# SLAM-Based IoT Project

Ashish Jacob Sam

B.Tech CSE

BCSE1605

ASET

Amity University Mumbai

## Introduction

### IoT

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.[1][2][3][4]

The definition of the Internet of Things has evolved due to the convergence of multiple technologies, real-time analytics, machine learning, commodity sensors, and embedded systems.[5] Traditional fields of embedded systems, wireless sensor networks, control systems, automation (including home and building automation), and others all contribute to enabling the Internet of Things. In the consumer market, IoT technology is most synonymous with products pertaining to the concept of the "smart home", covering devices and appliances (such as lighting fixtures, thermostats, home security systems and cameras, and other home appliances) that support one or more common ecosystems, and can be controlled via devices associated with that ecosystem, such as smartphones and smart speakers.

#### Applications of IoT

The extensive set of applications for IoT devices[23] is often divided into consumer, commercial, industrial, and infrastructure spaces.[24][25]

##### Consumer applications

A growing portion of IoT devices are created for consumer use, including connected vehicles, home automation, wearable technology, connected health, and appliances with remote monitoring capabilities.[26]

##### Smart home

IoT devices are a part of the larger concept of home automation, which can include lighting, heating and air conditioning, media and security systems.[27][28] Long-term benefits could include energy savings by automatically ensuring lights and electronics are turned off.

A smart home or automated home could be based on a platform or hubs that control smart devices and appliances.[29] For instance, using Apple's HomeKit, manufacturers can have their home products and accessories controlled by an application in iOS devices such as the iPhone and the Apple Watch.[30][31] This could be a dedicated app or iOS native applications such as Siri.[32] This can be demonstrated in the case of Lenovo's Smart Home Essentials, which is a line of smart home devices that are controlled through Apple's Home app or Siri without the need for a Wi-Fi bridge.[32] There are also dedicated smart home hubs that are offered as standalone platforms to connect different smart home products and these include the Amazon Echo, Google Home, Apple's HomePod, and Samsung's SmartThings Hub.[33] In addition to the commercial systems, there are many non-proprietary, open source ecosystems; including Home Assistant, OpenHAB and Domoticz.[34] [35]

##### Elder care

One key application of a smart home is to provide assistance for those with disabilities and elderly individuals. These home systems use assistive technology to accommodate an owner's specific disabilities.[36] Voice control can assist users with sight and mobility limitations while alert systems can be connected directly to cochlear implants worn by hearing-impaired users.[37] They can also be equipped with additional safety features. These features can include sensors that monitor for medical emergencies such as falls or seizures.[38] Smart home technology applied in this way can provide users with more freedom and a higher quality of life.[36]

The term "Enterprise IoT" refers to devices used in business and corporate settings. By 2019, it is estimated that the EIoT will account for 9.1 billion devices.[24]

#### Commercial application

##### Medical and healthcare

The Internet of Medical Things (IoMT), (also called the Internet of health things), is an application of the IoT for medical and health related purposes, data collection and analysis for research, and monitoring.[39][40][41][42][43] The IoMT has been referenced as "Smart Healthcare",[44] as the technology for creating a digitised healthcare system, connecting available medical resources and healthcare services.[45]

IoT devices can be used to enable remote health monitoring and emergency notification systems. These health monitoring devices can range from blood pressure and heart rate monitors to advanced devices capable of monitoring specialised implants, such as pacemakers, Fitbit electronic wristbands, or advanced hearing aids.[46] Some hospitals have begun implementing "smart beds" that can detect when they are occupied and when a patient is attempting to get up. It can also adjust itself to ensure appropriate pressure and support is applied to the patient without the manual interaction of nurses.[39] A 2015 Goldman Sachs report indicated that healthcare IoT devices "can save the United States more than $300 billion in annual healthcare expenditures by increasing revenue and decreasing cost."[47] Moreover, the use of mobile devices to support medical follow-up led to the creation of 'm-health', used "to analyse, capture, transmit and store health statistics from multiple resources, including sensors and other biomedical acquisition systems".[48]

