Space-Time Registration for Physical-Cyber World Mapping in Internet of Things

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***Abstract*—Internet of Things (IoT) aims to connect everything at anywhere and anytime, in which objects need to be mapped from the physical world to the cyber world for further processing. Time and space characteristics are the basic features of objects in the physical world, and are significant for objects' physical-cyber world mapping. However, space-time data is usually formatted in different ways, and may not be precise enough in some cases due to the variety of technologies and systems. In this paper, we study the space-time registration for a single IoT application (i.e., Unit IoT) and multiple IoT applications (i.e., Ubiquitous IoT). Meanwhile, space-time consistency is discussed in U2IoT (i.e., Unit IoT, and Ubiquitous IoT). Moreover, a case study is discussed to present trajectory estimation in the airport scenario, and indicate the importance of space-time data when objects are mapped from the physical world to the cyber world by different methods for IoT ubiquitous connection.**

Keywords-Internet of Things; space registration; time registration; space-time consistency; U2IoT

I. INTRODUCTION

Internet of Things (IoT) connects everything in both physical world and cyber world together. For the objects mapped from the physical world to the cyber world, the space-time data is significant for their modeling, discovery, and services. Since time and space are the basic characteristics of the objects in the physical world, the consistent space-time data is a significant component of the corresponding data in the cyber world. Different sensing technologies, such as Radio Frequency Identification (RFID), Global Positioning System (GPS), infrared and cameras, are available to obtain objects' space-time data. However, the obtained data is usually non-uniform, inconsistent and discontinuous due to the limitations of different technologies [1]. In IoT, space-time data is required to be accurate, comprehensive, and continuous. Therefore, the study on the space-time consistency and the space-time registration to achieve the consistency is noteworthy.

The space-time registration consists of time registration and space registration. Thereinto, the time registration eliminates the transmission delay and the inconsistency of the sensors' sampling cycles, and the space registration unifies the measurement reference frame and eliminates the system bias and position bias of the sensors. Moreover, space-time consistency should be realized for the space-time data utilization in many cases, which require accurate, mutual understanding and continuous data.

Several studies have worked to enable the consistency of space-time data, in which space-time registration receives wide attentions in multiple sensor fusion systems [2,3,4]. Nabaa *et al.* [2] proposed a homogeneous sensor registration solution to radar tracking issue in the aircraft. Li *et al.* [3] put forward a space-time registration method for the heterogeneous sensors of mobile radar and electronic support measure (ESM). Fuiorea *et al.* [4] presented a research on the registration algorithms to estimate the localization of the sensor in the Wireless Sensor Network (WSN). Zhou *et al.* [5] discussed the space-time consistency in distributed visual environment caused by the message transmission delay and clock asynchrony. Additionally, Zhong *et al.* [6] adopted the space-time consistency to achieve reliable object tracking over long sequences in video region track systems. However, space-time consistency related issues in IoT are still open challenges, and it is significant to introduce space-time registration into heterogeneous networks to achieve consistent data integration.

As showed in Fig. 1, the space-time registration in Unit IoT and Ubiquitous IoT is introduced separately to promote the accuracy and consistency of the objects' space-time data based on U2IoT [7]. Thereinto, Unit IoT refers to a single IoT application, and Ubiquitous IoT refers to multiple IoT applications, which refers to industrial IoT, local IoT, national IoT, and even global IoT.

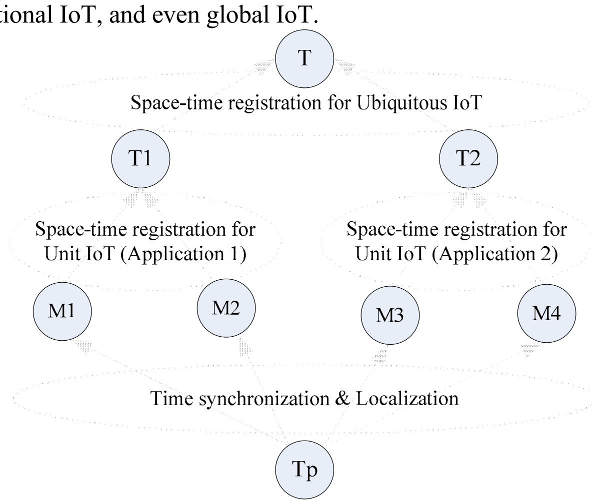

Figure 1. The space-time registration for Unit IoT and Ubiquitous IoT.

