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REVIEW PAPER

A survey on pervasive computing over context-aware system

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Abstract
Pervasive computing (PerC) systems are now being integrated into everyday life which is deployed in homes, offices, hospitals, universities. The sensor data can be integrated with different range of sources in pervasive systems which also offers an extensible, open and portfolio services. Due to remarkable progress in various domains such as smart phones, computing power, sensor, network and embedded devices, wireless communications which are combined with social networking paradigms, cloud computing and data mining techniques, that enabled the users for creating PerC systems with global accessibility. The major challenge of PerC is to provide the suitable consistent adaptive behaviors and context-aware systems in a vast amount of sensor data for these services which need to improve the accuracy, precision and dynamism. This research work provides an inclusive analysis of characteristics of data, then the complexities of the existing technique are reviewed which are mostly used in inferring situations from sensor data. The extensive experiments are carried out on benchmark dataset to validate the efficiency of existing techniques namely multi-context, mechanisms of user-side publish/subscribe by using the metrics such as accuracy, f-measure, precision, recall and communication overhead. Many open research opportunities are identified in this area by comparing and contrasting the existing techniques, which are discussed in this research work.

Keywords Cloud computing · Embedded devices · Internet of things · Pervasive computing · Sensor · Smart phones

1 Introduction

The PerC is a novel paradigm in the field of communication and computing, where many intelligent equipment involves in gathering information, sharing information, and making the collaborative decision (Yu et al. 2014). When combining with DM techniques, cloud computing and social networks, the smart phones, devices of sensors and embedded systems, computing power, wireless communication and networking paved a way to researchers for creating a wide variety of PerC systems (Bansod et al. 2017; Jayalakshmi 2018). The prototype testbeds such as health monitoring systems, smart homes, social networking media and body area networks are commonly used in PerC for its development (Bodaghi 2016). These underlying technologies are used to perform in various applications such as information fusion, tracking the location, activity, discovering the resources, smart device communications, learning the user preferences, dissemination and routing. But, these systems cannot be able to apply on large-scale application due to limited dissemination of results, dataset and tools (Lee et al. 2016; D'Angelo et al. 2019).

However, a vast amount of computational platforms, devices, users and applications are deal with massive amount of data involved in future large scale PerC which still needs to operate over different scales (Bordel et al. 2017). The recognition and ambiguity mediation in multi-context is a challenging process for PerC with the presence of noisy information in large amount of resource-constrained devices (Conti et al. 2012). Even though, probabilistic models are developed to improve the recognition accuracy in multi-context by using information theoretic reasoning, still a lot needs to be done for fundamental understanding of scalable interaction of a multitude of contexts, not only for single users but also for multiple users sharing the same PerC environment,

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often with conflicting goals (Doukas and Maglogiannis 2012; Al-Shargabi and Siewe 2013). The network resources and devices are effectively discovered and managed dynamically by using context-aware solutions and algorithms. In this research work, the taxonomy of PerC is reviewed in terms of various domains such as DM, mobile computing, health care and Internet of Things (IoT). The existing techniques which use the PerC in several domains are represented with parametric terms namely time consumption, Root Mean Square Error (RMSE), error rate and execution time. The problems faced by existing systems such as the presence of noise, outliers, large-scale datasets are discussed in this research work. For instance, the existing distributed index for ubiquitous system faces high energy cost which leads poor performance due to presence of outliers. This research work gives a solution to overcome the challenges by improving the appropriate techniques in PerC system.

This survey work is organized as follows, Sect. 2 describes the taxonomy of PerC system. Section 3 describes the fields of PerC with its effects on human factors. The survey of existing techniques with its advantage and limitations are represented in Sect. 4, whereas the conclusion is made with future work is explained in Sect. 5.

2 Pervasive computing system and its applications

A network devices are embedded in the environment by creating the ambient intelligence in PerC, which provides continual, reliable and unobtrusive connectivity and also improves the quality of life and human experience. An artificial intelligence and Machine Learning (ML) strategies are employed to adapt and control the physical surroundings, which is closely related to smart environments. Cyber-physical systems and other related systems include the integration of computation, control and communication, which may explore techniques outside of human context. At the community and individual level, PerC focuses on sensing data to help the humans and supports information technologies for providing communication and computing capabilities in distributed and mobile computing. Figure 1 describes the overview of PerC systems.

