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Research Article

Analysis of Context Aware Computing Systems in Internet of Things

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Abstract: Internet of Things (IoT) has been developed speedily due to modern advancements in communications and sensor technologies. Similarly IoT deployments are rising with accelerating speed. Since this field develops in number and heterogeneity, intelligence has become important aspect of IoT. The data has become Big in nature so understanding, extracting knowledge and interpreting this Big Data is critical step for upcoming future of IoT. One of the major difficulties in the way to smart IoT is understanding context. Context is defined as making sense of the situation or environment using data received from the sensors and performing actions accordingly. This is referred as context-aware computing. Context aware systems are in high demand in fields/area like Smart/Intelligent Environments, Pervasive & Ubiquitous Computing etc. They collect the data and adjust the system actions accordingly with the help of context details. In this survey paper, we discuss the perception of context awareness, context lifecycle, context modeling approaches and context reasoning methods in detail. The survey shows that Ontology based modeling and Supervised learning reasoning are widely used in context-aware computing systems. Finally, applications of context-aware systems are listed along with discussion on open issues to point out challenges and upcoming development direction of context-aware systems.

Keywords: Context, Context awareness, Context Aware Computing, Context modeling, Decision Making, Pervasive & Ubiquitous Computing

1. Introduction

Real world has become complex and dynamic. Users frequently move around with portable devices. Surrounding including nearby people, atmosphere and environment changes rapidly. Ubiquitous computing helps to indentify these circumstances appropriately and provides best adequate services to users. This situational information about entities is defined as context. Hence ubiquitous computing system needs to acquire context properly and present best adequate services to users according to the context. Many researchers have described context as per their own perception. Schilit and Theimer introduced Context awareness first in 1994 [1] and explained it in term of identities, location, objects and nearby people. P.J. Brown explained [2] context as the information that is used to characterize the situation of an entity. Context is defined generically by A.K. Dey as "any information that can be used to characterize the situation of an entity", where "an entity can be a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" [3].

Context-awareness is the critical element of the systems developed in areas like Intelligent Environments, Pervasive & Ubiquitous Computing and Ambient Intelligence. Context aware system has become well-liked research area**.** Context aware computing facilitates applications to have awareness about the context by making implications from the collected data and presents smart intelligent services to user. Sensed data is mainly used to mine the information about context which can be user context (profile of user, preferences, location, social situation), physical context (traffic situations, temperature, light, noise), Time context (season, year, month, day of the week, hour of day), communication context (connectivity of network, resource access, communication charges) etc.

Here, we present an overview of context, context awareness and context aware systems.

What is context? The term Context has been defined by researchers in various different ways. Commonly, context is defined as the information used to describe or relate an entity [4]. Context is information mined from raw sensory data generating from many sources. Context is the key information resource for systems to attain context awareness. The Oxford Dictionary describes a general definition for context as "the circumstances that form the setting for an event, statement, or idea and in terms of which it can be fully understood" [5].

What is context awareness? Context awareness was introduced first by Schilit and Theimer in 1994. The thought of context-awareness is originally derived from the concept of pervasive computing. It is used to explain technologies that are 'able to sense, recognize, and react to contextual variables' i.e. to determine the actual context of their use and adapt the functionality accordingly or respond appropriately to features of that context [6].

What are context aware systems? Context-aware computing refers to a general class of mobile systems that can sense their physical environment, and adapt their behavior accordingly [1]. There are three most critical

aspects of context such as where we are, who we are with and what resources are nearby. Context-aware system includes nearby people, devices, lighting, noise level, network availability, and even the social situation. Context aware systems make use of Heterogeneous data sources to adapt and offer services to user as per his choice or his interaction with the environment. Availability of context information to the computer system is the fundamental issue of context aware systems. Location, environment, device is used as context in context aware systems.

The remaining paper is organized as follows: Section 2 describes related work of context aware systems. Section 3 explains Context Life Cycle with help of 4 stages. Section 4 discusses various techniques available for context modeling and context reasoning. Section 5 lists various applications of context aware systems and discusses open issues & challenges in context aware computing. Finally, section 6 concludes the paper with pointers to future work.

2. Related work

In this paper, context is explained in terms of user's present location to device [7]. In context aware systems, context from the collected data is used for making decisions. Since data is heterogeneous due to different sources, it needs pre-processing and normalization to be applied on it. Big data analytics play important role in decision making from the context of sensed data [8]. The important applications enabled by data analytics and context-aware computing include transport, traffic lights and signals, energy systems, public safety and civil security, healthcare, education and learning, the quality of life etc. Classification model is constructed using machine learning algorithms (supervised and unsupervised) from the extracted features. Eunhoe Kim and Jaeyoung Choi presented context management system for supporting context-aware applications in a smart home. They explained context metadata ontology as the additional characteristic of context information to improve certainty, freshness, and understanding of the context information [9]. Pankaj Mehra described how context awareness is enabling web and mobile services on the Internet to develop beyond location-based search [10] along with methods and applications of the field. Pooja Mohan and Manpreet Singh presented a systematic understanding of context-aware computing by creating a formal model and notation for expressing context-aware computations [11]. Further described and compared current context modeling and reasoning techniques.

