A Novel Service Robot Supported by WSN: Architecture, Semantic Information Database and Navigation

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Abstract. With the advancement of sensors, wireless communication technologies and the intelligent reasoning theory, service robot ushers in a new development opportunity. The traditional service robot is aware of only a partial environment, and the limited environment information affects control policies such as navigation and the alerting service. Now, we can utilize the pervasive computing of the wireless sensor network (WSN) to perceive the entire surrounding. This paper proposes a novel service robot supported by the global context-aware wireless network, and emphasizes on architecture, wireless communication technology and path navigation. The research shows that the service robot can make a more accurate control policy based on the global environment information.

Keywords: Service robot, wireless sensor network, wireless body area network, context-aware, path navigation

1 Introduction

With the rapid development of context-aware technologies such as the machine-to-machine technology [1] and wireless communication technology [2, 3] in recent years, many institutes and researchers have a strong interest in the home service robot supported by wireless sensor networks (WSNs). The robot uses a large number of sensors to obtain information on the environment around it. The service robot with a context-aware capability that integrates perception, calculation, inference, wireless communication and self-adaptive control has become one of the leading domains of interdisciplinary research today [4]. There are two reasons for the popularity of service robots: First, people want to avoid doing annoying, boring and repetitive work such as household chores and take care of the sick, etc.; second, the decrease in the cost of electrical and electronic equipment has made service robots more affordable for households. To date, an eighth of China's population is above the age of 60, and more than half of them live alone. The elderly population will total 200 million by 2015. The aging society has a huge market demand for intelligent service robots. It is easy to expect that in the near future, care for the elderly will become a new challenge. It would require a large number of nursing personnel to handle nursing affairs such as delivering items, cleaning and rehabilitation services. However, the number of nurses is not able to meet the growing demand. The service robot is thus the best alternative as it can make up for the lack of manpower and improve the quality of elderly life.

In the past, the traditional service robot equipped with sensors in/on its body, and it uses these sensors to perceive changes in the ambient environment, such as using the acceleration meter to sense collision, using the gas sensor to detect dangerous gas leaks, and using the laser rangefinder to achieve positioning. However, the contextual information that the traditional service robot acquired is partial, mainly only the surroundings around the robot itself. The traditional service robot is obviously not able to have an optimized control policy without global context-aware information. Fortunately, with the development of the context-aware technology based on WSN, we can deploy sensors in every corner of the house to realize global contextual perception. The service robot can then understand each of the contextual changes and take the appropriate action promptly. For example, if it rains, the traditional robot does not discover it until it leaves the house. Now, however, the novel service robot is able to detect changes in the weather with its outdoor rain sensor as well as temperature and humidity sensor. If an elderly person living alone is ill, their family would usually take them to the hospital to be diagnosed and treated by the doctor. However, some diseases, such as cardiopathy, should be treated quickly, and constant monitoring is also necessary. The family also does not have enough time to keep the elderly company. The service robot supported by wireless body area network (WBAN) is thus good for this task.

In the family, people need service robot to deliver goods and services. When the commands are issued (e.g. to deliver fruit plate), the robot needs to understand first whose order it is immediately, what kind of fruits do people like, and the fruit plate's position. The service robot needs to determine which room the fruit plate is in, understand the room distribution, and which cabinet is the fruit plate on. The service robot finds fruit plate’s position and move to the fruit plate location. Context-aware information such as the intelligent space information as well as other contextual information such as smell, temperature and location etc. is very important to the service robot’s adaptive ability. At the same time, people's language or behavioral habits affect the human-computer interaction. A large number of data can be recognized and known through the wireless sensor network. In order to complete the task, we should analyze and classify the data, and utilize these data to ratiocinate the navigation path of the service robot. Using these isolated, one-sided data to build a global real-time semantic information database is necessary, as it is then able to perceive every detail of entire house.