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In Fig. 1, T_p denotes the target sensed in the physical world. M_1, M_2, M_3 and M_4 are the collected data by different sensing technologies in Unit IoTs. T_1 is the fused target data from M_1 and M_2 in application 1 (similarly, T_2 is the fused target data from M_3 and M_4 in application 2). T is the top corresponding data of T_p mapped to the cyber world by the Unit IoTs. The time synchronization and localization are the foundation of space-time registration, which work in the process from the target T_p in the physical world to measured data of M_1 and M_2 (or M_3 and M_4). There are two levels of space-time registration. One is space-time registration for Unit IoT, and the other is the space-time registration for Ubiquitous IoT. Correspondingly, the space-time registration for Unit IoT is in the process from M_1 and M_2 to T_1 (and from M_3, M_4 to T_2), and the space-time registration for Ubiquitous IoT is in the process from T_1 and T_2 to T.

In the following, Section II describes the time synchronization, localization of objects, and space-time registration for Unit IoT. Section III introduces the space-time registration for Ubiquitous IoT. The space-time consistency in U2IoT is discussed in Section IV, and a case study is discussed in Section V. Finally, Section VI draws the conclusion.

II. SPACE-TIME REGISTRATION FOR UNIT IOT

In Unit IoT, there may be different kinds of sensing technologies that are generally applied for object attributes detection at the same time. They can provide the time stamped space measured data for the identified objects. Four significant techniques including the time synchronization, object localization, time registration and space registration for Unit IoT are discussed in this section. Based on time synchronization, the sensing technologies identify objects with the same time standards. Meanwhile, space-time data can be obtained by localization. To get more consistent data, the time and space registration are required subsequently.

A. *Time Synchronization*

Time synchronization is the process of exchanging the local clock data of each node, to maintain internal time consistency of the whole system. Here, some typical time synchronization schemes and their advantages/limitations are introduced.

Traditional time synchronization algorithms like network time protocol (NTP) [8] and GPS [9] are widely used in the wired distributed systems. But they have obvious defects. For instance, NTP has high requirement for bandwidth and energy consumption. GPS is usually costly and its size is big. They are impractical to synchronize the huge networks, especially wireless networks due to the limited bandwidth and energy consumption. Thereafter, many new time synchronization algorithms are designed for the wireless network as follows.

Reference broadcast synchronization (RBS) [10], timing-sync protocol for sensor networks (TPSN) [11], and flooding time protocol for sensor networks (FTSP) [12] are three typical clock synchronization in wireless network. Thereinto, RBS with the receiver-receiver synchronization mechanism, synchronizes the separate stamped time when two adjacent nodes receive the beacons from the beacon node. TPSN adopts the sender-receiver synchronization mechanism. FTSP combines the advantages of TPSN and RBS. In addition, Sichitiu *et al.* [13] put forward the Tiny and Mini synchronization algorithms, and Greunen *et al.* [14] proposed tree-based synchronization algorithm. Tiny and Mini synchronization algorithms are relatively simple and have low energy consumption, and can be used in large-scale network. The tree-based synchronous algorithm can adjust its precision according to the bandwidth and energy supply of the network, and it has good extensibility and low operation requirement. Towards the mentioned Tiny, Mini and RBS algorithms, they can only achieve the internal time synchronization, and lack good external interface of the time reference, which brings great difficulty to the systematic and global time synchronization in IoT.

