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# Localization Challenges for the Emergence of the Smart World

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**ABSTRACT** Precise and accurate localization is one of the fundamental scientific and engineering technologies needed for the applications enabling the emergence of the Smart World. Localization techniques became popular with the global positioning system for outdoor applications, and in recent years, this has been followed by Wi-Fi localization for indoor applications. More recently, localization science and technology has progressed into in-body medical applications. Localization technologies have their own specific challenges depending on the application and environment, which are left for scientists and engineers to overcome. This paper presents the relation among different elements of the Smart World and corresponding localization technologies, classifies localization applications enabling smart devices and environments into logical categories, describes the complexity of the technologies used for localization, and introduces some of the open challenges for localization in the Smart World.

**INDEX TERMS** Position measurement, Navigation, Inertial navigation, Radio navigation, Smart homes, Radio propagation.

## I. INTRODUCTION

Today, it is well recognized that location and time are the prominent underlying features for any scientific and engineering observation. Every experience and every observation that is formed by an intelligent mind in a scientific/engineering sense is fundamentally associated with location and time. So, ever since the human being, a social animal, began to analyze and record its experiences intelligently, measuring the time of the experience and the location of the events have been an essential part for gathering intelligence for individual humans and the human society at large. In the same way as we humans transformed our civilizations from the farming economy to the industrialized world during the first industrial revolution in the late eighteenth century, over the past few decades, smartness and intelligence have become more important and so also is the importance of knowing the time and location of events, behavior of objects, individuals, crowds, and society itself.

Historically, we began measuring time using the sun and the moon a few thousands of years ago at the dawn of civilization, eventually to have an *absolute* value of time, needed for intelligent agricultural processing and associated festivities and administrates. The granularity of time here was over longer horizons. Around the same time we began measuring *relative* time with devices such as sand clocks for other important events with shorter durations. In the past few centuries, since the industrial revolution, human beings have discovered how to measure time precisely and the corresponding industry has learned how to make this information about time available and accessible to everyone, everything, and everywhere. Today, every ''Person'' carries a device such as a smart watch or a smart phone, capable of measuring time with near-atomic clock accuracy and almost every ''Thing'' has a clock with similar accuracies. However, this is not necessarily true for the location information.

The ''location industry'' also began in the early days of civilization using the sun, moon, and stars for navigating travelers on the ground and over the seas with a coarse precision. Later on these coarse technologies were complemented by compass and other devices using the earth's magnetic field. Popular and more precise location technology is going through a similar discovery and metamorphosis as those of the time measurement industry, only in the past few decades.

Figure 1, illustrates the chronology of the evolution of localization technologies in recent years. Today's most popular localization system, Global Position System (GPS) with accuracy of tens of meters (and better under ideal conditions) began in the 1970's for military applications and became

