Mobile Sensor Networks and Robotics

K.P. Udagepola

Abstract The collaboration between wireless sensor networks and the distributed robotics has prompted the making of mobile sensor networks. However, there has been a growing enthusiasm in developing mobile sensor networks, which are the favoured family of wireless sensor networks in which autonomous movement assumes a key part in implementing its application. By introducing mobility to nodes in wireless sensor networks, the capability and flexibility of mobile sensor networks can be enhanced to support multiple mansions, and to address the previously stated issues. The reduction in costs of mobile sensor networks and their expanding capacities makes mobile sensor networks conceivable and useful. Today, many types of research are focused on the making of mobile wireless sensor networks due to their favourable advantage and applications. Allowing the sensors to be mobile will boost the utilization of mobile wireless sensor networks beyond that of static wireless sensor networks. Sensors can be mounted on, or implanted in animals to monitor their movements for examinations, but they can also be deployed in unmanned airborne vehicles for surveillance or environmental mapping. Mobile wireless sensor networks and robotics play a crucial role if it integrated with static nodes to become a Mobile Robot, which can enhance the capabilities, and enables their new applications. Mobile robots provide a means of exploring and interacting with the environment in more dynamic and decentralised ways. In addition, this new system of networked sensors and robots allowed the development of fresh solutions to classical problems such as localization and navigation beyond that. This article presents an overview of mobile sensor network issues, sensor networks in robotics and the application of robotic sensor networks.

Keywords Mobile sensor networks · Robots · Coverage · Localization · Robotic sensor networks · Network topology · Healthcare

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1 Introduction

The wireless connectivity within the network is facilitated by main components of Wireless Sensor Network (WSN) connect with an application platform at one end of the network. Any part of network can use one or more sensor/actuator devices. Figure 1 depicts the required components link with the real world and the application platform. It uses g and sensor (S). Figure 1 shows an advanced WSN of the basic model because it has a relay node (R) to connect both a gateway and a sensor to make a mesh network. Another hand it is facilitating reducing obstacles to make model efficiency (Fig. 2).

Innovative advances such as 4G networks and that of ubiquitous computing have triggered new interests in Multi Hop Networks (MHNs). Specifically, the automated organization of wireless MHNs that are composed of large motes, which can be mobile and static, and can likewise be utilized for computational and power, is of great interest. On the other hand, WSNs are some of the ordinary examples of these networks. Their topology dynamically changes when connectivity among the nodes varies with their mobility due on the time factor. E.g. Fig. 3 shows Multi-hop WSN architecture.

A large part of the research in WSNs is focused on networks whose nodes cannot be replaced and are stationary. Mobility in sensor nodes has been taken advantage of in order to improve or enable the overall communication coverage and sensing of these networks [1]. The credit for the creation of mobile sensor networks (MSNs) goes to WSNs and also to the interaction of distributed robotics [2]. MSNs are a class of networks where little sensing devices communicate in a collaborative way by moving in a space to observe and monitor environmental and physical conditions [3, 4]. MSN is composed of nodes and all nodes have computation, sensing, locomotion modules and communication. Each sensor node is also capable of navigating human interaction or autonomously [5]. MSNs have emerged as an important area for research and development [6].

Fig. 1 Basic components of WSN

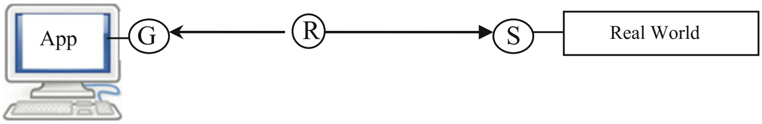

Fig. 2 Using relay node with basic model

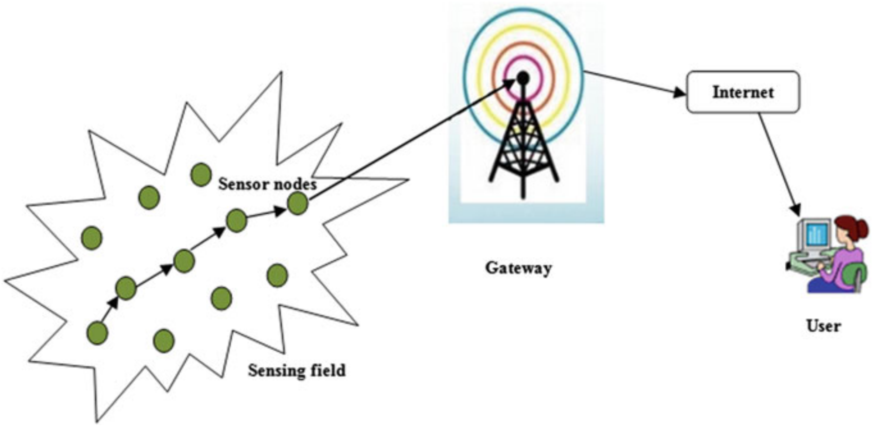

Fig. 3 Multi-hop WSN architecture

Even though MSNs are still developing, they can be used for monitoring the environment, disaster-prone areas and hazardous zones. It can also be used in monitoring healthcare, agriculture and defense. Mobile wireless sensor networks (MWSNs) can be used for both monitoring and control as many practical applications of MSNs that continue to emerge [7]. These include robotics, which is the science of technology having applications in various fields such as design, fabrication, and theory [8]. It can be considered as the area of technology that deals with the construction, operation and control of both robotic applications and computer systems. Furthermore, sensory feedback, as well as information processing, can be managed by robots. The main advantage of this technology is that it can replace humans in manufacturing processes, dangerous environments, or it can be made to resemble humans in terms of behavior, cognition or experience [8].

