants. This ensures that participants who pay monthly will continue to contribute with sensory data. Furthermore, the game protects the sensory data market's fairness by utilizing a safe reward distribution mechanism supported by blockchain technology.

To conclude, smart cities use information and communication technologies to offer efficient services to citizens, monitor and optimize infrastructure, promote collaboration, and encourage innovation. Mobile crowdsensing provides an effective means for gathering data in smart cities, with citizens playing an active role. Crowdsensing solutions can enhance emergency management, environmental monitoring, health care and wellbeing, e-commerce, and other domains within smart cities. Citizen engagement is critical to its success, and gamification techniques, such as reward programs, can promote participation. Strategies to promote participation can be classified into the categories of entertainment, service, and monetary incentives, with rewards based on the quality of contributed data.

5 Conclusion

Smart cities are considered a crucial element in achieving the sustainability of cities and urban areas with high-population densities. Thus, the involvement of

residents in the transition to smarter cities is essential and one of the main mechanisms for this is the application of crowdsensing and crowdsourcing strategies.

This article details a systematic review that aims to analyze the literature on smart cities and their implementation using crowdsensing and crowdsourcing. The review followed the PRISMA model and used the Scopus database as the primary source of information. Out of the 14,840 studies initially identified, 17 were finally selected based on the previously defined research questions after applying the PRISMA methodology.

The aim of the research questions was to evaluate the current state of crowdsensing and crowdsourcing in smart cities. Based on the studies collected, it was found that crowdsensing enables the collection and exchange of massive amounts of data, which can be utilized to track citizens' behavior and movement in urban areas. Crowdsourcing initiatives enable citizens' active and passive involvement in gathering data about the quality of life and services in the city, ensuring that they function at their best. Furthermore, several strategies and tools that have already been developed and used to implement and integrate mechanisms of crowdsensing and crowdsourcing in smart cities, were found in the literature. Finally, in most of the analyzed studies, all the authors agreed that the implementation of crowdsensing initiatives can improve the citizens' lives in a smart city. It was also identified the most promising application domains where MCS can play an important role, for example, environmental monitoring, e-commerce, health care and well-being, indoor localisation, intelligent transportation systems, public safety, urban planning, and waste management.

This project intends to examine how crowdsensing, crowdsourcing, and geofences can be incorporated into the infrastructure and framework of smart cities. Using the compiled information, the next step is to create a platform that integrates these concepts to form a valuable information system, enhancing the smart city concept and improving the quality of life for its residents.

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References

1. Alves, C., Chaves, A., Rodrigues, C., Ribeiro, E., Silva, A., Durães, D., Machado, J., Novais, P.: Survey for big data platforms and resources management for smart cities. In: Bringas, P.G., García, H.P., de Pisón, F.J.M., Flecha, J.R.V., Lora, A.T., de la Cal, E.A., Herrero, Á., Martínez-Álvarez, F., Psaila, G., Quintián, H., Corchado, E. (eds.) *Hybrid Artificial Intelligent Systems - 17th International Conference, HAIS 2022, Salamanca, Spain, September 5-7, 2022, Proceedings. Lecture Notes in Computer Science*, vol. 13469,

- pp. 393–404. Springer (2022). https://doi.org/10.1007/978-3-031-15471-3_34, https://doi.org/10.1007/978-3-031-15471-3_34
2. Amaxilatis, D., Mylonas, G., Diez, L., Theodoridis, E., Gutiérrez, V., Muñoz, L.: Managing pervasive sensing campaigns via an experimentation-as-a-service platform for smart cities. *Sensors (Switzerland)* **18** (7) (2018). <https://doi.org/10.3390/s18072125>
 3. Ande, R., Adebisi, B., Hammoudeh, M., Saleem, J.: Internet of things: Evolution and technologies from a security perspective. *Sustainable Cities and Society* **54** (3) (2020). <https://doi.org/10.1016/j.scs.2019.101728>
 4. Capponi, A., Fiandrino, C., Kantarci, B., Foschini, L., Kliazovich, D., Bouvry, P.: A survey on mobile crowdsensing systems: Challenges, solutions, and opportunities. *IEEE Communications Surveys and Tutorials* **21**, 2419–2465 (2019). <https://doi.org/10.1109/COMST.2019.2914030>
 5. Cheng, G., Guo, Y., Chen, Y., Qin, Y.: Designating city-wide collaborative geofence sites for renting and returning dock-less shared bikes. *IEEE Access* **7**, 35596–35605 (2019). <https://doi.org/10.1109/ACCESS.2019.2903521>
 6. Fernandes, B., Neves, J., Analide, C.: Safecity: A platform for safer and smarter cities. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* **12092 LNAI**, 412–416 (2020). https://doi.org/10.1007/978-3-030-49778-1_37
 7. Foschini, L., Martuscelli, G., Montanari, R., Solimando, M.: Edge-enabled mobile crowdsensing to support effective rewarding for data collection in pandemic events. *Journal of Grid Computing* **19** (9) (2021). <https://doi.org/10.1007/s10723-021-09569-9>
 8. Google: Geofencing api (2022), <https://developers.google.com/location-context/geofencing>
 9. Hu, J., Yang, K., Wang, K., Zhang, K.: A blockchain-based reward mechanism for mobile crowdsensing. *IEEE Transactions on Computational Social Systems* **7**, 178–191 (2) (2020). <https://doi.org/10.1109/TCSS.2019.2956629>
 10. Ismagilova, E., Hughes, L., Dwivedi, Y.K., Raman, K.R.: Smart cities: Advances in research — an information systems perspective. *International Journal of Information Management* **47**, 88–100 (8) (2019). <https://doi.org/10.1016/j.ijinfomgt.2019.01.004>, <https://linkinghub.elsevier.com/retrieve/pii/S0268401218312738>
 11. Kirimtat, A., Krejcar, O., Kertesz, A., Tasgetiren, M.F.: Future trends and current state of smart city concepts: A survey. *IEEE Access* **8**, 86448–86467 (2020). <https://doi.org/10.1109/ACCESS.2020.2992441>
 12. Kousiouris, G., Akbar, A., Sancho, J., Ta-shma, P., Psychas, A., Kyriazis, D., Varvarigou, T.: An integrated information lifecycle management framework for exploiting social network data to identify dynamic large crowd concentration events in smart cities applications. *Future Generation Computer Systems* **78**, 516–530 (1) (2018). <https://doi.org/10.1016/j.future.2017.07.026>
 13. Miranda, R., Ramos, V., Ribeiro, E., Rodrigues, C., Silva, A., Durães, D., Analide, C., Abelha, A., Machado, J.: Crowdsensing on smart cities: A systematic review. In: *Advances in Artificial Intelligence—IBERAMIA 2022: 17th Ibero-American Conference on AI, Cartagena de Indias, Colombia, November 23–25, 2022, Proceedings*. pp. 103–106. Springer (2023)
 14. Nizetić, S., Šolić, P., de-Ipiña González-de Artaza, D.L., Patrono, L.: Internet of things (iot): Opportunities, issues and challenges towards a smart and sustainable future. *Journal of Cleaner Production* **274** (11) (2020). <https://doi.org/10.1016/j.jclepro.2020.122877>

15. Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D.: The prisma 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* **372** (2021). <https://doi.org/10.1136/bmj.n71>
16. Pereira, P., Linhares Silva, A., Machado, R., Silva, J., Durães, D., Machado, J., Novais, P., Monteiro, J., Melo-Pinto, P., Fernandes, D.: Comparison of different deployment approaches of fpga-based hardware accelerator for 3d object detection models. In: *Progress in Artificial Intelligence: 21st EPIA Conference on Artificial Intelligence, EPIA 2022, Lisbon, Portugal, August 31–September 2, 2022, Proceedings*. pp. 285–296. Springer (2022)
17. Picaut, J., Fortin, N., Bocher, E., Petit, G., Aumond, P., Guillaume, G.: An open-science crowdsourcing approach for producing community noise maps using smartphones. *Building and Environment* **148**, 20–33 (1 2019). <https://doi.org/10.1016/j.buildenv.2018.10.049>
18. Pilloni, V.: How data will transform industrial processes: Crowdsensing, crowdsourcing and big data as pillars of industry 4.0. *Future Internet* **10** (3 2018). <https://doi.org/10.3390/fi10030024>
19. Pánek, J.: Emotional maps: Participatory crowdsourcing of citizens' perceptions of their urban environment. *Cartographic Perspectives* **2018**, 17–29 (2019). <https://doi.org/10.14714/CP91.1419>
20. Roman, C., Liao, R., Ball, P., Ou, S., Heaven, M.D.: Detecting on-street parking spaces in smart cities: Performance evaluation of fixed and mobile sensing systems. *IEEE Transactions on Intelligent Transportation Systems* **19**, 2234–2245 (7 2018). <https://doi.org/10.1109/TITS.2018.2804169>
21. Shahrour, I., Xie, X.: Role of internet of things (iot) and crowdsourcing in smart city projects. *Smart Cities* **4**, 1276–1292 (12 2021). <https://doi.org/10.3390/smartcities4040068>
22. Silva, G.O., Rocha, A.M.A., Witeck, G.R., Silva, A., Durães, D., Machado, J.: On tuning the particle swarm optimization for solving the traffic light problem. In: *Computational Science and Its Applications–ICCSA 2022 Workshops: Malaga, Spain, July 4–7, 2022, Proceedings, Part II*. pp. 68–80. Springer (2022)
23. Sousa, R., Lopes, D., Silva, A., Durães, D., Peixoto, H., Machado, J., Novais, P.: Sustainable and social energy on smart cities: Systematic review. In: Guarda, T., Portela, F., Augusto, M.F. (eds.) *Advanced Research in Technologies, Information, Innovation and Sustainability - Second International Conference, ARTIIS 2022, Santiago de Compostela, Spain, September 12–15, 2022, Revised Selected Papers, Part II. Communications in Computer and Information Science*, vol. 1676, pp. 72–84. Springer (2022). https://doi.org/10.1007/978-3-031-20316-9_6, https://doi.org/10.1007/978-3-031-20316-9_6
24. Wang, J., Wang, F., Wang, Y., Zhang, D., Wang, L., Qiu, Z.: Social-network-assisted worker recruitment in mobile crowd sensing. *IEEE Transactions on Mobile Computing* **18**(7), 1661–1673 (7 2019). <https://doi.org/10.1109/TMC.2018.2865355>
25. Yang, M., Zhu, T., Liang, K., Zhou, W., Deng, R.H.: A blockchain-based location privacy-preserving crowdsensing system. *Future Generation Computer Systems* **94**, 408–418 (5 2019). <https://doi.org/10.1016/j.future.2018.11.046>