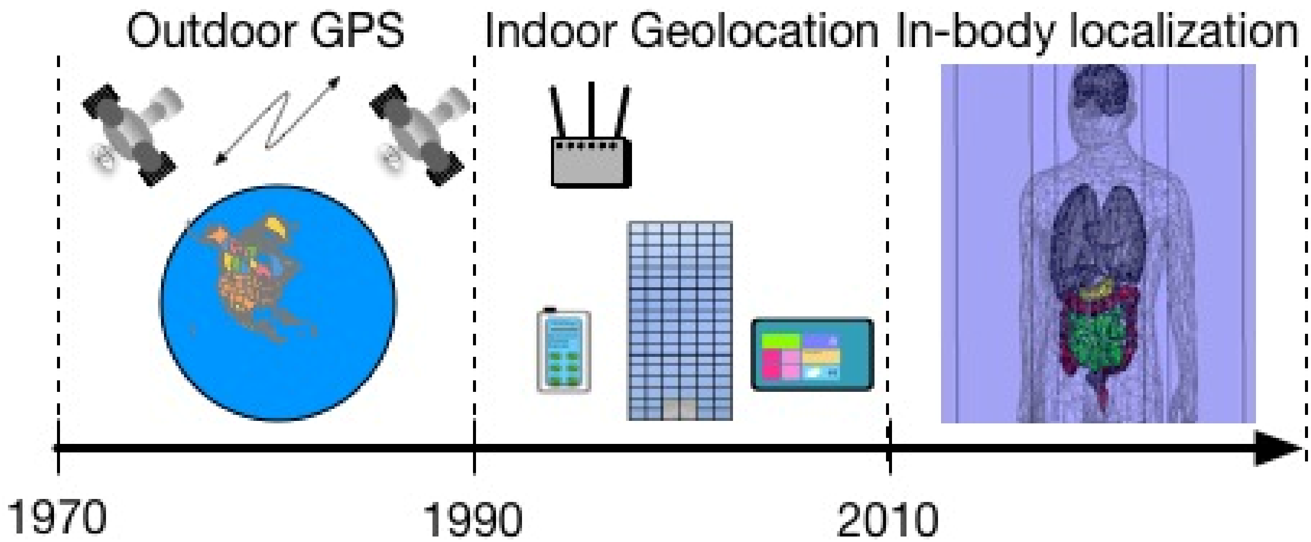



**FIGURE 1.** Evolution of popular localization technologies in past few decades.

available to commercial applications in early 1990's. In the past decade, the dramatic fall of the costs of GPS chips have made them popular in smart phones and other applications and Things (e.g., many wearable fitness devices now have GPS). Since GPS signals does not work properly in indoor areas and the indoor applications normally need accuracy on the order of meters or less, research efforts in indoor geolocation science and technology began in the late 1990's and became prolific in the late 2000's [57]. More recently, localization science is progressing towards positioning medical devices inside the human body where an accuracy on the order of a sub-centimeter are required [18], [58] to locate the area where a medical problem may exist. As we will discuss later, these localization technologies have their own challenges, which are resolved in completely different scientific domains, resulting in significant applications related useful scientific and engineering intellectual problems and solutions.

In the rest of this paper we first explain how the Smart World connects to localization and then we explain technical complexity, applications, and open challenges for localization science and engineering in the Smart World. We explain why localization science is a complex multi-disciplinary area of research and technology and identify the technical aspects associated with this field of research. We categorize different applications, the accuracy/precision they need, and technologies they use and finally we introduce a few technical challenges and explain what is needed to overcome these challenges.

## II. LOCALIZATION AND THE SMART WORLD

The relationships among localization and the elements of the Smart World are very fundamental [14], [46] and intertwined. As shown in Figure 2, the Smart World consists of four major elements: the Physical World, the Social World, the Cyber World and the Thinking World. We describe the relation between localization and each of these worlds next.

The *Physical World* is a mixture of People and Things that are associated with these people as well as the context of their encounters. Certainly, we want to know where these People are and how they are positioned in space and time with respect to the Things with which they associate. Since both People and Things are always in motion, we are also keen on discovering the relations between location and time to analyze how one may have to move to encounter a successful experience with the other. Examples of such encounters include smart vehicles, perhaps self-driving, which need location information to navigate roads. And this may include smart objects that provide information to humans based on location and context, such as the arrival of buses, taxis and shared vehicles. Or it may involve a map showing alternative pricing for a human requesting information about the stores in the proximity that have a particular brand of an item she or he wants to purchase. These examples illustrate the explicit connection between People and Things.

In the *Social World* we observe the relation among the People and Things and how they network together, especially people and groups of people. Certainly, the analysis of any social behavior demands the knowledge of how the relative location of these People and Things with respect to one another in time is needed to track the *behavior* of their relation. Examples include location based games, such as geocaching [55], or finding locations of close by friends. Networks of people and things may reveal influential individuals or objects, show how influence or epidemics may spread and the resilience of such networks [69].

In the *Cyber World* we use location and tracking information of the People and the Things to create the so called Location Intelligence, the smartness that evolves out of observing absolute and relative location of the