The word “robot” has its roots from “robota,” which is a Czechoslo-vakian word meaning work robot. The word was first used in Karel Chapek’s 1920s play Rossum Universal Robots. A leap forward in the autonomous robot technology happened in the mid-1980s with the work on behavior based robotics. This work was laid the basis for several robotic applications today [9]. Most of the problems encountered in traditional sensor networks may be addressed by integrating Mobile Robots (MRs), which are intelligent directly into sensor networks. MRs offer ways to interact and survey the environment in a more decentralized and dynamic way. The new system of robots and networked sensors has led to the emergence of new solutions for existing issues such as navigation and localization [10–12]. Mobile nodes can be utilized as intuitive self-controlled mobile robots or as intuitive robots whose sensor systems are capable of solving both environmental and navigational functions. In this way, sensor systems on robots are the dispersed systems. MRs carry sensors around an area to produce a detailed natural appraisal and sense phenomena [13–16].

The fundamental parts of a sensor node are a transceiver, a micro controller outer memory, multiple sensors and a power source [17]. The controller regulates the range of capabilities of other components in the sensor nodes and processes the data. The feasible option of wireless transmission media is infrared, radio frequency (RF) and optical communication. As far as external memory is concerned, the most applicable types of memory are the flash memory and the on-board memory of a micro controller. An availability of energy is the most important requirement to consider design and making a wireless sensor node. It should be always without interrupt the activation. Figure 4 shows DHT11 digital humidity and temperature, which is a blended sensor containing a calibrated digital signal output of the humidity and temperature. Sensor nodes consume energy for data processing, detection and communication; power is stored in capacitors or batteries. Batteries can be both rechargeable and non-rechargeable for sensor nodes. They are the main resource of a power supply. A sensor is a device that senses or detects motion, etc. It responds in a particular way [18–25]. The Analog to-digital converter (ADC) is making calibration match with the required data to a processor once sensor picked the data. Figure 5 presents a sensor node architecture that we discussed above.

A solution is given by the use of multi-robot systems for carrying sensors around the environment. It has received a considerable attention and can also provide some exceptional advantages as well. A number of applications have been addressed so far by Robotic Sensor Networks (RSNs) such as rescue, search and environmental monitoring. In WSNs, robotics can also be utilized to address several issues to advance performances such as responding to a particular sensor failure, node distribution, data aggregation and more. Similarly, to address the issues present in the field of robotics, WSNs play a crucial role in problems such as localization, path planning, coordination (multiple robots) and sensing [14, 27].

Today, the industry has many applications of sensor networks which are on the ground, in the air, underwater and underground. In mobile underwater sensor network (UWSN), mobility offers two main advantages. Firstly, floating sensors can increase system reusability. Secondly, it can help to enable dynamic monitoring as well as coverage. These features can be used to track changes in water aggregates

Fig. 4 Temperature humidity sensor module [26]

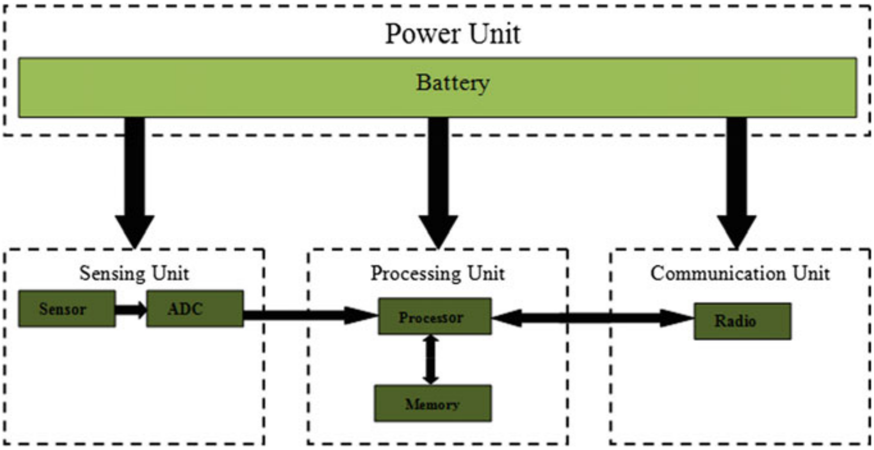

Fig. 5 A sensor node architecture

in this way providing 4D (space and time) environmental monitoring. As compared to ground-based sensor networks, mobile UWSN has to employ acoustic communications because radios do not work in hard water environments. Similarly, the underground sensor network makes a huge impact for monitoring number of characteristics at underground s as the properties of the soil, toxic substances and more. These sensor networks are buried completely underground and do not require any wire for connection. On the ground, they can be used for target tracking, environmental monitoring, forest fire detection, industrial monitoring and machine health monitoring. Wireless sensor nodes have been in service for a long time and are still used for different applications such as warfare, earthquake measurements and more.

National Aeronautics and Space Administration (NASA) embarked on the sensor webs project and smart dust project after the recent growth of small sensor nodes in 1998. The main aim of the smart dust project was to make self-controlling, sensing and corresponding possible within a cubic millimeter of space. The task drove numerous research activities incorporating real research focus in the center for embedded networked sensing (CENS) and Berkeley NEST. The term mote was coined by researchers working in these projects to indicate a sensor node, and the pod was the name used to refer to a physical sensor node in the NASA sensor webs project. In a sensor web, the sensor node can be another sensor web itself [17].

The crossbow radio/processor boards usually recognized as motes. It permits to wirelessly transmit many sensors scattered over a large area. This helps to receive t data to the base station. TinyOS is an operating system for the mote. This uses for low power wireless devices. E.g. ubiquitous computing, PAN, smart building, smart meter, sensor network and more. It controls radio transmission, power and networking transparent to the user. Subsequently, an ad hoc network initiates [18, 28].