As the dimensions of system increase, it can able to maintain the level of functionality or efficiency is known as scalability. While incurring the associated overheads, these increasing dimensionality adds some capability to the system, which can be measured by using storage capacity, price tags, accessibility, communication and computation resources, energy, human time or other resources usage. When compared with overhead rate, the PerC system provides rate of increase in capacity, which will increase the effective value added by system to zero, otherwise the

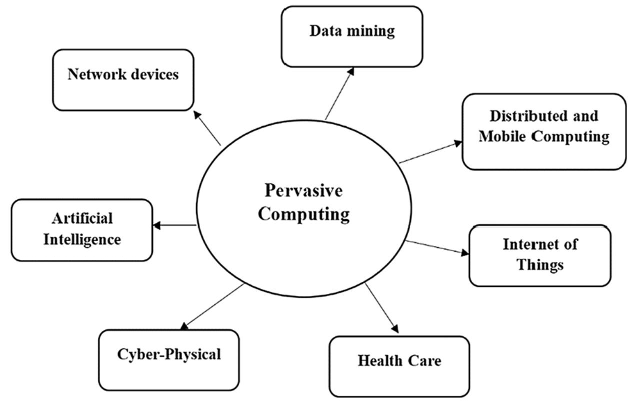

Fig. 1 Overview of pervasive computing

overhead will consume all resources. The smart vehicles are enabled with current research in PerC, but the future systems contain an entire country's traffic system. Every tagged object in IoT can be a part of vast pervasive connected system across the world. The transformation as well as challenging the scaling in PerC can be carried out by both IoT and social networking environment. The design of middleware, services, networking, hardware and applications are developed by new approaches and paradigms in PerC system. A massive number of devices or heterogeneity devices are involved to communicate in PerC, which leads to increase the data generation, collection and transmission significantly. While improving the efficiency, accuracy and reliability with cost-effectiveness, these data dimensions need to increase significantly in PerC.

3 Fields of pervasive computing systems

The areas of research that are influenced by PerC and the future of PerC with respect to some focused areas are discussed. Here, cloud computing, IoT, DM and health care systems of PerC are discussed.

3.1 Models of data mining

A wide variety of sensors are deployed at a large scale due to rapid advances in PerC system, which leads to create the vast amount of data must be analyzed for extracting the relevant information. The spatio-temporal data at large scales are handled by this relevant information with ML and DM techniques. The human behavior can be understand by building data models automatically with necessary information. While the current progress is promising, there are a number of challenges that have to be addressed to achieve this vision. In the past few decades, the researchers studied the techniques of DM and ML based PerC applications to model the human behavior that is reflected in various areas namely identifications of emotions, activities, abnormal behavior and body mannerisms. Most of these technologies are currently limited to data gathered from a laboratory or controlled real-world setting. There are some of the challenges faced by DM and ML techniques are given below:

3.1.1 Large scale datasets

There is truly a lack of large scale data sets available for experimentation and analysis in PerC system. In real-world settings, the design and development of architectures and algorithms are carried out by collecting the large scale data in multiple domains includes speech, vision, phone, wearable and environmental sensors. While it is sometimes impractical to collect data using different modalities, development of standardized data formats will facilitate in sharing and fusing heterogeneous data. Developing a novel means of annotating data and building ontologies can alleviate the problems of time-consuming and expensive, which will be a new direction to pursue. Developing crowdsourcing and interactive ML algorithms can actively query the relevant data samples which will help to address these challenges.

3.1.2 Capturing context

In PerC system, contexts are of various types such as the user contexts which includes profile, social situations, location, activity, time context includes day of week, season, year or hour of day, physical contexts include noise, temperature, lighting and finally, and communication contexts such as costs, network connectivity and resource accessibility. A PerC system create and build the targeted contextual picture of current situation by combining the heterogeneous sources of information namely satellite maps, social media information, recognized activities and Geographical Positioning System (GPS) information.