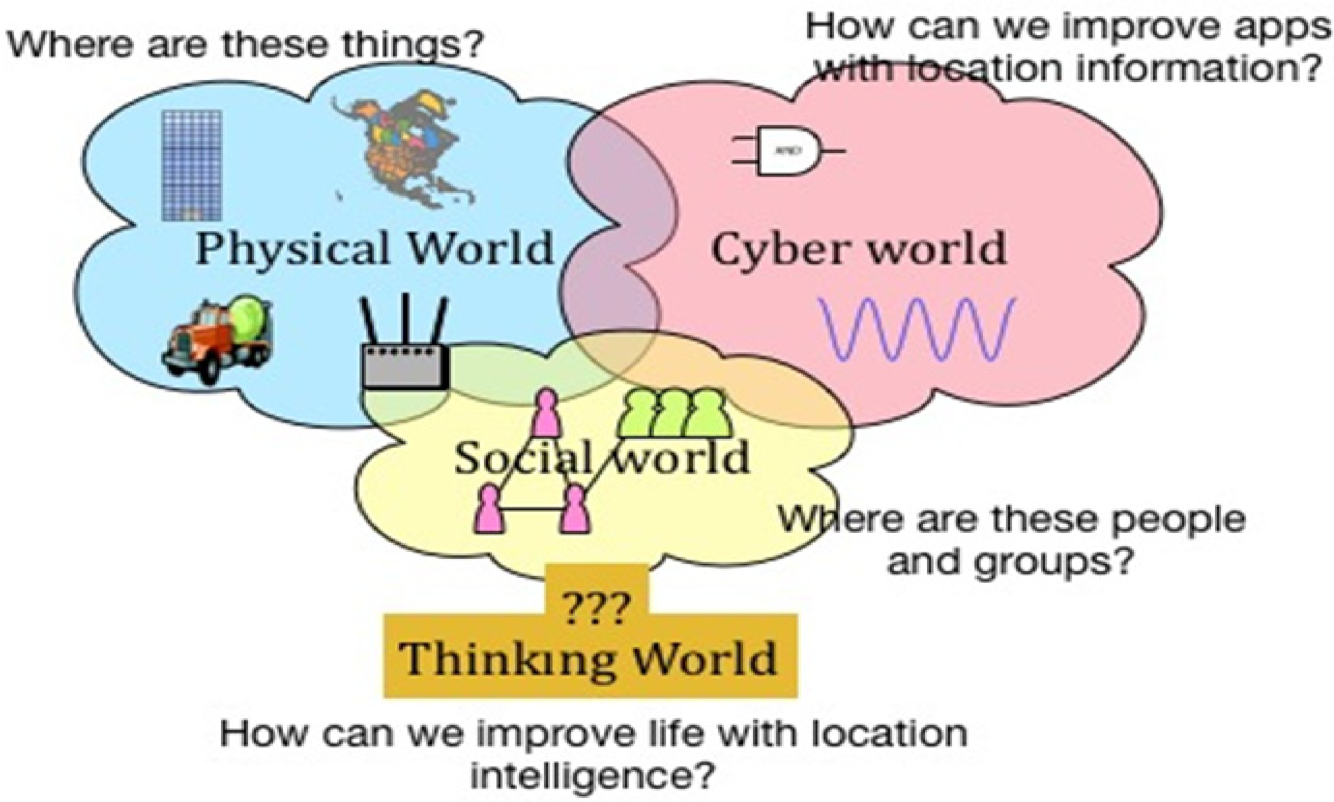



**FIGURE 2.** Relation among the elements of the Smart World and localization technology.

People and Things. As an example, web searches on the Internet may provide location specific, sometimes called local search, results.

In the *Thinking World* ultimately we use Location Intelligence to make living a better experience for the human being and other living creatures. Thus, localization touches every aspect of the emerging Smart World.

## III. COMPLEXITY OF LOCALIZATION IN THE SMART WORLD

The complexity of localization technology in the smart world arises from the fact that the variety of smart applications enabling the smart world require different precisions, different smart devices hosting these applications carry different sets of sensors, behavioral characteristics of the different sensors in different environments are complex, and the availability of maps and the need for the visualization platform for different applications are quite diversified [8], [56], [62]. As a result, the behavior analysis of the characteristics of the sensors and selection of the suitable algorithms to provide the needed precision for an application implemented on a platform has become a scientific area of research in the past couple of decades and the industry is in need of highly educated professionals in localization science and engineering [59], [72].

Figure 3 illustrates the functional block diagram of a wireless geolocation system, which zooms into the functionality for positioning in the smart world. The main elements of the system are as follows: (*i*) a number of location-sensing devices that provide metrics related to the relative position of a mobile station with respect to a known landmark, called reference point, (*ii*) a positioning algorithm that processes metrics reported by location sensing elements to estimate the location coordinates of the target moving object, (*iii*) a display system that illustrates the location of the target on a map, and (*iv*) a location intelligence engine which extracts useful features of location data tailored to generic applications.

The most popular location metrics for wireless localization are extracted from radio frequency (RF) based localization systems [6], [68]. The RF location metrics may indicate the approximated received signal strength, direction of arrival or the time of arrival of the signal or it can be a packet of information with the identity of an object read through RF signals [15], [16]. Other localization metrics include imaging cameras used to extract visual information by direct image processing techniques [17], [33], [54] such as the plate number of a car or by comparing features of consecutive images to analyze the motion of an object [9], [53]. There are a number of mechanical sensors such as accelerometer, magnetometer, and barometer, which are used to determine the speed, direction and height of a device such as a smart phone or a Robotic platform. The positioning algorithm processes the received metrics to determine the coordinates of the target object. These algorithms may use signal processing