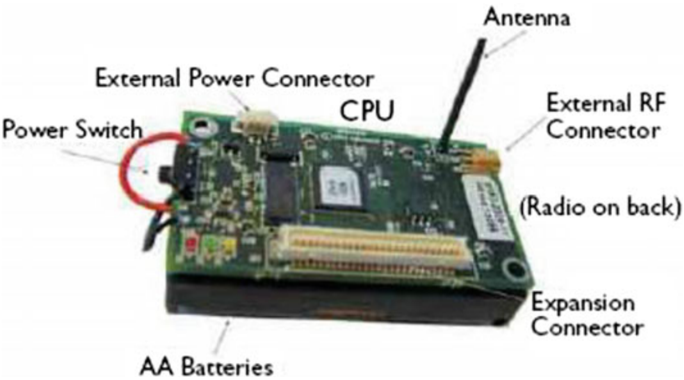

Fig. 6 Mica 2 processor

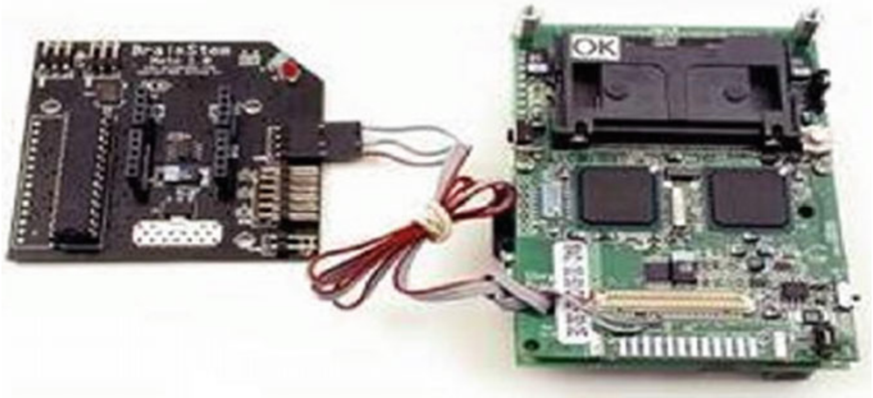

Fig. 7 Stargate processor [26]

The MICA2 (see Fig. 6) Mote is a third generation mote module with 512 KB of measurement (serial) flash memory, 128 KB of program flash memory and 4 KB of Programmable read-only memory.

Stargate (see Fig. 7) is a 400-MHz Intel PXA255 Xscale processor with 32 MB of flash memory and 64 MB of synchronous dynamic random-access memory. Different classes of sensors are available in the current market. E.g. barometric pressure, acceleration, seismic, acoustic, radar, light, temperature, relative humidity, magnetic camera, global positioning system (GPS) and more. Usually, sensors are categorized into three different kinds: passive, omnidirectional and narrow-beam (Wikipedia). Passive sensor has a self-activation characteristic is giving more powerful to fetch the data without actually manipulating the environment. Narrow beam sensor has a distinct direction of the measurement. Omni-directional sensor has no direction of the measurement [29].

Internet of Things (IoT) employs WSN systems to give lots benefits for numerous applications in real life. E.g. healthcare systems manufacturing (Sensors with Connectivity), Home systems, smart city,… etc. WSN systems are using data acquisition from various long-term industrial environments for IoT. Sensor interface device is acquiring sensor data from real time and makes a precious picture through WSN in IoT environment. This is a reason major manufactures pay attention to ongoing research on equipments in multi sensor acquisition interface [30].

2 Mobile Sensor Networks

MSN is a class of networks in which small devices capable of sensing their surroundings moved in a space over time to collaboratively monitor physical and environmental conditions [3, 29]. Worldwide researches conducted many investigations on MSNs because there could be a lot of current applications with adopted sensors. Potentially, the sensors have many capabilities such as environmental information sensing, locomotion, dead-reckoning and many more. The architecture of MSN can be broken down into node, server and client layer [5, 31]. The job of the node layer is to acquire most kinds of data as it is straight embedded into the current world. This layer also includes all the mobile and static sensor nodes. Server layer comprises a single board computer running a personal computer or server software. Any smart terminal can use at the client layer devices. Remote and local clients are also linked with the client layer. The detail is shown in Fig. 8. Mobility is an unrealistic or undesirable characteristic of a sensor node as it can address the objective challenges [3, 5, 32, 33]. References [3, 29, 34] analyzed the research issues on MSNs based on data management and communication. Our work is focused on communication issues which include coverage and localization issues.

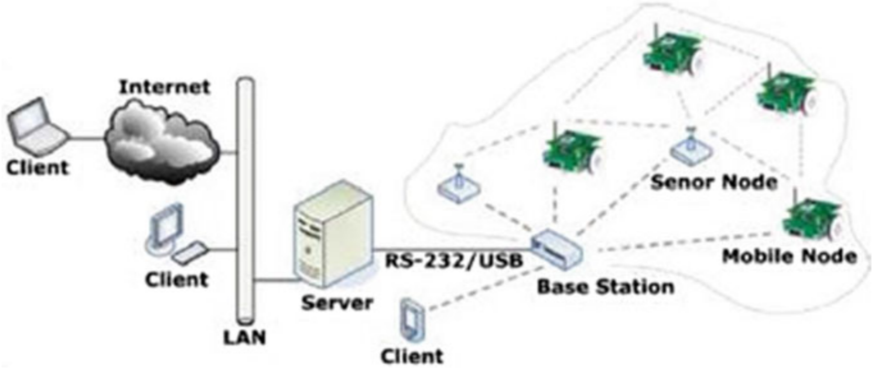

Fig. 8 The system architecture of a MSN [26]