This paper will discuss some recent issues with the service robot that needs to be resolved. In a dynamic environment, the service robot builds and maintains wireless sensor network. It also perceives the global contextual data, analyzes contextual data, constructs contextual semantics description model, and establishes a semantic information database that contains all types of information such as location, status, properties and behavior, etc. On the basis of the semantic information database, the service robot is able to adapt to the changes in the environment autonomously and make the right decision quickly.

The remainder of this paper is organized in the following way: We discuss the architecture of the context-aware network in Section 2. In Section 3, we outline the communication of building wireless sensor network such as UWB, WBAN and wireless positioning technology. Section 4 discusses ontology, the web ontology language (OWL) description model, and the semantic information database. Section 5 presents the novel navigation method in the global context-aware environment. Section 6 concludes this paper and outlines issues that need to be resolved in the future.

2 Architecture of context-aware network of service robot

The service robot integrates WSN, WBAN and wireless positioning technology into a complicated heterogeneous wireless network for collecting global contextual information. First, we deploy different types of sensors in every corner of the house, for example, deploy them in kitchen to collect gas and smoke data for determining whether there is a gas leak and fire disaster; deploy them in the balcony to detect the strength of the sunlight and the weather outdoors; deploy them in the bedroom to collect temperature and humidity data; deploy WBAN in the human body and using the medical sensor to collect people's physiological vital signs as well as monitor and judge people's body status. Second, we deploy a storage unit with wireless communication capability in furniture such as the bed, desk, stool and chest. In the unit, we store some attributes of the furniture, such as the location, shape, weight and mobility (whether it can be moved), etc. Third, we store personal information (e.g. height, weight, telephone, physical condition and behavioral habits) into a tiny portable unit. Finally, we put these unit into an interworking network. The robot acquires real-time contextual data via the interworking network. At the same time, the wireless sensor network should achieve high accuracy positioning, which is used primarily for the service robot’s navigation as well as people's positioning and tracking. The architecture is shown in Fig. 1.

The entire network can be divided into WBAN and WSN. In WBAN, all nodes and hubs are organized into logical sets, and are coordinated by their respective hubs for medium access and power management, as illustrated in left of Fig. 1. There is only one hub in a WBAN, whereas the number of nodes in a WBAN ranges from zero to 2m. In a one-hop star WBAN, frame exchanges occur directly between nodes and the hub of the WBAN. In a two-hop extended star WBAN, the hub and a node exchange frames optionally via a relay-capable node.

The WSN is a wireless *ad hoc* network equipped with sensors, which is a decentralized type of wireless network. It does not rely on a pre-existing infrastructure such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, each node participates is routed by forwarding data for other nodes, so the determination of which nodes is forwarding data is made dynamically based on network connectivity. A WSN consists of spatially distributed autonomous sensors that monitor physical or environmental conditions, and it delivers data through the multi-hop network to service robot. The networks are bidirectional, and the service robot is able to control the sensors’ activities. The connectivity of the WSN is not impacted by a certain defeated node, and has strong survival ability in a complex environment. Due to the significant advantages of the WSN, researchers use it initially in military applications such as battlefield surveillance. Now, however, it is used in many industrial and consumer fields such as industrial process monitoring and control, machine health monitoring, etc. [5]. The service robot supported by WSN is able to collect the context-aware information reliably. We will discuss the wireless communication technologies in detail in section 3.