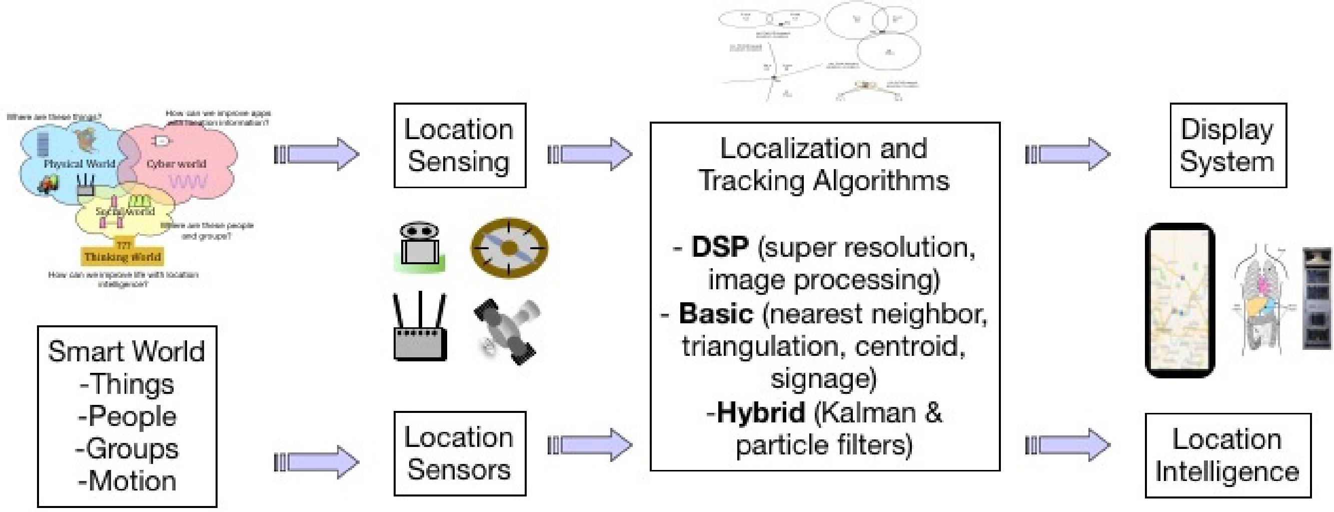



**FIGURE 3. Elements of localization science in the Smart World.**

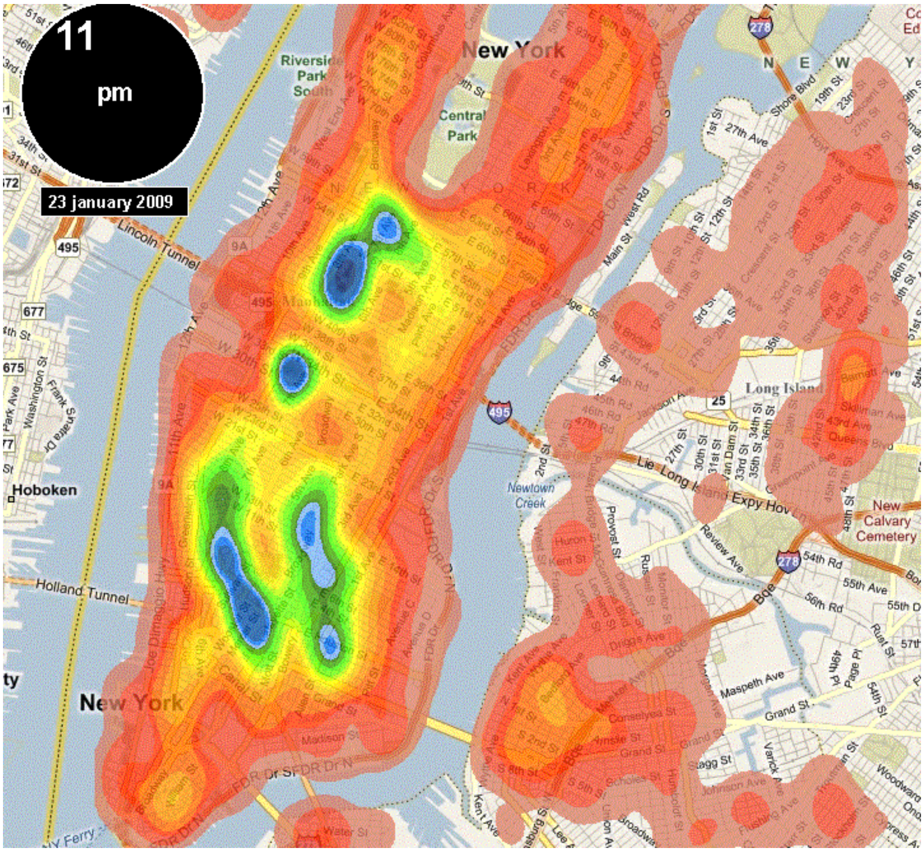
algorithms such as super-resolution algorithms [43], to refine the sensor data and prepare better metrics, algorithms to process metrics and come up with a location estimate. As the measurement of metrics become less reliable or exact, the complexity of the position algorithm increases. In navigation applications, when we have some information regarding the movement of the target object, we combine the position estimates with the information on the pattern of movements of the object to refine the location estimates [24], or algorithms such as Kalman filters [1], [13], [38] or Particle filters [7], [71] to take advantage of the history of other location estimates as well as combining metrics obtained from different sensors [11], [40].