2.1 Coverage

The degree of the quality of service is one of the methods to analyze the coverage. The quality of service can be also depended on upon the reach of a sensor network [35–37]. It can be seen that for all the applications of MSNs, network reach coverage is one of the most fundamental issues [38]. It decreases as a result of sensor failure and undesirable sensor deployment. Reference [39] defines coverage as the maintenance of spatial relationship, which adjusts to the exact local conditions to optimize the performances of some functions. Gage describes three coverage behavior types, which are blanket, barrier, and sweep. The aim of the blanket coverage is to bring about a fixed layout of nodes that minimizes the overall detection area. Likewise, the main goal of the barrier coverage is to reduce the chances of undiscovered penetration via the barrier. The concept of sweep coverage comes from robotics, which is less or more equivalent to the moving barrier. The lifetime of sensors is strongly affected by hardware defects, battery depletions and harsh external environments such as fire and the wind [3, 29]. In MSNs, already revealed territories get to be covered when sensors travel through and far from the zone. As a result, the already covered areas become uncovered. The zones covered by sensors change after some time, and more regions get to be secured at any rate once time goes [36, 40]. For robotic applications, Ref. [41] was a person to describe potential field techniques for tasks such as obstacle avoidance and local navigation. He introduced a similar concept 'Motor Schemas'. This uses the superposition of spatial vector fields to make behavior. Reference [42] used potential fields, but for the issue of deployment. He considered the issue of arranging mobile sensors in an anonymous environment where fields are constructed, i.e. each node is repelled by the other node. Also, throughout the environment as obstacles that force the network to spread [43]. In addition, the proposed potential field technique is distributable, scalable and requires not a prior map of the environment. In reference [44], for the uncovered areas by the sensor network, new nodes are always placed on the boundary of uncovered areas. The potential field technique is also able to find a suboptimal deployment solution and also makes sure that each node is in the line of sight with the other node. Thus, in order to increase the coverage [45], proposed algorithms needed to calculate the desired target positions where sensors should move and identify the coverage holes existing in the network. To find out the coverage holes [46] used the Voronoi diagram. It has designed three movement-assisted sensor deployment protocols. The concept called based) and Minimax. These concepts base on the principle of sensors moving from densely to sparsely deployed areas. A virtual force algorithm (VFA) was proposed by [46, 47] to increase the sensor field coverage by combining repulsive and attractive forces to determine randomly deployed virtual motion paths and sensor movements. The static sensors guide the mobile sensors to the position where the task is to occur and thus become aware of the arrival of tasks. References [45, 46] deal with the dynamic aspects of coverage in MSNs with characterized area coverage during a time interval, at specific time instants and the detection time of the randomly located target [48–53].

2.2 Localization

Much attention has been given to building mobile sensors lately. This has also led to the evolution of small-profile sensing devices capable of controlling their locomotion. Mobility has turned into an imperative territory of examination in mobile sensor systems. Mobility empowers sensor nodes to aim and locate dynamic situations such as vehicle movement, chemical clouds and packages [54, 55]. Localization is one of the main difficulties to achieve in mobile sensor nodes. Localization is the capacity of sensor nodes to calculate their current coordinates; and on mobile sensors, it is performed for navigational and tracking purposes. Thus, localization is needed in several areas such as health, military and others. The broad examination has been done so far on localization, and numerous positioning systems have been proposed to remove the need for GPS on each sensor node [56].

GPS is usually thought to be a decent answer for open air localization. Nonetheless, it is still costly and thus not utilized for a substantial number of gadgets in WSN. Some of the problems associated with GPS are as follows:

GPS does not work reliably in some situations: Because a GPS receiver needs line of sight to multiple satellites, its performance is not admirable in indoors. The receivers are accessible only for mote scale devices. GPS receivers are still expensive and undesirable for many applications [57]. The problem of using GPS is requiring a real environment to get measurements. Normal GPS shows 10–20 m of error at standard outdoor environments. This error can be minimized but should use a costly mechanism. Deploying large numbers of GPS in MSNs have possibilities and limits.

There [56] are two sorts of localization algorithms to be specific: centralized and distributed algorithms. Centralized location methods rely upon sensor nodes to send information to a base station. It is there that calculation is implemented in order to find out the position of every node. On the other hand, distributed algorithms need to not have a central base station and for determining their location. They relay with each node restricted data and information with nearby nodes [56]. References [3, 29] Localization algorithms in MWSNs are categorized into range-free, range and mobility-based methods. These methods vary in the information utilized for the idea of localization. Range-based methods employ range computations while range-free techniques operate only the content of messages [58–60]. Range-based methods also require costly hardware to measure the angle of signal arrival and the arrival period of the signal. As compared to range over free methods, these two methods are expensive because of their pricey hardware [3, 29]. While range free methods use local and hop count techniques for range-based approaches, these methods are very cost effective. Many localization algorithms have been proposed so far such as the elastic localization algorithm (ELA) and the mobile geographic distributed localization algorithm. Both of these algorithms assume non-limited storage in sensor nodes [3]. Two types of range-free algorithms introduced for the sensor networks. These are local and hop count techniques. The local technique based on high speed on a high-density seed. This method gives a chance to node to pick several seeds, which ever close. The hop count technique depends on a flooding network. In here, each node considers a location to calculate distance from the seeds' location. This method is correctly calculated if the seeds are static but in ad hoc situation, this is impossible. If the triangular regions need to separate environment use beaconing nodes, the approximate point-in-triangulation test (APIT) method is suitable. In this case, the grid algorithm calculates the maximum area and gives chance to a node to settle at the environment [61]. Hop count techniques propagate the location estimation throughout the network where the seed density is low. Figure 9 shows coordination, measurement and location estimation phase. Mobility-based method was to improve accuracy and precision of the localization method. Sequential Monte-Carlo Localization (SML) was proposed by [49] without additional hardware except for GPS [3]; and without decreasing the non-limited computational ability, many techniques using SML is also being proposed. In order to achieve accuracy in localization, researchers proposed many algorithms using the principles of Doppler shift and radio interferometry to achieve accuracy [3, 29]. References [54, 55] described the three phases typically used in localization, which are: coordination, measurement and position estimation.