Specialized sensors can also be equipped within living spaces to monitor the health and general well-being of senior citizens, while also ensuring that proper treatment is being administered and assisting people regain lost mobility via therapy as well.[49] These sensors create a network of intelligent sensors that are able to collect, process, transfer, and analyze valuable information in different environments, such as connecting in-home monitoring devices to hospital-based systems.[44] Other consumer devices to encourage healthy living, such as connected scales or wearable heart monitors, are also a possibility with the IoT.[50] End-to-end health monitoring IoT platforms are also available for antenatal and chronic patients, helping one manage health vitals and recurring medication requirements.[citation needed]

Advances in plastic and fabric electronics fabrication methods have enabled ultra-low cost, use-and-throw IoMT sensors. These sensors, along with the required RFID electronics, can be fabricated on paper or e-textiles for wirelessly powered disposable sensing devices.[51] Applications have been established for point-of-care medical diagnostics, where portability and low system-complexity is essential.[52]

As of 2018 IoMT was not only being applied in the clinical laboratory industry,[41] but also in the healthcare and health insurance industries. IoMT in the healthcare industry is now permitting doctors, patients, and others, such as guardians of patients, nurses, families, and similar,to be part of a system, where patient records are saved in a database, allowing doctors and the rest of the medical staff to have access to patient information.[45] Moreover, IoT-based systems are patient-centered, which involves being flexible to the patient's medical conditions.[45] IoMT in the insurance industry provides access to better and new types of dynamic information. This includes sensor-based solutions such as biosensors, wearables, connected health devices, and mobile apps to track customer behaviour. This can lead to more accurate underwriting and new pricing models.[53]

The application of the IOT in healthcare plays a fundamental role in managing chronic diseases and in disease prevention and control. Remote monitoring is made possible through the connection of powerful wireless solutions. The connectivity enables health practitioners to capture patient's data and applying complex algorithms in health data analysis.[54]

#### Transportation

##### Digital variable speed-limit sign

The IoT can assist in the integration of communications, control, and information processing across various transportation systems. Application of the IoT extends to all aspects of transportation systems (i.e. the vehicle,[55] the infrastructure, and the driver or user). Dynamic interaction between these components of a transport system enables inter- and intra-vehicular communication,[56] smart traffic control, smart parking, electronic toll collection systems, logistics and fleet management, vehicle control, safety, and road assistance.[46][57] In Logistics and Fleet Management, for example, an IoT platform can continuously monitor the location and conditions of cargo and assets via wireless sensors and send specific alerts when management exceptions occur (delays, damages, thefts, etc.). This can only be possible with the IoT and its seamless connectivity among devices. Sensors such as GPS, Humidity, and Temperature send data to the IoT platform and then the data is analyzed and then sent to the users. This way, users can track the real-time status of vehicles and can make appropriate decisions. If combined with Machine Learning, then it also helps in reducing traffic accidents by introducing drowsiness alerts to drivers and providing self-driven cars too.

##### Building and home automation

IoT devices can be used to monitor and control the mechanical, electrical and electronic systems used in various types of buildings (e.g., public and private, industrial, institutions, or residential)[46] in home automation and building automation systems. In this context, three main areas are being covered in literature:[58]

The integration of the Internet with building energy management systems in order to create energy efficient and IOT-driven "smart buildings".[58]

The possible means of real-time monitoring for reducing energy consumption[59] and monitoring occupant behaviors.[58]

The integration of smart devices in the built environment and how they might to know how to be used in future applications.[58]

#### Industrial applications

##### Industrial Internet of Things

Also known as IIoT, industrial IoT devices acquire and analyze data from connected equipment, (OT) operational technology, locations and people. Combined with operational technology (OT) monitoring devices, IIOT helps regulate and monitor industrial systems.