B. *Localization of Objects*

The localization of objects based on time synchronization is the foundation of mapping the identified object from the physical world to the cyber world. The earliest technology in modern localization is the global navigation satellite systems (i.e., GPS). GPS is widely applied in the area of the earth measurement, navigation and logistics. But, its high power consumption, high cost and big size limit its application in the localization of objects in IoT and it can only be used in open areas. Subsequently, other local and indoor localization technologies are developed, such as RFID positioning technology, 3rd-generation (3G) cellular network positioning technology, Wi-Fi positioning technology, and audio/video based positioning technologies. The accuracy and cost of different localization technologies are different. They are the premier factors that should be considered when choosing location technology. Each localization technology has its special application environment and function, and most technologies are market-oriented product for certain applications. Therefore, integrating the data from different localization technologies becomes significant.

C. *Time Registration for Unit IoT*

Time registration aims to eliminate the transmission delay and the inconsistency of the sampling cycles of the sensors, and adjust the measurement sequence to the same time level.

There are many time registration methods like least squares, interpolation and extrapolation, curve-fit method and the 3-point parabola interpolation method. Thereinto, the least squares algorithm [15], and the interpolation and extrapolation algorithm [16] are the most famous and widely used. The least squares algorithm requires that the sensors must have the same initial sampling time point, and the synchronous cycle is equal to the maximum one among all sensors' sampling cycles. The interpolation and extrapolation algorithm can be used when the ratio of the sampling cycles of sensors is not an integer.

D. *Space Registration for Unit IoT*

The space registration has two aspects: one is converting the measured data to the reference frame or the reference expression, and the other is estimating and eliminating the registration bias of measured data. The space registration is particularly essential when the object is simultaneously identified by multiple sensors.

For the consistent expression of the object location data, a reference frame is necessary for Unit IoT. But the applied sensing technologies may have different frames (e.g., polar coordinate, orthogonal coordinate, and Cartesian coordinate) or expressions. So the first step in space registration is the conversion of frames and expressions.

The second step of the space registration is the estimation and elimination of the registration biases. The major sources of registration biases include the system bias and position bias. The system bias is caused by the defect of each sensor and the position bias refers to the bias of the initial position of the sensor. The registration bias is usually assumed to be systematic and constant. It can be estimated by various space registration algorithms like the least squares, maximum likelihood estimation, and Kalman filter algorithm.

III. SPACE-TIME REGISTRATION FOR UBIQUITOUS IOT

Space-time registration for Ubiquitous IoT is the process to get the final fused data in the cyber world using the data from Unit IoTs. Different with the space-time registration in Unit IoT, we consider more factors that affect the space-time data in Ubiquitous IoT, including the time reference for time registration and the location model for space registration.

A. Time Registration for Ubiquitous IoT

The time reference determines the internal time of Unit IoT. For Ubiquitous IoT, time registration in Unit IoT is not enough due to the different time references. Thus, time registration for Ubiquitous IoT mainly focuses on the time reference. A Unit IoT may adopt the local time as its time reference, while another Unit IoT may adopt the time of another time zone as its time reference. Time in different industries may also be different and used to be reference for certain Unit IoT. The different kinds of time references and the inconsistency among them brings time bias to Ubiquitous IoT. It turns out that the major work of the time registration for Ubiquitous IoT is to eliminate the time bias caused by the difference in time reference and adjust the internal time of each Unit IoT to ensure the global time synchronization in Ubiquitous IoT.

B. Space Registration for Ubiquitous IoT

Different location expressions and models are usually used by different Unit IoTs, and the location data mapped from physical world to cyber world may be based in different models in Ubiquitous IoT. In general, the location models include two types: symbolic location models and geometric coordinate location models. The symbolic location models emphasize the description of the location. If there exists none additional data, symbolic coordinates will not provide any reasoning on the distance and inclusion. The data in geometric coordinate refers to a point in a plane or three-dimensional space. The topological properties of such a model allow the distances calculation between points. So the key point of space registration for Ubiquitous IoT different from that in Unit IoT is the effective location modeling and the interconversion among different location models.

IV. SPACE-TIME CONSISTENCY DISCUSSION IN U2IOT

In U2IoT, the real-time localization and track of objects are useful in the fields of logistics, safety, health and other location based services. Space-time consistency is the consistency of mapped space-time data of object in cyber world and its real space-time distribution in physical world. In order to ensure the space-time consistency of the data, the following three requirements should be considered.