To initiate the localization a group of nodes, coordinate first, a signal is then emitted by some nodes and then some property of the signal is observed by some other nodes. By transforming the signal measurements into position estimates, node position can then be determined. Reference [62] proposed three approaches which are Mobility Aware Dead Reckoning Driven (MADRD), Dynamic Velocity Monotonic (DVM) and Static Fixed Rate (SFR).

1. Mobility Aware Dead Reckoning Driven: This approach predicts future mobility with computes the mobility pattern of the sensors. The result of difference between the predicted mobility and expected mobility reaches the error threshold at the time the localization should be triggered [62].
2. Static Fixed Rate: This approach uses the performance of the protocol changes linked the mobility of sensors. In the fix time, every sensors appeal to their localization as the periodical way. If sensors are moving quickly, the glitch or laps will be high and Vs versa [63, 64].
3. Dynamic Velocity Monotonic: This is an adaptive protocol with the mobility of sensors localization called adaptively in DVM [65].

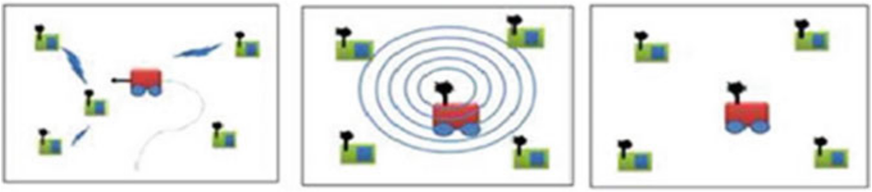

Fig. 9 Coordination, measurement and location estimation phase [26]

A new method called the Mobility Aware Interpolation (MAINT) was proposed by [65]. It estimates the current position of a mobile node with a better tradeoff with advantage of accuracy and energy consumption. This method uses interpolation to get best estimation in most cases.

In this section discusses a brief overview of the localization methods used by some researchers. Under mobile node localization, Ref. [66] proposed a system appropriate for the real environment in moving both anchors and unknown nodes. In this method used the history of anchor information to find out the current position. User's movement was module by the archived information; and for discovering new positions, movement models were also used. Reference [62] used in complex situations where anchors and nodes are mobile. The above three methods are used to resolve the localization problem. Once the sensor has at least two anchors in the neighborhood, the methods determine the exact position. Otherwise it gives a fairly accurate position and in that situation and it can compute the generated maximal error. The method also defines the intervals a node will invoke its localization. Reference [67] proposed a GPS free localization algorithm in MWSN's. To build the coordinate system, the proposed algorithm uses the distance between the nodes; also, nodes positions are computed in two dimensions. Based on Dead Reckoning, Refs. [63] and [64] put forward a series of methods for locating mobile sensors. Among all the forwarded methods, the Mobility Aware Dead Reckoning Driven finds the approximate the location of the sensor, instead of localizing the sensor each moment it manoeuvres. Inaccuracy in the approximated area is calculated every moment the localization is invoked and with time, the error in the estimation grows. Also, the next localization time is fixed depending on the value of this error. Rapid moving mobile sensors cause localization with a higher frequency for a particular degree of precision in position estimation. Instead of localizing the sensor [65] proposed a technique for guessing the location of a mobile sensor. His method gave higher precision results for a given cost of energy. Thus, the location of the sensor is only required when the sensor contains data, which is to be sent while an inactive sensor transmits neither data nor information. The most of it apply to the base because in order to decrease the complexity of computation in sensors. For solving the sets of equations [56] proposed the novel algorithm for MSN localization where they chose three nodes, which are neighbors to each other. Thus, if the answers are the equations are exclusive, it means that they are the points of the node; and for searching the position of the final node, a scan algorithm was also introduced called a Metric Average Localization Error (MALE) (which is the root-mean-square error of node locations divided by the total number of nodes) to evaluate the localization error.

3 Robotic Sensor Network Applications

Most of the issues encountered with traditional sensor networks may be addressed by integrating intelligent mobile robots directly into it. MRs present the way to investigate and interface with nature in dynamic and decentralized ways. Notwithstanding empowering mission capacities well past those provided by sensor networks allows these new systems of networked sensors and robots develop new answers to traditional problems such as localization and path finding [1]. Many problems in sensor networks can be solved by putting robotics into use. Problems such as node positioning and localization; identifying and responding to sensor failure; acting as a data mule and for nodes as a mobile battery charger is also possible. In addition, WSNs can take care of numerous issues in robotics such as navigation, localization mapping and sense [14]. There are many applications of WSNs in robotics such as advanced robotic sensing, multiple robot coordination, robot planning and navigation, and robot localization. Using WSNs helps emergency response robots to be conscious of conditions such as electromagnetic field monitoring, forest fire detection and others. These networks improve the sensing capability and can also help robots in finding the way to the area of interest. WSN's can be useful for organizing various robots and swarm robotics because the network can assist the swarm to share sensor data and track its members. To perform the coordinated tasks, WSNs send robots to different locations, and a swarm decides to depend on the localization of events; thus, enabling path planning and coordination for many robots to happen efficiently and optimally as well as directs the swarm members to the area of interest. In the localization part, there are many methods for localizing robots within a sensor network. Cameras have been put into use to identify the sensors mounted with infrared light to triangulate them in view of the space gotten from the pixel size. A modified SLAM algorithm has been utilized by some methods, which uses robots to localize themselves inside the surroundings the environment and later the compensation for SLAM sensor error is achieved by fusing the approximated area with the approximated area in the WSN based on Received Signal Strength Indicator (RSSI) triangulation [14]. References [68, 69] presented an intruder detection system, which uses both WSNs and MRs. In order to learn and detect intruders in a previously unknown environment, a sensor network uses an unsupervised fuzzy adaptive resonance theory (ART) neural network [70, 71].