Derrick Ntalasha, Renfa Li and Yongheng Wang explained how the context in the IoT complex domain can be acquired and represented in a hybrid context model using Web Ontology Language Description logic OWL DL and XML [12]. This model described how the Internet of Things context can bemodeled and used to achieve goals of computational awareness. Sélindevan Engelenburg, Marijn Janssen, Bram Klievink described Guidelines, tools and frameworks for developing context-aware systems and presented method for the development of a context-aware system for business-to-government (B2G) information sharing in the container shipping domain[13]. Rahim Mohammad Forkan, Ibrahim Khalil, Ayman Ibaida, and Zahir Tari proposed Big data Context-aware Model [14] that helps in analysis of big data inside cloud environment. It described how to mine trends and pattern in the data of patients along with probabilities and used it to learn abnormal conditions. The learning outcomes are used in context-aware decision making process for the patient.

3. Context Life Cycle

Context life cycle consists of four phases as Context Acquisition, Context Modeling, Context Reasoning and Context Dissemination. Fig 1 shows all stages of the Context Life Cycle.

Context acquisition is the first step of context life cycle [18]. In this step, context is acquired from various available sources. It consists of gathering context from the users and the environment. It involves various kinds of sensors such as physical sensors, virtual sensors, and logical sensors. This step needs to work with responsibility (using two methods including push and pull methods), event frequency (instant or interval events), context source, sensor types (temperature sensors, touch sensors, motion sensors, pressure sensors, light sensors, etc.) and acquisition process (sensing, deriving and manually providing methods).

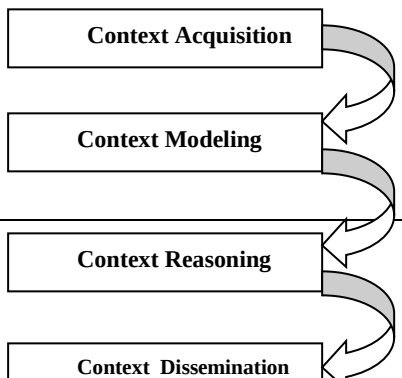

Figure 1 Context Life Cycle

Second step is context modeling i.e. the collected data needs to be modeled and represented in meaningful manner. This step is important for reusing and sharing context information among applications. It mainly concerns with the dependencies and relationships between different types of context. There are several context modeling techniques such as key-value, mark-up schemes, graphical based, object-based, logic based, and ontology-based modeling.

Third step is context reasoning in which the modeled data is processed to derive high-level context information from low-level raw sensor data. In this, the sensed context is used for obtaining new knowledge. It is defined as a method of creating new knowledge and inferring better understanding based on available context. Context reasoning techniques can be classified broadly into six categories (which are from fields of artificial intelligence and machine learning) including rules, fuzzy logic, supervised learning, unsupervised learning, ontological reasoning, and probabilistic reasoning.

Finally, both high-level and low-level context needs to be allocated to the consumers who are interested in context with efficient and effective ways in the timely manner i.e. context dissemination. Two method used for context dissemination includes query and subscription. In query method, consumer needs to make request so that context management system uses this query to generate results. In subscription method, the context consumer subscribes to the context management system by depicting its requirements. In turn the system returns the results when the event occurs or periodically.

4. Techniques for Context Modeling and Context Reasoning

Context Modeling: Context Modeling is referred as the representation of context. It is required because it's necessary to have common understanding of the system and all components of it. Context modeling is helpful for reusing and sharing of context information among various applications. It helps in understanding the characteristics, relationships and particulars of context. There are various popular context modeling techniques used in context-aware computing. It includes [15] Key-Value Modeling, Markup Scheme Modeling, Graphical Modeling, Object Oriented Modeling [16], Logic-Based Modeling and Ontology-Based Modeling. Each of the technique has its own strength and weakness. The actual execution of these techniques can differ based on application domain.