3.1.3 Learning from large, noisy data sets

When PerC systems scale to incorporate thousands or millions of sensors, DM algorithms will have to deal with massive data collected from these devices. Compressed sensing approaches adopted in the signal processing and computer vision community can provide insights for developing such algorithms. ML algorithms have to often make decisions based on insufficient, incomplete and noisy data samples (i.e., uncertainty), which is the same scenario for pervasive computing. Design and development of robust algorithms, capable of making decisions in such uncertain conditions, and confidence measures that quantify the uncertainty have to be explored.

3.2 Models of internet of things

The ideas of scaling the number of devices, diversity and inherent capabilities of devices are described by PerC system. The physical objects such as mobile devices, buildings are enhanced with communication and computational elements by focusing on characteristics of objects. The histories of recent interactions are recorded, register their presence and route the salient information via network by smart tags or objects. The human daily lives are profoundly influenced by advancement and deployment of smart objects. Despite these advances, there are still several conceptual gaps for the community to explore.

3.2.1 Object ecosystems

PerC cannot able to create smart object ecosystems, even though it has greater solutions in enhancing the specific objects. First, researchers must have the knowledge to build smart objects, but how to design scalable communication architecture for smart objects is less clear. Second, programming languages, tools, and abstractions must be specified to work across multiple smart objects in a device independent way. Because such objects are typically energy constrained, the developed programming models must view energy complexity as fundamental to the operation of the smart objects. Finally, a consistent semantics must be designed across devices to enable service composition and integration.

3.2.2 Smartphones

Today's smartphone is as powerful as larger mobile devices which integrate powerful processors, multiple communication technologies, multimedia capability (e.g., audio, image) and ample storage and a multitude of sensor suites. A lot of information are cached in current smart phones, which leads to offload expensive computation due to increasing power of clouds. The future smart phones be more powerful than current devices, communicate more quickly, store more data, and integrate new interaction technologies. With battery capacities and wireless data bandwidth, these goals are at odds and the another challenge of heterogeneity of deployed devices is to limit the inter-operation of device and interact with other objects for smart phones.

3.3 Models of health care

In this section, the application of health care domain is discussed, because PerC is used in every aspects of human life specifically for aging people. The quality of life as well as independence are improved by reducing the cost of pre hospitalization for health care by using PerC technologies. The last half decade has seen significant progress in the domain of smart health care. The availability of web-based tools for monitoring personal health, electronic records of personal health is increased due to advances in healthcare applications. By using sensors/wireless mobile devices, monitoring and managing the physical activity of humans are also increased.

The wellbeing and health of society are improved by PerC in various ways includes, demanding the health information using ubiquitous access, attention to mental health, delivering timely interventions, predictive assessment, prevention, validation of hypotheses and technologies. Extensive research is needed to make this dream into a reality. The research is used to validate the real-life adoption, which leads to expensive on smart health and also should ensure that it doesn't affect the health adversely. The open extensible platforms are designed for smart health, where the sensor network community is benefited from TinyOS and open hardware platforms. Along with smart health datasets, testbeds should be designed first and made available to the community. The first step is identifying the datasets for healthcare system which are MIT arrhythmia dataset, PhysioNet physiologic signal dataset, and the CASAS dementia assessment dataset.

3.4 Models of cloud computing

The limitations for consuming the power and storage capacity are the major challenges in mobile phones and sensors of PerC. Therefore, PerC focuses on cloud computing to overcome the above mentioned challenges. The wearable or portable devices are developed to collect and store the data, which is also utilized to analyze the power of various computers throughout the world. The sub-sections of cloud computing can be described as below:

3.4.1 Cloud accessibility

The locality of cloud is the major issues in PerC, because the cloud can be far way or reachable through Internet or placed away using Wi-Fi (i.e., cloud-let). The researchers should plan strategically and define the metrics for accessibility to use different types of resources. This will lead to a problem of how to maintain the cloud-lets and managing their roles in mobile devices.