The display system pins the estimated location coordinates to a map of an environment. In the most traditional localization application, in direction finding for car driving, we refer to a geographic map with absolute coordinates. In other contexts, such as indoor areas or within a human body, it may be better to employ local or relative coordinates and an alternative "map" of the indoor area or body [5]. In indoor areas we have multiple maps associated with different floors of a building, when a smart device carried indoor and outdoor, we need different maps and a smart display system needs to sense the environment for selection of the appropriate map [67]. In any case, the display system could be a service or an application residing in a server or a mobile locating unit, locally accessible software in a local area network, or a universally accessible service on the web such as Google maps. Obviously, as the horizon of the accessibility of the information increases, the design of the display system becomes increasingly complex.

Location intelligence is extracting information for a specific intelligent application using location and track information. Location information uses pattern of movement of a device to analyze the behavior of the person or a mechanical platform carrying the device [64]. Such location intelligence include location-time traffic analysis, Geo fencing (for elderly people, animals, prisoners, suspicious people, ..), real world consumer behavior, location certification for security, positioning IP addresses, and customizing contents and experiences. Video 1 illustrates the customer behavior of Wi-Fi localization requests in New York City in different times of a day, collected by Skyhook, Boston, MA. Marketing agents of different organizations for targeted marketing use this type of location intelligence.

## IV. LOCALIZATION TECHNOLOGY AND SMART WORLD APPLICATIONS

The word "smart world" has started to become popular because a number of ***smart applications*** began to emerge in the recent years to solve problems using time, location, sensor data, and general context. Figure 4 provides an overview of several popular and important smart applications that has emerged in the recent year leading to evolution f the smart world. As we integrated extensive computing abilities to mobile phones starting with the iPhone, we began to call it a "smart phone". As we increased the artificial intelligence of moving mechanical devices using computer programs and electronic circuits, we called them Robots, to connote the fact that they benefit from computing intelligence. More recently, we have used the words "smart health" for better processing of a patient's data to improve the health outcomes and to reduce the cost of improving health services. We refer to buildings with extensive pervasive programmability (and intelligence – such as knowing when to increase the thermostat) as smart spaces [31] and we expect these environments to use RFID tags, Bluetooth, and other technologies to enable intelligent location aware Robotic applications [2]. We use the words "smart transportation" in the context of adding




**Video Clip 1.** **Customer behavior for Wi-Fi localization requests in NYC for different hours of a day (source: Skyhook Wireless). (Note: animation is a supporting video).**