In WSNs, robotics can also play a crucial role. They can be used for replacing broken nodes, repositioning nodes, recharging batteries and more. To increase the feasibility of WSNs, Ref. [72] used robots because they have actuation, but limited coverage in sensing while sensor networks lack actuation, but they can acquire data. In servicing WSN's, Ref. [73] examined the robot allotment for a task and its achievement. Problems were examined in its task allotment like multitasking and single-tasking robots in a network, and how to sort out their behavior to ideally benefit the system. The course in which a robot takes to administration hubs is analyzed in the robot errand satisfaction. The route in which a robot takes to service nodes is examined in the robot task fulfillment. To improve the robot localization [74] adapts sensor network models with information maps and then checks the capability of such maps to improve the localization. The node replacement application was created by [75] in which a robot would explore a sensor system based on RSSI from nearby nodes and sends a help signal if a mote begins to experience power shortage. It is through the network that the help signal would pass to guide the robot to change the node. On the other hand, robots can be used to recharge batteries as well. The problem of localization can also be solved using robots. They can be utilized to limit the nodes in the network and also in data aggregation. In a network, they can serve as data mules; data mules are robots that move around the sensor network to collect data from the nodes and then transport the collected data back to the sink node. It can also be used in performing aggregation operations on data [14, 27]. The utilization of multi-robot systems for moving sensors around the environment served as an answer, which has obtained appreciable attention and can provide some remarkable advantages [13]. When put into use, RSNs can be used for effective search and rescue, monitoring of electromagnetic fields and others. The search and rescue systems rapidly and precisely find casualties, model search and space; and with human respondents, it should maintain communication. Thus, in order to satisfy the main goal of a search and rescue system, the system ought to be capable of quickly and accurately trace casualties within the search space and should also be capable of handling a changing and likely unfriendly environment. For utilizing ad hoc networks [10, 11] presented an algorithmic framework consisting of a large number of robots and small, cheap, simple wireless sensors to perform proficient and robust target tracking. Without dependence on the magnetic compass or GPS localization service, they described a RSN for target tracking, focusing on algorithms, which are simple for information propagation and distributed decision making. They presented a robotic sensor network system that freely handles object tracking without component possessing localization capabilities. Their approach provides a way out with a little hardware hypothesis in relation to detection, localization, broadcast, memory or processing capacity while subject to a progressively evolving environment. Moreover, their framework adjusts actively to object to movement and inclusion/exclusion of network units. The network gradient algorithm grants a beneficial trade-off between power consumption and performance and requires a reasonable bandwidth [10]. The monitoring of electromagnetic fields is highly necessary for practice, particularly to ensure the safety of the general population living and working where these fields are present [76]. Reference [13] presented a specific RSN oriented to monitor EMFs. In this network, the activities of the system are being supervised by a coordinator computer while a number of explorers (MRs equipped with EMF sensors) navigate in the environment and perform EMF measurement tasks. The system architecture is hierarchical. The activities of the system are being supervised by a computer and to perform the EMF tasks a number of explorers (MRs equipped with EMF sensors navigate through the environment). The grid map of the environment is maintained by the system in which each cell can be either free or occupied by an obstacle, or by a robot. In addition, the map should also be known to the coordinator and the explorers. The environment is assumed to be static, and the map is used by the explorers to navigate in the environment and is also used by the coordinator to localize the EMF source [13, 77, 78].

4 IoT Concept and Applications

MIT added a new phrase "Internet of Things" to our dictionary at the start of 21st century. This phrase considers all the kind of good and services link with the Internet at the current world. E.g. Sensing, identification, communication, networking, and informatics devices and systems, and seamlessly connects. Figure 10 presents impressive details of the idea, and it was published in the Economist magazine in 2007.

Currently, IoT connects with human life through sensors and actuators, WSN and much more [80]. It is making huge differences in human life using direct applications. E.g. human body (checking on the baby, remember take medicine, track activity levels, monitor an aging family members, stay out doctor's office, smart walking sticks or smart canes [81] … etc.), home (heat home efficiency, control all house hold appliances, track dawn lost key, lighting home, avoid disasters, keep plants alive, discovery of public things [82] … etc.), City (keep city clean, Light Street more effectively, share findings, Intelligent Traffic Monitoring

Fig. 10 A Impressive description of the vision of IoT [79]

System [83] … etc.) Industry (maintaining and repairing, stop guessing, monitoring, keep track assets [84] … etc.) environment (monitor pollution levels, track water, help protect wildlife, get advanced warning… etc.) … etc.

5 Coverage for Multi-Robots

The use of multi-robots holds numerous advantages over a single robot system. Their potential of doing work is the way far better than that of a single robot system [85, 86]. Coverage for multi-robot systems is an important field and is vital for many tasks like search and rescue, intrusion detection, sensor deployment, harvesting and mine clearing and more [87]. To get the coverage, the robots must be capable of spotting obstacles in the environment, and they should also swap their insight about their surroundings and have a tool to assign to dole out the scope of errands among themselves [55, 88]. The problem of deploying a MSN into an environment was addressed in [89, 90] with the task of maximizing sensor coverage; and also [89, 90] proposed two behaviors based techniques for solving the 2D coverage problems using multiple robots. Informative and molecular are the techniques proposed for solving coverage problems and both of these techniques has the same architecture. When robots are with-in the sensor range of each other, the informative approach is to assign local identities to them. This approach allows robots to spread out in a coordinated manner. It has ephemeral identification with temporary local identities and the mutual local information. The molecular approach does not have local identities, and robots do not perform any direct communication. Instead, each robot moves in a direction without communicating with its neighbors. Robot can select its own direction without support immediate sensed neighbors. Reference [51] then compares these algorithms with another approach known as the basic approach, which only seeks to maximize each individual robot's sensor coverage [87]. Both these approaches perform significantly better than basic approach and with the addition of a few robots the coverage area quickly maximizes. References [91–93] proposed (StiCo) coverage algorithm for multi-robot systems. This algorithm is based on the principle of stigmergic (pheromone-type) coordination known from the ant societies. These were a group of robots that coordinated indirectly via ant-like stigmergic communication. This algorithm does not require any prior information about the environment and also no direct robot to robot communication is required. Similar kind of approach was used by [93] for coverage in multi-robots in which a robot deposits a pheromone, which can then be detected by other robots, these pheromones come up with a decay rate that allows the continuous coverage of an area via implicit coordination [55, 88]. For multi-robot coverage, Refs. [55, 88, 94] proposed Boustrophedon decomposition algorithm in which the robots are at first dispersed through space and each robot is distributed essentially with a limited zone to cover and is then disintegrated into cells with a static cell width. By using the adjacency graph, the broken down area is described, which is incrementally developed and shared among all robots with no limitation; and robot correspondence is accessible. By sharing information regularly, task selection protocol performance is improved. By planting laser reference points in the earth, the problem of localization in the hardware experiment is overthrown utilizing the laser range finder to localize the robots as this is the major problem for guaranteeing accurate and consistent coverage. Reference [95] addressed strength and productivity in a group of multi-robot coverage algorithms in view of the spanning-tree coverage of estimated cell disintegration.