3.4.2 Mobile clouds

A proactive data delivery framework is designed to overcome the latency problem by using user's contextualized behavior of data access with mobility route fingerprints of user. This approach enhances various networking scenarios such as personal content distribution, health delivery in mobile, on-demand social networks, transportation systems, resource augmentation and smart grids by trading the bandwidth and storage for latency.

3.5 Effects of pervasive computing on human factor

Researchers and commercial designers anticipate the scaling of PerC to an even greater number of users, devices and applications. In many ways, human life is impacted by PerC future applications, therefore, developing the PerC for security, privacy, ethics and human interfaces should be carefully carried out to implement.

3.5.1 Security and privacy

The platforms such as smartphones, heavily-deployed gadgets are secured by employing only crude methods from internal or external attacks. Even though, PerC collects and aggregate huge amount of data, it offers only limited controls to the users and the uncertain privacy implications must be faced by the user. The priorities, needs, structure of organization as well as individual's preferences within the organization should be understood by research for gaining a better knowledge in PerC systems. A cyber welfare is used to find the system such as misleading, disturbing or even terrorizing among vast population in large-scale PerC. A single record in context of databases represents each person for preserving the privacy of data by using DM techniques. The data describes the user or collection of user's time series observation in PerC, whereas, the social interactions of collective behavior of user can be described in multiple PerC. The existing methods are unable to work on complex structured sensor data, which contains not only a linear-value attributes collection, but also have non-linear attributes. Hence, the relational privacy of user's online social data can be preserved by developing new paradigms in PerC system.

4 Literature review

Several techniques on various applications are suggested by researchers in the PerC system. In this scenario, brief evaluations of some important contributions to the existing techniques that are used in data mining, big data, IoT and healthcare applications are presented (Table 1).

5 Conclusion

Nowadays, user's behavior or attitudes are changed due to the development of services and information technology systems. When people are interacting to exchange the information, a PerC system delivered the customized services to users by using entities in context-aware applications, such

Table 1 Contributations of existing techniques in context-aware pervasive computing

Authors	Methodology employed	Motivation	Advantage	Limitation	Performance measure
Wang et al. (2016)	Designed a Bloom-filter based distributed index for representing the objects of ubiquitous system	Lookup procedure is used to represent the objects on each node in PerC and ubiquitous systems	The Bloom filter method reduced the energy consumption by 43% and improved the system performance by focusing on false checking times	The total energy cost on ubiquitous devices is very high and also the method provides poor performance when add a new function to algorithm	Battery life time and false checking time are used to test the efficiency of Bloom filters
Chabridon et al. (2013)	Implemented a context-awareness meta-model (CA3M) and a domain specific language for context management (COSMOS DSL) for designing a QoC	The main aim is to obtain the location-awareness of mobile end-user by using Flash sale application	The best location among several users can be identified at context management level and trigger the appropriate service according to the current context situation at application level	During the whole context management process, the method did not focus on the privacy of personal context data	The performance of CA3M and COSMOS DSL can be evaluated by using memory and processing time
Cassales et al. (2016)	Designed a Apache Hadoop Capacity Scheduler to detect and adapt the resource availability	The major aim of this work is to improve the Apache Hadoop scheduling through context-aware approach	The speculative tasks and context-aware scheduler are used to perform the tasks migration, where Hadoop is unable to do the migration	The execution performance are reduced due to drop of available resources	The method uses the execution time, WordCount, TestDFSIO and TeraSort for evaluating the performance of scheduler algorithm
D'Angelo et al. (2017)	The behavioral patterns are extracted by Apriori algorithm and Naive Bayes is used for final decision making	Designed a PerC in cloud to solve the issues of privacy, trust and identity	The typical attacks such as time-based, context-based and counting-based are identified by these model	Sometimes, trust values of honest entities are reduced by recommenders falsely and vice versa. Hence, the method provides poor performance in trust values because of non-filtering of false recommendation	Accuracy, sensitivity, specificity, precision and area under ROC curve
Riboni et al. (2019)	According to available context data sources, the method implements the user-side publish/subscribe mechanism	Based on sensor data, the method recognize the different activities of patients by considering adaptive healthcare application for self-administration of therapies	In context-aware function, the optimal trade-off among conflicting goals of privacy and urgency are find out by interface adaptation	The method did not focus on the preserving the privacy of user, which leads some attacks may happen on the user data	Accuracy, precision, recall and f-measure are used to evaluate the performance of the context recognition system
Roy et al. (2016)	Developed a novel framework to determine the multiple context metrics such as quality and energy of sensor data in pervasive computing	At a minimum cost, the application requirements for specific accuracy is satisfied by using Quality of INFerence Function (QoINF)	The multi-context search heuristic algorithm (Lagrangian-based) is developed to solve the proposed optimization problem dealing with quality versus-communication cost trade off	While maintaining the method, the cost of QoINF is very high	Communication overhead and accuracy with SunSPOT, Shimmer and Smartphone sensors in smart home environments