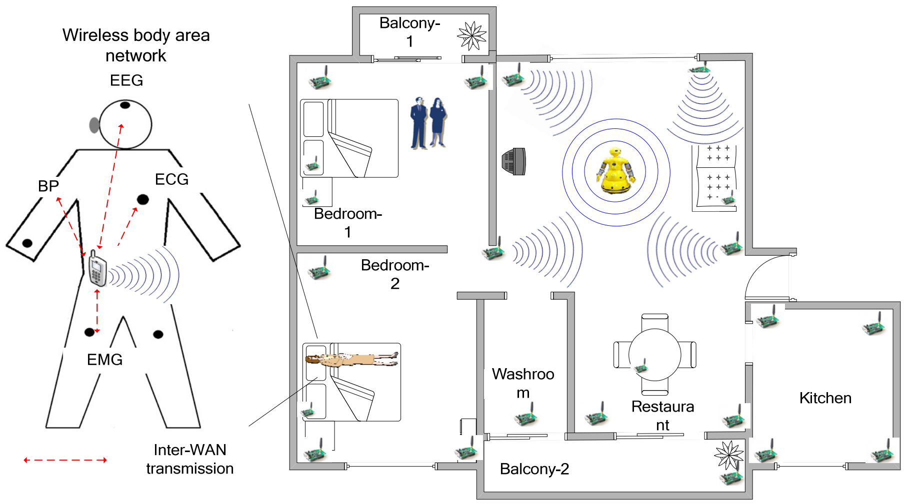

Fig. 1. Architecture of wireless context-aware network of service robot

The contextual data converges well into the service robot favorably by the WSN, but the data is isolated and one-sided, and cannot be utilized by the service robot directly. Since there are different definitions or formats of data in a heterogeneous system, the service robot, sensors, people and other interfaces are not able to understand one another. The communication between the machines is different from communication among peoples. The medium of communication between people is natural language, which everyone can understand. The communication (dialogue, interoperability and sharing) among different objects (people, robot and sensors, etc.) is very complex. This communication requires a common descriptive language that all objects can understand. The ontology semantic model for robots provides a kind of like a natural human language, with which the robot can understand semantic expressions. The service robot uses its own and external sensors to perceive the surrounding contextual information using ontology semantic model to describe these information. If the amount of data is large, we usually create a semantic information database to contain all the information.

3 Wireless communication

Sophisticated wireless communication systems have highly complex and partially contradictory requirements. For instance, the signals must be distributed over wide areas without loss despite the fact that the signal can be interfered by other wireless systems and that multipath fading can effect the quality of the signal (that is, signals are reflected during transmission). In the past decade, the constantly increasing use of wireless communication systems and wireless services has led to another urgent requirement. The precious channel capacity in the electromagnetic spectrum must be utilized as effectively as possible so that as many bits per second can be transmitted through overcrowded and expensive channels. To meet these challenging requirements, an ideal wireless communication method should be robust and flexible enough to adapt bandwidth needs to the required transmission quality (Quality of Service). Furthermore, modern communication systems should have be low-cost, and they should consume little energy (a requirement particularly important for mobile applications).

A range of different wireless solutions exist, and short-range solutions include Bluetooth, Wi-Fi, Zigbee and others. Long-range solutions are generally cellular systems that ranges from 2G to 4G but also include private systems and satellite solutions. The wireless communication systems to date are divided into in-building systems such as home automation, for which the short-range solutions are suitable, and long-range systems (more than 100m), for which cellular systems tend to be used. The service robot wireless context-aware network includes mainly radio, WBAN and wireless positioning technology.

3.1 Radio

Ultra-wideband (UWB) was known formerly as "pulse radio". The FCC and the International Telecommunication Union (ITU) Radio communication Sector currently define UWB as a transmission from an antenna for which the emitted signal bandwidth is below 500 MHz or 20% of the center frequency. A significant difference between conventional radio transmissions and UWB is that conventional systems transmit information by varying the power level, frequency and/or phase of a sinusoidal wave. UWB transmissions transmit information by generating radio energy at specific time intervals and occupying a large bandwidth, thereby enabling pulse-position or time modulation. The information can also be modulated on UWB signals (pulses) by encoding the polarity of the pulse, its amplitude and/or by using orthogonal pulses. UWB pulses can be sent sporadically at relatively low pulse rates to support time or position modulation, but they can also be sent at rates up to the inverse of the UWB pulse bandwidth. Pulse-UWB systems have been demonstrated at channel pulse rates in excess of 1.3 gig pulses per second using a continuous stream of UWB pulses (Continuous Pulse UWB or C-UWB), supporting forward error correction encoded data rates in excess of 675 Mbps [6].