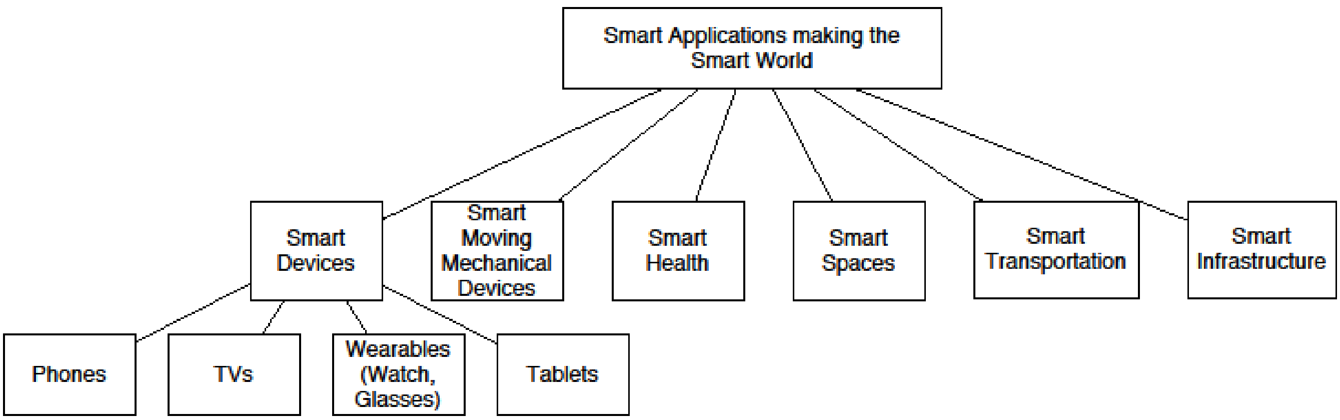



**Fig. 4.** **Overview of popular smart applications associated with the emergence of the Smart World.**

substantial computational intelligence to traffic monitoring and management. The electric grid that can adapt itself to changing weather and diverse sources of energy as well as intelligently handling electric usage in homes and buildings is now called the ''smart grid''. In essence, we are realizing a vision of the ''smart world'' through the variety of smart applications with intelligent capabilities to solve problems. All of these applications demand location information. In this section, we describe examples of some of these applications to show their need for localization information.

### A. LOCALIZATION FOR SMART DEVICES

Smart devices are the most popular platforms used for the creation of smart environment and the smart world. Billions of smart devices such as smart phones, tablets, smart watches, smart glasses, and smart TVs use location information for hundreds of thousands of applications either directly in applications such as turn-by-turn direction finding, recommendations through Yelp, flight fares through Kayak or indirectly as part of applications for gaming or customer behavior analysis. The accuracy and precision requirements for these applications are quite diversified and range from centimeters in gaming, to meters in indoor geolocation, to tens of meters in turn-by-turn direction, and hundreds of meters for broadcasting advertisements in targeted areas.

Smart phone are perhaps the most popular of smart devices and the overvaluing majority of those hundred of thousands of applications have been designed for mobile application in smart phones. Smart phones also carry a number of location sensors. These sensors include the most popular RF based location sensors such as GPS, Wi-Fi signal, Cell Phone signals, iBeacon (Bluetooth) as well as Mechanical location sensors such as magnetometer, barometer and accelerometer, and of course high quality cameras and microphones. Because of diversity of applications and their requirements, availability of multiple sensors on the platform, and the inherent mobility of the device, which demand operation in diversified environments, most of the research and developments for localization in smart devices has been initiated for smart phone applications [57].

### B. LOCALIZATION FOR SMART MOVING PLATFORMS: THE ROBOTS

Robotic platforms are another essential components of the evolving smart world. A variety of ground rolling and flying robots of different sizes are emerging to facilitate operation in the smart environment of the smart world in variety of applications in warehouse management, manufacturing, military missions, security, commercial delivery, aerial photography, and health. Every robot moves and it/we need to know where it is, so it should have a location and mapping system. The visualization platform for land robots is usually a 2D map while flying robots need the more complex 3D localization and mapping. Robot localization systems need to know a landmark as origin or destination and a method to track the movement of the robot. Traditionally robots benefit from 2D simultaneous localization and mapping (SLAM) algorithms for navigation [10], [36] and more recently 3D localization for flying robots and for microbots inside the human being are emerging [22], [32], [70].

Location sensors in Robotic platforms include camera, speedometer, RF communication devices, RFID readers, and optical measuring meters. A land robot may carry all of these sensors while a flying robot or a Robot with medical mission inside the human body may only carry a camera and an RF device to communicate between the controller and the robot [37].

The accuracy and precision needs of moving mechanical devices varies by the application, size and environment of operation of these devices and it may range from millimeters for robots operating inside the human body, to a few meters for robots operating in indoor areas, and tens of meters for outdoor robots. The mission of the robot also affects these values. For example a robot operating in a laboratory in an indoor area or a flying miniature robot may need centimetric or millimetric precision for certain tasks rather than a few meters accuracy commonly perceived for indoor operations [25].

### C. LOCALIZATION IN SMART HEALTH

Since we cannot see inside the human body directly and the inside of the human body comprises a number of complicated organs, each treated by a separate specialist doctor, the term ''localization'' in medicine is commonly used for locating a lesion, tumors, bleeding or pain inside the human body. The term is also used for locating an external device such as intrusive surgery equipment or an endoscopy capsule inside the human body [58]. In addition, in the hospitals there are numerous localization applications ranging from locating, doctors, patients, nurses and visitors to locating commonly used equipment such as wheelchairs and specialized tools such as surgery equipment inside the surgery room. With the current wave of elderly health monitoring research using sensor networks [26], [28], localization technology for patients is needed everywhere. Technologies used for locating people or objects inside the hospitals are one of the major applications for the emerging indoor geolocation science and technologies [56]. Other commonly used technologies for indoor and outdoor localizations are used for health monitoring whenever tracking and location of the patients are essential.