Key-value Modeling is the easiest form of context representation among all available techniques. It mainly makes use of the key-value pairs to model context information available in different formats. This modeling method is suitable for small amount of data but it is not scalable hence not appropriate for complex data structure. This method is not capable to model hierarchical or relationship structures if any. It is mostly used to store independent and non-related information [17]. Markup scheme modeling technique represents the context information using tags. This technique has seen as advancement when compared with key-value pair method as data retrieval has become more efficient in it. XML is one of the popular markup techniques. It is used in many application domains to accumulate and transfer data between various applications and their components. But this technique has drawback as it does not support reasoning and hence the interoperability and reusability over various markup schemes can be complicated [18].

Table 1. Comparison of Context Modeling Techniques

Sr No	Context Modeling type	Description	Drawbacks
1	Key-Value Modeling	Provide Simplicity, flexibility Used in distributed service frameworks	Not suitable for complex, hierarchical structures and relationships
2	Markup Scheme Modeling	Hierarchical data structure Uses XML tags to store data Used in profile modeling	Retrieval of information is not easy. No support for Reasoning
3	Graphical Modeling	Models context with relationships Used for large volume of permanent	Interoperability among different implementation is difficult

		data	
4	Object Oriented Modeling	Uses classes and relationships Provides encapsulation and reusability	Lack of validation Retrieval information is complex
5	Logic-Based Modeling	Represents context with rules , logic expressions and variables	No standards Lack of validation
6	Ontology-Based Modeling	Application independent and allows Sharing , More expressive representation of context	Information retrieval is complex

Graphical Modeling method represents the context with relationships. As the context model contains relationships, it is more efficient than markup and key-value method. Unified Modeling Language (UML) [19] and Object Role Modeling (ORM) [20] are well known tools for graphical modeling. It is easy to understand and apply. It is suitable for storing historical context that includes huge amount of data and providing easier data retrieval. Object Oriented modeling technique incorporates object-oriented theory with the help of concepts of encapsulation and inheritance in order to represent context using programming. It models the context data with class hierarchies and their relationships hence it supports encapsulation and reusability. As most of the programming languages support object-oriented concepts, this modeling technique can be simply combined with existing context-aware applications. This modeling technique is appropriate for code based and run-time modeling.

Logic-Based Modeling applies logic based method to describe the formal model. It mainly uses the facts, expressions and rules for building knowledge. Rules are utilized to explain policies, preferences and constraints. Lack of standardization decreases reusability and applicability of this technique. Ontology-Based Modeling technique explains taxonomies of concepts and relationships. In this modeling, context is represented as ontology with various semantic technologies. Ontologies make use of specific language to model the context and its relationship. Available standards include Resource Description Framework (RDF) [21], Web Ontology Language (OWL) [22].

Table 1 differentiates amongst various context modeling techniques with their limitations. After evaluating several context modeling techniques, in context-aware computing and sensor data management, Ontology based context model is the best choice for developing context-aware applications though its time complexity increases with increase in data volume [23]. Similarly, the best way to generate efficient and effective results is to integrate multiple modeling techniques that will alleviate each other's weaknesses. There is a powerful relationship between context modeling and reasoning.

Context Reasoning: Once the context is being modeled, it will be used for acquiring new knowledge. This is referred as context reasoning. Context reasoning is described as the process of mining of new knowledge from available context for enhanced understanding [24]. It has seen as process of extracting high level context from low level context. Context reasoning techniques can be broadly classified into 6 categories as [15]: fuzzy logic, ontology-based, probabilistic logic, rules, supervised learning, and unsupervised learning.

Fuzzy logic is dissimilar to traditional logic in which we use 0 and 1 to depict each and everything. The fuzzy logic permits the uncertainty of truth reasoning instead of hard reasoning. Fuzzy logic actually accepts the partial truth. This method is suitable for integrating human views which can be simply expressed in linguistic terms and worked with inadequate and uncertain data. In this reasoning technique, precise quantitative model is not required hence it has quick and easy program development. Fuzzy logic reasoning is mostly employed with other reasoning methods like probabilistic, ontology and rule based reasoning.

Table 2. Comparison of Context Reasoning Techniques

Sr No	Context Reasoning Technique	Description	Drawbacks
1	Fuzzy Logic	Accepts Partial truth values hence supporting approximate reasoning Allows the use of natural language	Reduce the precision of the results due to natural representation
2	Ontology-Based	Uses description logic (family of logic based knowledge representations) Reusability	Unable provide missing values and discover ambiguous information

3	Probabilistic Logic	Decisions based on the calculation of event probabilities and facts Used in activity recognition in context-aware domains	Should know the probabilities
4	Rules based	Rules in an IF-THEN-ELSE format structure are used for generating of high level context information from low-level context	Error prone due to manual work
5	Supervised Learning	Training data is labeled as per the expected outcome. Ex. ANN, DT, BN, SVM Widely Used in real-world problems ex. mobile phone sensing and activity recognition	Needed significant amount of Data Takes lot of computation time.
6	Unsupervised Learning	Extracting meaningful results or hidden structures from unlabeled data. No error or reward signal to assess a possible solution as no training data set and outcomes are unknown Ex. Clustering, k-Nearest Neighbor	Less semantic Less accuracy of the results