6 Localization for Robot

In mobile robotics, localization is a key component [96]. The process of determining a robot's position within the environment is called localization or it is a process that takes a map as an input estimates the current position of the robot, a set of sensor readings and then outputs the robot's current posed as a new estimate [97]. There are numerous technologies accessible for robot localization including GPS, active/passive beacons, odometer (dead reckoning), sonar and others. For robot localization and map count, Ref. [98] presented a method for using data from a range based sonar sensor. The robots position is determined by an algorithm, which correlates a local map with a global map. As a result, there is no need for pre-insight of the surrounding which is assumed, thus it utilizes sensor data to build the complete map progressively. The algorithm approximates the robot's location by computing the location known as feasible poses where the normal view of the robot matches approximately to the observed range sensor data. The algorithm chooses the most matching one among the feasible poses [92, 98]. It requires the robot's orientation information to make sure that the algorithm identifies the feasible poses. For location information, Vassilis 2000 used dead reckoning as another source, when connected with range sensor-based localization algorithm it can produce an almost real-time estimated location. References [99, 100] introduced a Monte Carlo Localization (MCL) for mobile robot position estimation. They used the Monte Carlo type methods and then combined the pros of their previous work in which they used grid based Markov localization with the performance and precision of Kalman filter based method. The MCL technique can manage ambiguities and subsequently can comprehensively localize the robot when contrasted with their previous grid based technique. The MCL technique has altogether decreased memory necessities while fusing sensor estimations at a significantly higher rate. Based on the condensation algorithm the MCL method was proposed in [101]. It localizes the robot all around by utilizing scalar brightness estimation when given a visual guide of the roof. Sensor information of a low feature is used by these probabilistic methods, specifically in the 2D plane and needs the robot to move around for probabilities to step by step focalize toward a pack. The pose of the robots was also computed by some researchers based on the appearance. All encompassing picture based model for robot localization was used by [102]. With the depth and 3D planarity data, the panoramic model was developed while the image matching is achieved by taking into account the planar patches. References [55, 103] utilized all encompassing pictures for probabilistic appearance based robot localization. Markov localization is applied to hundreds of training images for extracting the 15-dimensional feature vectors. In urban environments, the problem of a mobile robot localization was forwarded by [104] by utilizing feature correspondence between pictures taken by a camera on the robot and a computer aided design program, or a comparable model of its surroundings. For localization of cars in urban environments, Refs. [17, 105, 106] used an inertial measurement unit and a sensor suite consists of four GPS antennas. Humanoid robots are getting popular as a research tool as they offer a new viewpoint compared to a wheeled vehicle. A lot of work has been done so far on the localization for humanoid robots. In Order to estimate the location of the robot [107] applied a vision based approach and then compared the current image to be previously recorded reference images. In the local environment of the humanoid [108, 109] detects objects with given colors and shapes and then determines its pose relative to these objects. With respect to a close object [107, 109] localizes the robot to track the 6D pose of a manually initialized object relative to the camera by applying a model-based approach [26].

7 Wireless Medical Sensor Network

WSN has opened many doors and potential to be utilized in medical applications, which are known as Wireless Medical Sensor Networks (WMSNs). In 21st century, the medical instruments were enhanced and embedded with this technology. WMSNs are rapidly used conduct medical diagnoses physiological condition of patients. E.g. temperature, heart rate, blood pressure, oxygen saturation … etc. This type of technology is faster transmitting data to remote location without the need for human interaction; a doctor could read and analyze data to make quick decisions of patience conditions. WMSNs are giving more and more benefits for modern healthcare as continuous and ubiquitous monitoring (see Fig. 11). The doctors and their patients' direct interactions are going shorter and reducing health care coast. WMSNs are direct human involvement and facilitate mobility and demand high data rates, with reliable communication and multiple recipients.

In current healthcare sector is using application with WMSNs for the following purposes.

1. Monitoring of patients
   E.g. Oslo University Hospital uses a biomedical wireless sensor network (BWSN) for their patients.
2. Home and elderly care
   E.g. this purpose is using ZigBee Wireless Sensor Networks (ZWSN) and robots integrated [110].
3. Collection clinical data [111].