The accuracy and precision needed for localization inside the human body may vary from a fraction of a mm for neurons inside the brain to cms inside the GI-tract. Localization precision of the people and equipment in health related applications follows the same guidelines as smart devices and robots.

For in-body localization and mapping, traditional 2D and more recently 3D X-ray [50], 3D ultra-sound imaging [66], 3D Magnetic Resonance Imaging (MRI) [63], and Computer Aided Tomography Scan (CAT-scan) [41] are used. More recently RF signals [58] as well as hybrid RF and imaging techniques have been used for locating microbots inside the human body [5]. An animated video clip demonstrating the RF and visual elements of hybrid localization inside the human body is available at [3]. Since there is no map in vivo for tracking inside the gastro-internal tract (GI-tract) and the vascular tree mapping inside the organs has been another current area of research.

### D. SMART SPACES AND LOCALIZATION USING RFID

RFID tags are another essential elements of the emerging smart worlds. Currently, passive RFID tags are used in numerous popular application such as tagging newly born babies or patients in the hospitals, checking cars in the highway pay tolls, checking progress in long assembly lines, tracking small items in warehouses, implanting microchip IDs in animals and the human being, and tracking robots in indoor areas [52]. It is expected that RFID tags become widely deployed in the smart buildings [47], [61] and smart phones of the future carry RFID readers [35], [45]. We expect trillions of RFID tags to be used for numerous applications in the smart world of the future. As important as it is to connect these tags through the Internet of Things (IoT), a need for localizing RFID tags is becoming essential. Passive RFID readers are simple proximity check localization systems communicating the tag information with the cyber domain. The real time location system (RTLS) technology addresses indoor localization for RFIDs tags using Wi-Fi, iBeacon (Bluetooth) and UWB Technologies [51]. As important as is to know the location of an RFID, if the RFID is installed in a fixed location it can be used for opportunistic location and smart evacuations in challenging environments for RF localization such as inside the tunnels [19] or they can be used to improve the accuracy of indoor geolocation systems as a component of a more complex hybrid localization system [45].

### *E. LOCALIZATION FOR SMART TRANSPORTATION SYSTEMS*

Indeed smart transportation is an important part of emerging smart cities and the smart world. As a result smart transportation systems have received considerable attention in the recent literature [23]. Today we know absolute location of the ground and air transportation systems operating in outdoor environments. If properly networked, this information can revolutionize efficiency of the transportation systems resulting in huge saving in fuel cost and transportation costs. The vehicular navigation systems primarily rely on GPS and mechanical sensors measuring the speed and direction of movement of the car [59]. The weakness of current vehicular systems is lack of networking infrastructure to coordinate these movements in a smart manner. This is a long process involving networking standardizations. Another emerging localization application for vehicles is finding the relative location with respect to surrounding mobile and fixed objects. Such application is needed to assist drivers in maneuvering the vehicle movements with respect to other moving vehicles as well as the fixed infrastructure surrounding the move. With the investments on the thousands of sensors on those moving vehicles and surrounding infrastructures, ideally we expect to know their locations as well as the trace. Such information carries mobility patterns of dynamic individuals and it enables further data mining based applications such as smart itinerary guidance, trace-based social event analysis [39], urban traffic planning [12], land usage monitoring [29], smart public security [23] and even traffic flow based smart advertising [42]. All these applications need a smart transportation system as the backbone, therefore, localization science and technology has wide variety of applications in the emerging smart transportation systems as well.

### *F. LOCALIZATION FOR SMART INFRASTRUCTURE*

In recent years, several critical national infrastructures are becoming smart – in particular the electric grid, intelligent transportation, water systems, etc. [34]. Managing the resources of the critical infrastructures efficiently and for enabling their resilience and smooth operation, localization is essential. Although there is limited work in this area (see for example [20], [30] for localizing faults in the smart grid), identifying where a resource is being constrained or added becomes important. When sensors are used for sampling water quality, or to assess the load in the electric grid, the locations of these sensors are important as they relate to the measured quantities and the infrastructure that is in place near the sensor. In terms of accuracy and precision, there are a variety of requirements – at a macroscopic level, it may be sufficient to know the locations of various components at the granularity of several tens of meters on a map, but within a specific component (for example an electric sub-station) the localization accuracy may have to be on the order of cm.