A valuable aspect of the UWB technology is the ability for a UWB radio system to determine the "time of flight" of the transmission at various frequencies. This helps overcome multipath propagation, as at least some of the frequencies have a line-of-sight trajectory. With a cooperative symmetric two-way metering technique, distances can be measured to high resolution and accuracy by compensating for local clock drift and stochastic inaccuracy. Another feature of pulse-based UWB is that the pulses are very short (less than 60 cm for a 500 MHz-wide pulse, and less than 23cm for a 1.3 GHz-bandwidth pulse), so most signal reflections do not overlap the original pulse, and the multipath fading of narrowband signals does not exist. However, there are still issues such as multipath propagation and inter-pulse interference to fast-pulse systems which must be mitigated by coding techniques.

As with other spread spectrum methods, the chirp spread spectrum (CSS) uses its entire allocated bandwidth to broadcast a signal, making it robust to channel noise. Furthermore, because the chirps utilize a broad band of the spectrum, the chirp spread spectrum is also resistant to multi-path fading even when operating at very low power. However, it is unlike the direct-sequence spread spectrum (DSSS) or the frequency-hopping spread spectrum (FHSS) in that it does not add any pseudo-random elements to the signal to help distinguish itself from noise on the channel, but relying on the linear nature of the chirp pulse instead. In additional, the CSS is resistant to the Doppler effect, which is typical in mobile radio applications. The CSS is ideal for applications that require low power usage and need relatively low data rates (1Mbit/s or less). In particular, IEEE 802.15.4a specifies the CSS as a technique for use in Low-Rate Wireless Personal Area Networks (LR-WPAN). However, whereas IEEE 802.15.4-2006 standard specifies that WPANs encompass an area of 10m or less, IEEE 802.15.4a-2007 specifies the CSS as a physical layer to be used when longer ranges and devices moving at high speeds are part of your network. Nanotron's CSS implementation was actually seen to work at a range of 570 meters between devices. Further, Nanotron's implementation can work at data rates of up to 2Mbit/s - higher than specified in 802.15.4a. Finally, the IEEE 802.15.4a PHY standard actually mixes CSS encoding techniques with differential phase shift keying modulation (DPSK) to achieve better data rates. Table 1 gives a comparison of UWB, CSS and ZigBee.

Table 1. Comparison of UWB, CSS and ZigBee

Radio	Accuracy of positioning	Bandwidth	Power dissipation	Anti-interference
UWB	10-30cm	500Mbps	Low	High
CSS	1-3m	1Mbps	Low	Medium
ZigBee	3-5m	800M: 20kbps 2.4G: 250kbps	Medium	Low

3.2 Wireless body area network

Wireless Body Area Networks (WBANs), or a body sensor networks (BSNs), is a wireless network of wearable computing devices[17, 18]. WBAN is a basic technology that is able to monitor and record the signal of the human health over a long period of time. In particular, the network consists of several miniaturized body sensor units and a single body central unit [19]. A typical WBAN requires vital sign monitoring sensors and motion detectors to help identify the location of the individual being monitored and some form of communication, and to transmit vital sign and motion readings to medical practitioners or care givers. A typical WBAN would consist of sensors, a processor, a transceiver and a battery. Physiological sensors, such as the ECG and SpO2 sensors, have been developed. Other sensors such as a blood pressure sensor, EEG sensor and a PDA for BSN interface are under development [20].

Early application is used to continuously monitor and keep a record of chronic diseases such as diabetes, asthma and heart diseases, as well as health parameters in patients, to provide some ways of automatic therapy control. For example, once the insulin levels of the patients with diabetes drops, their WBAN can immediately activate a pump to inject insulin automatically so that patients without a doctor can maintain insulin at a normal level. The WBAN is the smallest coverage network, but it benefits a wide network. The WBAN is used in the service robot, and the robot uses this advanced technology to monitor the physical condition of the elderly. At the same time, this technology may boost the actual implementation of telemedicine.