- *Consistent to the real data:* The space-time data collected by a variety of sensing technologies to map the object from physical world to the cyber world, should be consistent to the real data of the object. This consistency should adapt to the different objects, applications, and environments. Different applications have different requirements on the accuracy levels of space-time data, and the expression of the space relationship. So appropriate technologies are required to meet the scope, precision and cost requirements in the specific applications. This requirement needs the reliable localization technologies and data fusion technologies to provide consistent data.
- *Mutual understanding and the same connotation:* When the space-time data of the same object is obtained by various technologies and expressed in various forms, the data should also be mutual understanding. The interconversion is needed for data sharing and combined detection, and the same connotation means that the data obtained from the same object must point to one object in cyber world. This requirement considers more about the interconversion of data expressions between different technologies, and covers time synchronization, time registration, and space registration.
- *Continuous trajectory:* The object's data obtained by sensing technologies is generally discrete, while its real space-time information is continuous. So we need to explore the closest trajectory for the object. It is the holistic requirement of the space-time consistency in IoT. This is more about the data processing to derive the objects' trajectory as precise as possible.

V. CASE STUDY IN THE AIRPORT SCENARIO

Assume that in the airport scenario, the local IoT consists of several Unit IoTs, including ticket check system, security check system, and monitor system. When a person enters the airport, his space-time characteristics can be detected by the systems and space-time consistency needs to be considered in both Unit IoT and Ubiquitous IoT.

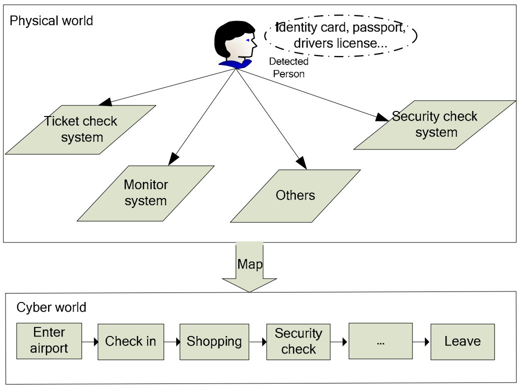

Figure 2. A person identified by multiple systems at the airport.

As shown in Fig. 2, the space-time data of the person in airport can be obtained by different systems. For instance, when the ticket system identifies the person and checks his ticket, the recorded time data can be used to remind him the left time by combing the data in the ticket. At another moment when the person passes the security check, the check time and place are recorded. Similarly, the space-time data like when the person enters the airport, goes shopping, leaves the airport, can also be mapped to the cyber world by the monitor system. A series of space-time data can be obtained and analyzed in chronological order to derive the person's trace and trajectory.

As the person is identified by different systems, space-time registration for Unit IoT and Ubiquitous IoT are needed to make the data consistent for further processing. If the person identified by the systems is confirmed as the same one, the achieved space-time data can be associated to the person's identity and combined used to provide location-based or time-based services. The space-time data can also facilitate for the prediction of person's location next time. And the person's trajectory can be obtained by analyzing the series of space-time consistent data.

VI. Conclusion

Based on U2IoT, this paper mainly introduces the space-time registration, and discusses the space-time consistency. Before the space-time registration, time synchronization and object localization are required to obtain accurate space-time data. Space-time registration should be considered in Unit IoT and Ubiquitous IoT to provide more consistent data. After analyzing the requirements of space-time consistency in U2IoT, a case in the scenario when a person is identified by multiple systems at the airport is studied to show the usage and importance of space-time data for objects' physical-cyber world mapping for IoT.

However, the space-time data also brings severe threats on the location privacy. Considering an illegal party may find a person's sensitive information (e.g., residence, personal interests, social relationship, and living habits) by the space-time data, data access control should be enhanced. We need to prevent unauthorized parties access to others' location and protect the location privacy in IoT. This issue should be intensively considered when establishing space-time data based IoT.

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