Manufacturing[edit]

The IoT can realize the seamless integration of various manufacturing devices equipped with sensing, identification, processing, communication, actuation, and networking capabilities. Based on such a highly integrated smart cyber-physical space, it opens the door to create whole new business and market opportunities for manufacturing.[60] Network control and management of manufacturing equipment, asset and situation management, or manufacturing process control bring the IoT within the realm of industrial applications and smart manufacturing as well.[61] The IoT intelligent systems enable rapid manufacturing of new products, dynamic response to product demands, and real-time optimization of manufacturing production and supply chain networks, by networking machinery, sensors and control systems together.[46]

Digital control systems to automate process controls, operator tools and service information systems to optimize plant safety and security are within the purview of the IoT.[62] But it also extends itself to asset management via predictive maintenance, statistical evaluation, and measurements to maximize reliability.[63] Industrial management systems can also be integrated with smart grids, enabling real-time energy optimization. Measurements, automated controls, plant optimization, health and safety management, and other functions are provided by a large number of networked sensors.[46]

Industrial IoT (IIoT) in manufacturing could generate so much business value that it will eventually lead to the Fourth Industrial Revolution, also referred to as Industry 4.0. The potential for growth from implementing IIoT may generate $12 trillion of global GDP by 2030.[64]

Design architecture of cyber-physical systems-enabled manufacturing system[65]

Industrial big data analytics will play a vital role in manufacturing asset predictive maintenance, although that is not the only capability of industrial big data.[66][67] Cyber-physical systems (CPS) is the core technology of industrial big data and it will be an interface between human and the cyber world. Cyber-physical systems can be designed by following the 5C (connection, conversion, cyber, cognition, configuration) architecture,[65] and it will transform the collected data into actionable information, and eventually interfere with the physical assets to optimize processes.

An IoT-enabled intelligent system of such cases was proposed in 2001 and later demonstrated in 2014 by the National Science Foundation Industry/University Collaborative Research Center for Intelligent Maintenance Systems (IMS) at the University of Cincinnati on a bandsaw machine in IMTS 2014 in Chicago.[68][69][70] Bandsaw machines are not necessarily expensive, but the bandsaw belt expenses are enormous since they degrade much faster. However, without sensing and intelligent analytics, it can be only determined by experience when the band saw belt will actually break. The developed prognostics system will be able to recognize and monitor the degradation of band saw belts even if the condition is changing, advising users when is the best time to replace the belt. This will significantly improve user experience and operator safety and ultimately save on costs.[70]

##### Agriculture

There are numerous IoT applications in farming[71] such as collecting data on temperature, rainfall, humidity, wind speed, pest infestation, and soil content. This data can be used to automate farming techniques, take informed decisions to improve quality and quantity, minimize risk and waste, and reduce effort required to manage crops. For example, farmers can now monitor soil temperature and moisture from afar, and even apply IoT-acquired data to precision fertilization programs.[72]

In August 2018, Toyota Tsusho began a partnership with Microsoft to create fish farming tools using the Microsoft Azure application suite for IoT technologies related to water management. Developed in part by researchers from Kindai University, the water pump mechanisms use artificial intelligence to count the number of fish on a conveyor belt, analyze the number of fish, and deduce the effectiveness of water flow from the data the fish provide. The specific computer programs used in the process fall under the Azure Machine Learning and the Azure IoT Hub platforms.[73]

##### Infrastructure applications

Monitoring and controlling operations of sustainable urban and rural infrastructures like bridges, railway tracks and on- and offshore wind-farms is a key application of the IoT.[62] The IoT infrastructure can be used for monitoring any events or changes in structural conditions that can compromise safety and increase risk. The IoT can benefit the construction industry by cost saving, time reduction, better quality workday, paperless workflow and increase in productivity. It can help in taking faster decisions and save money with Real-Time Data Analytics. It can also be used for scheduling repair and maintenance activities in an efficient manner, by coordinating tasks between different service providers and users of these facilities.[46] IoT devices can also be used to control critical infrastructure like bridges to provide access to ships. Usage of IoT devices for monitoring and operating infrastructure is likely to improve incident management and emergency response coordination, and quality of service, up-times and reduce costs of operation in all infrastructure related areas.[74] Even areas such as waste management can benefit[75] from automation and optimization that could be brought in by the IoT.[76]