3.3 Wireless positioning technology

Positioning plays an important role in a system. We know that positioning is difficult in a non-line-of-sight (NLOS) environment. There are various obstacles, such as walls, that lead to multi-path effects [3]. Some interference and noise from other wireless networks such as WiFi, or electrical radiating equipment such as microwave ovens, degrade the accuracy of positioning. Irregular building geometry and the density of water vapor in the air leads to reflection and extreme path loss. Therefore, indoor positioning is more complex.

Positioning algorithms can be classified into two categories: range-based and range-free. Range-based algorithm positioning is achieved by measuring the distance between the anchor nodes and mobile nodes or angle information, and uses the trilateration, triangulation or Maximum Likelihood estimator (ML) positioning method for the calculation of the node location; range-free location is not required for distance or angle information, thus it is only achieved through network connectivity information and so on. Range-based algorithms usually need special hardware to obtain accurate absolute range measurements, and are able to achieve higher positioning accuracy than range-free algorithms. Range-free algorithms, on the other hand, do not need special hardware and are low-cost [7]. Range-based positioning algorithm includes Angle of Arrival (AOA) [8], Time of Arrival (TOA) [9], Time Difference of Arrival (TDOA) [10], Received Signal Strength Indication (RSSI) [11], Time of Flight (TOF) [12] and Symmetrical Double Sided Two Way Ranging (SDS-TWR) [13], etc.

The Ubisense 7000 serial, developed by the company Ubisense [14], is an in-building UWB radio-based tracking system which can determine the positions of people and objects to an accuracy of tens of centimeters using small tags attached to objects and carried by personnel as well as a network of receivers placed around buildings. The UWB is well-suited to the in-building of the emergency field [15] because of its non-line-of-sight nature, 3D position, modest infrastructure requirements and high tracking accuracy [16]. A properly architected UWB tracking system is low-power, and its fundamental technology is simple and low-cost.

4 Semantic information database

The data collected by sensors are isolated, and some data are inaccurate or incomplete. Different type of sensors have different data formats, and they are incompatible with one another. The service robot cannot understand the meaning of the data, and neither can it use the data to make policy directly. The system want a common language (semantic expression) to provide a consensus that all the different objects (service robot, sensors and people, etc) can understand. In order to help all the objects understand each other, we have introduced the ontology technology into this system. Ontology represents knowledge as a set of concepts within a domain as well as the relationships between those concepts. Ontology provides a shared vocabulary which can be used to model a domain and support reasoning about concepts. It is a structural framework for organizing information and are used in artificial intelligence, the Semantic Web, systems engineering, software engineering, biomedical informatics, library science, enterprise bookmarking as well as information architecture as a form of knowledge representation about the world or some parts of it. The creation of domain ontology is also fundamental to the definition and use of an enterprise architecture framework.