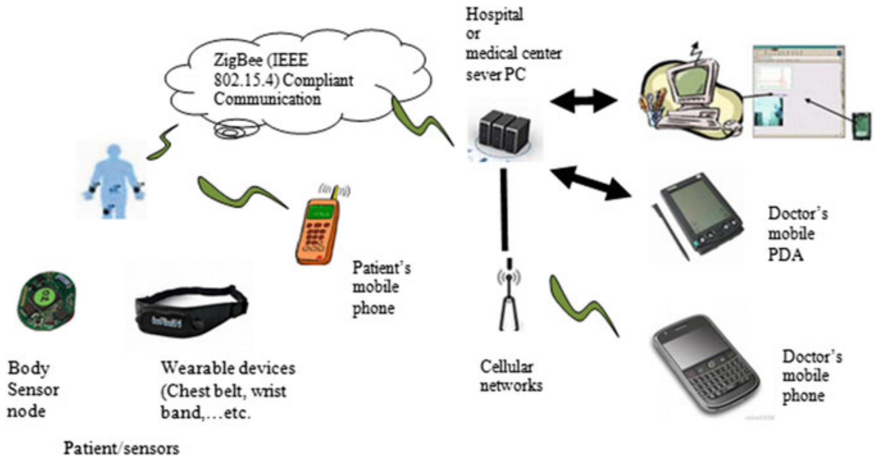

Fig. 11 Monitoring of patients in clinical data

8 The Challenges in the MSN and Their Limitations

Mainly MSN has two sets of challenges, which are hardware and environment. Without power is nothing running and same situation for the hardware as well. Another issue the power should be sufficient to run the system. If the system uses complex algorithms, then more power needs to complete the process. Based on these circumstances, the system should use low complexity algorithms, simple microcontrollers and radio. MSN should have used low cost materials to embed within the system. The major environmental components are topology and medium. The topology is going to vary in the circumstances. The medium is sharing too. The shared medium mandates that channel entry must be governed in some way. This issue is overcome by a medium access control (MAC) scheme. Designers are always using code division multiple access (CDMA), frequency divisions multiple access (FDMA) or carrier sense multiple access (CSMA) for better solutions. The changing topology of the network initiates from the nodes' mobilization. The result of this is giving unstable multi hop paths from the sensors.

MSNs are a unique network type, and they will require specific solutions to the research problems they have. The major issues that affect the design and performance of a MSN include MAC and routing protocols, localization techniques, security, physical layer transmission, resource management, quality of service and many more.

Current research and development is used much more mobile sensors to make new applications in MSNs. E.g. patrol defense, map productions, disaster managements and more. The major difference of WSNs and MSNs is static vs mobile sensors. Sensors are moving all the time. Sensor mobility makes a great impact on most existing protocols of WSNs. It could find three main challenges in MSNs include challenges for localization coverage services, data collection. MSN could be divided two types as follows controllable sensors and uncontrollable sensors. Sensor mobility is giving a lot of challenges in MSNs but it is giving good opportunities to support in improving many protocols such as localization, coverage and data collection [112].

9 Conclusion

The current trend is widely going with sensor network technology to solve the real-world problems. This paper gives a comprehensive review of sensor network working with a robotic paradigm. The sensor networking system is a form of capturing data from the source and transferring it into robotic devices to activate the required functions.

Focusing on WSNs, the paper describes the architecture of how sensor nodes are manipulated to retrieve and process data through wireless communication. Furthermore, it emphasizes the advantages of underwater WSN such as the system reusability and coverage whilst neglecting the use of wires for connections as underground wireless networks are installed via acoustic communications compare to ground based networks.

Prior studies have shown that MSN consists of capabilities such as locomotion, environmental information sensing and dead-reckoning to name a few. The design of MSN describes the use nodes, serves and client layers describing the complexity as opposed to simple WSN. MSN faces objective challenges due to unreliable characteristics such as communication and data management. The studies conducted on this paper particularly focus on the communication issues split into problems base on coverage and localization. MSN coverage issues are simply described as a degree of the quality of service; fundamental issue being the network reach coverage issues as it decreases due to sensor failure or undesirable sensor deployment. Speaking of localization issues, this paper focuses on the difficulties caused to sensor nodes due to errors introduce when calculating coordinates. GPS is a typical method of utilizing open air localization. However, studies show that GPS have major vulnerabilities as it needs the constant sight of multiple satellites thus indoor functionality of GPS is hindered greatly. As an alternative for GPS, this paper discusses two methods of localization algorithms as well as improvements that can be done to increase the reliability of localization.

Further studies were conducted in RSN application as a method of utilizing WSN. RSN is intelligent MRs, which is an improvement into a traditional sensor network. RSN studies have shown that it can provide answers to issues face by traditional sensor network such as localization and path finding by integrating to utilization of robots. A great example of RSN's ability compares to WSN is where robotics technology has the ability to replace broken nodes, repositioning nodes, recharging batteries, etc. Publication [69–71] shows the amazing capabilities of RSN such as battery recharge and mapping information to improve localization as opposed to WSN. Furthermore, multi-robot systems prove to be an improvement to the RSN as it provides further advantages. Some of the applications of RSN are they can be used for effective search and rescue, monitoring of electromagnetic fields and others. Further studies were conducted on RSN utilizing MRs equipped with EMF sensors to ensure all aspects RSN application is thoroughly described. As mentioned earlier, multi- robot is advantages in many ways compare to a single robot ensuring higher potential to maximize an area of coverage at a time. The studies described further into issues faced by RNS such as sensor coverage. Techniques and algorithms such as informative and molecular were investigated as solutions for coverage problems. Another issue covered in this study is the localization for robots as it is a key component in determining the robot's position within the localized environment; it is a process of determining the position of the robot by taking a map as an input. Further studies described techniques and algorithms relevant to improve the localization of the robot.

In summary, this paper broadly discusses MSN and WSN functions to think about future directions with robotic and WSN. It is a green light to combine new proactive based solution for the current issues which are discussed in this paper; it also provides examples of how sensor networking can lead to a further modernized future in the sensor technology field. These technologies could be adaptive to the medical instruments, so that they can be successfully integrated as part of our healthcare monitoring system to upgrade healthcare management.

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