##### Metropolitan scale deployments

There are several planned or ongoing large-scale deployments of the IoT, to enable better management of cities and systems. For example, Songdo, South Korea, the first of its kind fully equipped and wired smart city, is gradually being built, with approximately 70 percent of the business district completed as of June 2018. Much of the city is planned to be wired and automated, with little or no human intervention.[77]

Another application is a currently undergoing project in Santander, Spain. For this deployment, two approaches have been adopted. This city of 180,000 inhabitants has already seen 18,000 downloads of its city smartphone app. The app is connected to 10,000 sensors that enable services like parking search, environmental monitoring, digital city agenda, and more. City context information is used in this deployment so as to benefit merchants through a spark deals mechanism based on city behavior that aims at maximizing the impact of each notification.[78]

Other examples of large-scale deployments underway include the Sino-Singapore Guangzhou Knowledge City;[79] work on improving air and water quality, reducing noise pollution, and increasing transportation efficiency in San Jose, California;[80] and smart traffic management in western Singapore.[81] Using its RPMA (Random Phase Multiple Access) technology, San Diego-based Ingenu has built a nationwide public network[82] for low-bandwidth data transmissions using the same unlicensed 2.4 gigahertz spectrum as Wi-Fi. Ingenu's "Machine Network" covers more than a third of the US population across 35 major cities including San Diego and Dallas.[83] French company, Sigfox, commenced building an Ultra Narrowband wireless data network in the San Francisco Bay Area in 2014, the first business to achieve such a deployment in the U.S.[84][85] It subsequently announced it would set up a total of 4000 base stations to cover a total of 30 cities in the U.S. by the end of 2016, making it the largest IoT network coverage provider in the country thus far.[86][87] Cisco also participates in smart cities projects. Cisco has started deploying technologies for Smart Wi-Fi, Smart Safety & Security, Smart Lighting, Smart Parking, Smart Transports, Smart Bus Stops, Smart Kiosks, Remote Expert for Government Services (REGS) and Smart Education in the five km area in the city of Vijaywada.[88]

Another example of a large deployment is the one completed by New York Waterways in New York City to connect all the city's vessels and be able to monitor them live 24/7. The network was designed and engineered by Fluidmesh Networks, a Chicago-based company developing wireless networks for critical applications. The NYWW network is currently providing coverage on the Hudson River, East River, and Upper New York Bay. With the wireless network in place, NY Waterway is able to take control of its fleet and passengers in a way that was not previously possible. New applications can include security, energy and fleet management, digital signage, public Wi-Fi, paperless ticketing and others.[89]

##### Energy management

Significant numbers of energy-consuming devices (e.g. switches, power outlets, bulbs, televisions, etc.) already integrate Internet connectivity, which can allow them to communicate with utilities to balance power generation and energy usage[90] and optimize energy consumption as a whole.[46] These devices allow for remote control by users, or central management via a cloud-based interface, and enable functions like scheduling (e.g., remotely powering on or off heating systems, controlling ovens, changing lighting conditions etc.).[46] The smart grid is a utility-side IoT application; systems gather and act on energy and power-related information to improve the efficiency of the production and distribution of electricity.[90] Using advanced metering infrastructure (AMI) Internet-connected devices, electric utilities not only collect data from end-users, but also manage distribution automation devices like transformers.[46]