## V. SOME OPEN CHALLENGES IN LOCALIZATION FOR THE SMART WORLD

Localization science and engineering has made considerable fundamental growth in the past few decades, which has enabled a spurt in the number of smart applications [59]. As the smart applications in the world expand, need for localization in challenging environments grows. Today, a number of challenges are facing the location science and technology as a fundamental enabling technology for the evolution of the so called smart world.

Localization in crowded environments during the events in outdoor, such as stadiums, or indoors, such as large lecture halls, is an existing challenge for a number of smart applications tailored for these environments. These applications involve 3D map of the environment and an accuracy of less than a meter to locate targeted seats for delivery of a smart service. To support the audience with wireless access for smart phone as well as localization for delivery of physical services, most probably we need temporary infrastructure deployment using Balloons and Drones that can cover the areas of interest during the events attracting the crowd. To guide people intelligently to their seats we may need to resort to hybrid and cooperative localization using RF signals, RFID based signs, as well as mechanical sensors commonly available in smart phones. The map could be a 3D map layered into 2D map of individual floor or step levels or an interface with direction of movement pointers guiding the target smart phone to the seat location.

Finding *cost efficient* locating systems for smart item finding in shelves of a department store is another long-standing problem for localization systems. Smart shopping of the future needs that type of technology to direct customers to the location of the desired products. –Similar challenges may exist for localizing specific entities in the various critical infrastructures to enable smart applications. Such challenges are created in layers – as an example, first we have to find which floor the human being is located to select the associated map for the floor [65], [67]. Next, we have to identify which shelf in which aisle contains the item of interest. The accuracy needed for this type of localization intelligence is around few centimeters to differentiate small items from one another.

The most commonly used indoor localization of today is Wi-Fi localization with accuracy of a few meters which is not adequate for this type of application. We need additional RF infrastructure and more complex hybrid and cooperative localization algorithms to achieve the needed accuracy. iBeacon technology, using mechanical sensors and Bluetooth in smart phones, or adding UWB infrastructure seem to be useful for such applications, but the technology has not yet stabilized, nor are the costs associated with it.

Another challenge for localization in the emerging smart world is locating flying smart tiny robots in indoor areas. 3D localization needed for these flying robots demands accuracy on the order of the size of these robots to navigate them intelligently without any crash incident. The display map for these applications needs to be 3D and certain amount of details for the furniture and other large items and people in the room is needed to control the movements of the robots. This is a very complex technology and very far away from the current states of the art. Similar to smart finding of items in the shelves, here accuracy of existing Wi-Fi infrastructure is not adequate and we may need additional RF infrastructure and integration of visual and mechanical sensors.

Application of microbots in the emerging smart medicine delivery and health monitoring systems has opened another horizon for localization of microbots inside the human body [44], [49]. Challenges for localization inside the human body begin with issues related to the map. We do not have any map for the path of movements of these microbots inside the specific human GI-tract or vascular tree in vivo. All we have is the general anatomic cartons of the shape of the organs and the paths, not the real 3D map needed for navigation inside the human body. Most microbots carry a camera, if the path of movement is reconstructed the camera pictures can be used to reconstruct the inside of the individual organs in vivo. The infrastructure for localization in these scenarios is body mounted sensors, which are always moving with respect to one another with the human body moves. Int3elligent localization in an infrastructure that is in motion needs new algorithms to be discovered. Intelligent navigation of these microbots needs hybrid localization using RF signal and the images taken by the cameras [4], [5]. RF propagation inside the human body is very complex because it is a non-homogeneous and liquid immersive environment, which opens a new horizon for scientific discoveries [21], [48].

Finally, associated with the localization of objects and humans is the challenge of privacy and securing the information so that it is available to only authorized entities (e.g., the human whose location is being captured). While research work on location privacy has been ongoing in recent years, there are open questions on how location privacy can be maintained, while providing the utility of this information in a smart world.

## VI. CONCLUSION

There are several emerging disciplines, such as fog computing [73] that are looking at an amalgamation of the interaction of mobility, a large number of nodes (People and Things) and their interactions towards a Smart World. Knowledge of location information is critical in the materialization of Smart World. We have explained the dependence of several aspects of the emerging Smart World on localization science and technology by describing a variety of intelligent applications needed for popular application in smart devices, robots, smart health monitoring and delivery systems, smart space using RFID tags, and emerging smart city transportation systems. We argued that localization science and technology is a complex phenomenon demanding further research to accommodate the accuracies needed by these applications in variety of application environments and on different platforms, and we have pointed to some open challenges for researchers in this field.

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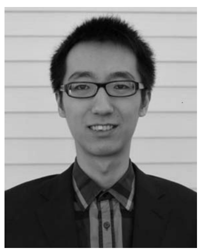

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