Ontology-based method uses description logic [25] i.e. a family of logic-based knowledge representation. In this, reasoning is done with ontology modeled data. It supports semantic web languages such as RDF and OWL for implementing reasoning. One advantage of this reasoning is that it can be integrated easily with ontology modeling. But it cannot support missing values and uncertain information. Ontology reasoning is used in various applications such as activity recognition, event detection etc.

Probabilistic logic utilizes the probabilities of the facts associated with the decision making. In this, decisions are made based upon estimation of event probabilities and facts. Dempster–Shafer and HMMs are examples of probabilistic reasoning used in predicting the forth coming event, identifying activities and predicting uncertainty. Rules-based method is easy and traditional way of reasoning. Generally, rules are constructed in If-Then-Else format for producing high level context from low level context. Rules are utilized with ontological reasoning. Even though this technique is easy, it has drawback of generalization and count of rules.

Supervised learning is type of machine learning algorithm in which the training data is gathered and labeled according to expected target or outcome. Generalization function creates the required results using training data. Generalization function produces reasonable outcome for inputs that are not trained during training step. This technique is fast and accurate. It includes Bayesian networks, artificial neural network, support vector Machines, decision tree etc. Unsupervised learning is type of machine learning algorithm in which labeled data is not available. As training data is not available, error or reward cannot be considered to assess potential solution. Clustering is one of the most commonly used unsupervised techniques in which significant results are extracted from unlabeled data. Clustering groups the similar objects into some class, by finding similarity between them, called cluster.

Various context reasoning techniques for helping user are compared in Table 2. Supervised learning is most commonly used technique in which training data is labeled as per expected outcome. Similarly Ontological reasoning is applied to infer extra context information with help of the domain knowledge at the higher level. From discussion, it is clear that each has its own strengths and weakness. Therefore, the best way to handle the issue of context awareness is to incorporate multiple models in such a way that, as a whole, they diminish weaknesses by complementing each other.

5. Applications of Context Aware Systems

The context aware systems are found in various applications domains such as

1. Location Recommendation systems: Using user's location history and profile, location is recommended. Location bridges gap between physical world & online social networks.

2. Security

3. Location aware services: Location-based nursing application provides the potential location of the nurse and provides the required services in hospital environment.

4. Smart health service system: It constantly monitors the health status of the drivers and reacts to abnormal situations. This context-aware service system provides a configurable architecture for the design and implementation of the smart health service system for safe driving.

5. Smart home system: Context aware smart home control system can be used to efficiently reduce the energy consumption of the appliances. Other applications include home climate control application & home music application.

Open issues: Relevant techniques and applications of context-aware systems have been introduced in the above sections. Some critical open issues [18] are presented as follows:

1. Security & Privacy: Sensitive context data is used to characterize the complex environment and to offer relevant services. With the development of cloud computing, context-aware services are becoming cloud oriented. The context of mobile computing is much more variable, complex and risk driven. Therefore research on Security and privacy should focus on both end-user and cloud.

2. Heterogeneity: The important and well-known attribute of context-aware environment is heterogeneity. Research is needed on how to use multiple sensors to acquire useful context information in heterogeneous environment and facilitate accurate decision making. Similarly, bigger volume of context data needs performance-oriented data-intensive processing frameworks.

3. Service Efficiency & Accuracy: These two are very important evaluation parameters of context-aware systems. Real-time context processing involves related study in areas such as context data storage, parallel streaming computing, data acquisition and information retrieval. The dimension of context information decides the service accuracy. Therefore, how to reduce the context dimension and retain good service accuracy is a critical issue.

4. Visualization: AR applications with context awareness improve the user satisfaction through visual experience. There are few researches about AR context-aware system. In the future, related works should focus on the performance evaluation of AR context-aware systems.

6. Conclusion

The IoT has received major attention over the last few years. One of the important challenges that IoT faces is understanding sensor data. In this survey paper, we discussed concept of context and context awareness. Different context modeling and context reasoning techniques are analyzed and evaluated with their strengths and weaknesses. Finally, the common applications of context aware system are listed with open issues. Context aware systems with social context of user can be utilized for generating personalized recommendation to users. Similarly, context information through modeling and reasoning can be used to draw the inferences that will be used in decision making process. Future work could be focused on overcoming limitations in the existing techniques and propose a novel development direction of context aware systems.

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