##### Environmental monitoring

Environmental monitoring applications of the IoT typically use sensors to assist in environmental protection[91] by monitoring air or water quality,[92] atmospheric or soil conditions,[93] and can even include areas like monitoring the movements of wildlife and their habitats.[94] Development of resource-constrained devices connected to the Internet also means that other applications like earthquake or tsunami early-warning systems can also be used by emergency services to provide more effective aid. IoT devices in this application typically span a large geographic area and can also be mobile.[46] It has been argued that the standardization IoT brings to wireless sensing will revolutionize this area.[95]

##### Living Lab

Another example of integrating the IoT is Living Lab which integrates and combines research and innovation process, establishing within a public-private-people-partnership.[96] There are currently 320 Living Labs that use the IoT to collaborate and share knowledge between stakeholders to co-create innovative and technological products. For companies to implement and develop IoT services for smart cities, they need to have incentives. The governments play key roles in smart cities projects as changes in policies will help cities to implement the IoT which provides effectiveness, efficiency, and accuracy of the resources that are being used. For instance, the government provides tax incentives and cheap rent, improves public transports, and offers an environment where start-up companies, creative industries, and multinationals may co-create, share common infrastructure and labor markets, and take advantages of locally embedded technologies, production process, and transaction costs.[96] The relationship between the technology developers and governments who manage city's assets, is key to provide open access of resources to users in an efficient way.

#### Military Applications

##### Internet of Military Things

The Internet of Military Things (IoMT) is the application of IoT technologies in the military domain for the purposes of reconnaissance, surveillance, and other combat-related objectives. It is heavily influenced by the future prospects of warfare in an urban environment and involves the use of sensors, munitions, vehicles, robots, human-wearable biometrics, and other smart technology that is relevant on the battlefield.[97]

##### Internet of Battlefield Things

The Internet of Battlefield Things (IoBT) is a project initiated and executed by the U.S. Army Research Laboratory (ARL) that focuses on the basic science related to IoT that enhance the capabilities of Army soldiers.[98] In 2017, ARL launched the Internet of Battlefield Things Collaborative Research Alliance (IoBT-CRA), establishing a working collaboration between industry, university, and Army researchers to advance the theoretical foundations of IoT technologies and their applications to Army operations.

### SLAM

In navigation, robotic mapping and odometry for virtual reality or augmented reality, simultaneous localization and mapping (SLAM) is the computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.[1][2][3][4] While this initially appears to be a chicken-and-egg problem there are several algorithms known for solving it, at least approximately, in tractable time for certain environments. Popular approximate solution methods include the particle filter, extended Kalman filter, Covariance intersection, and GraphSLAM.

SLAM algorithms are tailored to the available resources, hence not aimed at perfection, but at operational compliance. Published approaches are employed in self-driving cars, unmanned aerial vehicles, autonomous underwater vehicles, planetary rovers, newer domestic robots and even inside the human body.[5]

## Literature Survey

The given table provides details on the research done relavant to the topic so far

| S.no | Paper Title | Authors | Opinion |
| --- | --- | --- | --- |
| 1 | Simultaneous Localisation and Mapping (SLAM): Part I The Essential Algorithms | Hugh Durrant-Whyte, Fellow, IEEE, and Tim Bailey | Discussed SLAM problem definition and following algorithms:  Extended Kalman Filter  Rao-Backwellised Filter |
| 2 | A Tutorial on Graph-Based SLAM | Giorgio Grisetti Rainer Kümmerle Cyrill Stachniss Wolfram Burgard | Discussed implementation of SLAM using Graph-Based approach |
| 3 | Cloud-based Parallel Implementation of SLAM for Mobile Robots | Supun Kamburugamuve, Hengjing He, Geoffrey Fox, David Crandall | Implementation of IoT-based SLAM to upload data and process it |
| 4 | FastSLAM: A Factored Solution to the Simultaneous Localization and Mapping Problem | Michael Montemerlo, Sebastian Thrun, Daphne Koller and Ben Wegbreit | A factored approach for implementation of SLAM |