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......
<owl:class rdf: ID ="Person"
   <rdfs:subClassOf>
      <owl:Class rdf: ID = "OldMan"
   </rdfs:subClassOf>
</owl:Class>
......
<OldMan rdf: ID = "Jone">
   <LocatedIn>
      <Location rdf: ID = "Bed">
   </LocatedIn>
</OldMan>
......
```

Fig. 2. OWL description model

In order to effectively represent contextual information, we use the OWL language to describe the semantics ontology. Using first-order predicate calculus to represent contextual information, its basic form is: *Predicate* (*subject, value*), wherein:

subject $\in \Omega$: Subject collection, such as a *person* (*object*), *a place* or *time*;

Predicate $\in \Psi$: Predicate collection， such as *IsLocatedIn*, *HasStatus* or *IsRoledAs*;

value $\in \Phi$: All the values of collection Ω, such as *bedroom1*, *sick* or *the elderly*.

The OWL description model is a ternary collection of resource description framework (RDF), as shown in Fig. 2. The service robot and other objects can understand "Jone is old man, and his location is in bed". Based on this model, the service robot can further reason control policy by contextual data. For example, by the sentence "Where is Jone ?", the service can reason the result by the predicate reason *IsLocatedIn(Jone, 0)*.

We should transfer all data collected by sensors or other software interface into a semantic unit with the OWL description and integrate the semantic unit into a semantic information database. The flow of building the semantic information database is shown in Fig. 3.

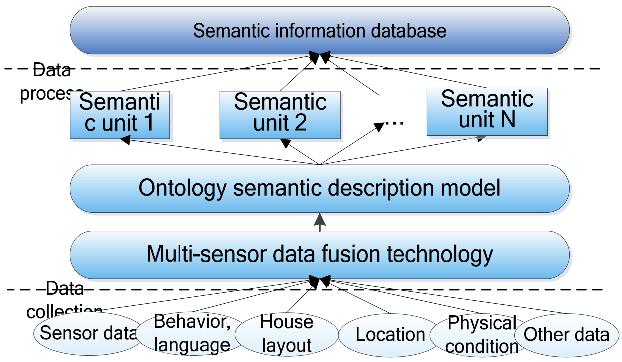

Fig. 3. The flow of building the semantic information database

5 Navigation path

The navigation path programming is simply based on the semantic information database. First, determine the coordinate of destination; second, use the traditional method to program a path; third, query the object (such as a desk or people) around the path by the predicate reason (*IsLocatedIn(path,* ± 30)). If there are objects within 30cm around the path, the semantic information database would give a hint. The example is shown in Fig. 4. If the service robot wants to go to B from A, it would encounter a person on the first path. The service robot can then plan a new path.

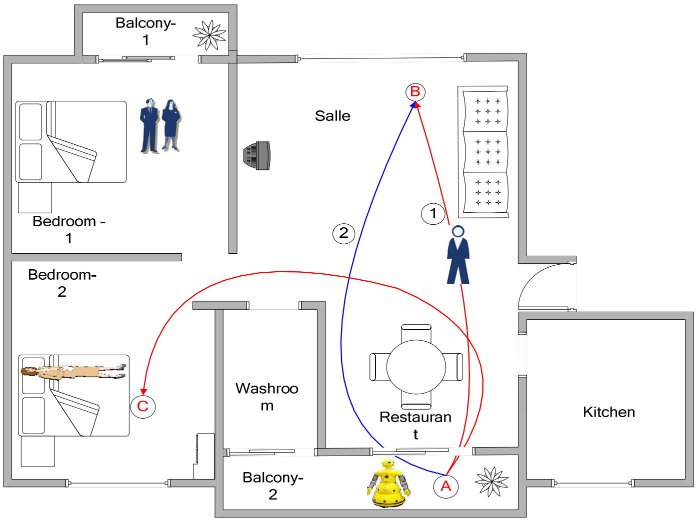

Fig. 4 Robot navigation path

6 Conclusion

This paper has discussed the service robot global context-aware network, analyzed the limitations of the traditional robot, and proposed a new architecture of service robots to perceive global environment. The UWB radio has an advantage over other communication radio in that its positioning accuracy is high and its performance is very stable. The WBAN network monitors the physical status, and can save time for the patient's family introducing the WSN into the service robot domain would bring forth new revolution. The semantic information database helps the service robot to understand the data collected by a range of sensors, and helps it to make correct policy promptly. However, there remain many issues to be resolved. For instance, the WBAN can collect people's physiological vital signs as well as monitor and judge people's physical statuses, and so building a prediction model for people's physical diseases is extremely urgent. This model aims to discover the nonlinear association between risks of illness and the body's vital signs (such as temperature, blood sugar, blood pressure, heart rate and pulse, etc.).

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