Table 1 (continued)

Authors	Methodology employed	Motivation	Advantage	Limitation	Performance measure
Serral et al. (2018)	Introduced an user-adaptive task models for Ambient Intelligence (AmI), an executable modelling language that guides pervasive systems at runtime	The method satisfied the maximum number of user by using personalized adaption mechanisms in PerC systems	By using this approach, specific routine can be presented to different users by changing the contextual preference model, which is reusable for multiple routines	The system adaption provides poor performance when the historical data with unsuccessful executions are used	Non-Functional Requirements (NFRs) such as efficiency, comfort, energy saving, etc. are used to validate the user-adaptive task performance
Roth et al. (2018)	The different middleware platforms are discovered and integrated by XWARE	Every middleware platforms are supported and different nodes are distributed by XWARE instance	A new platforms are added and use it in different domains shows the flexibility of this framework	The method is designed to tackle the heterogeneity challenges, but failed to tackle the non-functional heterogeneity	Deployment location, communication between interoperability instances, extensibility, customizability and no to minimal changes at legacy services
Karthik and Ananthanarayana (2019)	Proposed a Context Aware Trust Management Scheme (CATMS) for data fault detection, data reconstruction and medical event detection for pervasive healthcare	The medical emergency detection problems are resolved by CATMS approach. The detection problems are raised due to presence of untrustworthy sensor data and data loss in PerC	The data fault and misbehaving sensor nodes produced high false alerts and alarms, which is reduced by CATMS. To identify the patient's condition, the data loss and faults are reconstructed	The complexity of data reconstruction techniques is increased, only when the parameters are too large. In data reconstruction methods, statistical techniques did not consider the underlay distribution of the input data	RMSE, Error Rate, False Positive Rate (FRR) are used to validate the CATMS
Avenoğlu and Eren (2019)	Developed a work flow engine and rule engine with Complex Event Processing (CEP) are incorporated to enhance the workflow adaptation and execution	Context-aware workflow is used to integrate a rule engine with the workflow engine of context information by without changing the structure of the workflow engine	The interaction between rule engine and workflow engine for loosely coupled is used by event-driven architecture for exchanging the data among themselves without modifying the workflow language	The method cannot able to handle the multiple workflow engines and rule engines and running them in parallel. The method needs to connect the workflow and rules by using identification number of workflows and tasks in rules, even though it use a modular architecture	Time consumption for different steps of proposed method is used as parameter metric in experiments

as healthcare, intelligent workplaces, smart homes, gaming etc., In this paper, the state-of-the-art research in PerC are represented in terms of DM, health care, IoT and cloud computing. Based on the contextual applications and highly sensitized environments, this research work has reviewed the complexity of PerC, which is customized to variety of factors. This paper explained the existing techniques in PerC, and compared them against the qualitative metrics. In the future, this survey suggests to develop a hybrid approach of learning- and specification based techniques, which is based on the context-aware system analysis. According to learning-based techniques, a new knowledge can be derived for dealing with uncertainty in sensor data, whereas the representation of knowledge and sharing can be carried out by specification-based techniques.

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