On the Way to WSN Collaboration with Robots

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Abstract: Over the past years Wireless Sensor Networks (WSNs) have been applied to a range of fields from military applications to medical and multimedia ones. Meanwhile, robots have managed to prove their necessity in cases where actuation is needed, therefore, achieving high accuracy tasks indeed. New prospects of collaboration for these two *avant-garde* technologies have already emerged and have been put into practice. In this paper a min-review of this collaboration and the prospects are analysed and discussed.

1 INTRODUCTION

In the past decades, Wireless Sensor Networks (WSNs) have been tested on a large number of scenarios and applications and hold the focus of research worldwide. WSNs consist of sensor nodes, with embedded microprocessor, and form a smart network, using wireless technologies (Akyildiz et al, 2002). WSNs represent a significant improvement over traditional wired data acquision networks since they can collect measurements from inaccessible areas of interest. These areas can vary from a battle field to an area in the middle of a jungle or inhabited areas. WSNs can deliver physical quantity measurements successfully and with very low power demands since they run on common batteries and they do not need to be replaced for several years.

In addition the advantages of autonomous robots have already been proved. An autonomous robot can be considered as a mechanical artificial entity that is able to perform tasks without human intervention, and regardless of its workplace. Regarding the way in which robots approach the area of interest we can categorize them as ground robots, aerial robots (drones or Unmanned Aerial Vehicles- UAVs) or underwater robots.

From the aspect of applications that have been developed both WSN and robots can be found in very divergent fields. For example WSNs applications can be deployed for health and medical diagnosis, multimedia and video streaming, industrial monitoring, military, security and border surveillance applications.

Since the evolution of robots has reached the point of developing applications with acceptable accuracy, researchers are focusing their interest on developing more complex robotic systems that can be integrated to other technologies such as WSN. Collaborative WSN and Robotic systems can be a very promising perspective. In this paper a min-review of this collaboration and its prospects are analysed and discussed.

2 WSN COLLABORATION WITH ROBOTS

Recently multimodal applications which adopt collaborations of different but supplementary technologies are gaining ground. An aspect of this concept explores the idea of using autonomous (or semi-autonomous) agents (sensor nodes and robots) in order to meet the requirements with a potential reduction of cost and an increase in the overall reliability (Agmon et al, 2008). Under this scope, in this paragraph a literature review of WSN-Robot collaboration defines the context and the main areas of collaboration.

1. Network deployment, maintenance and connectivity repair

One of the most compelling WSN/Robot scenarios is to let the Robots deploy and manage the sensors of the network in the field. For example in (LaMArca et al, 2002), the PlantCare project is presented, which is an autonomous indoor system for managing the health of houseplants. The authors

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demonstrate how a single robot as a central system administrator can be used to deploy and calibrate sensors, detect and react to sensor failure, deliver power to sensors, and maintain the overall health of the WSN.

In addition, in ((Corke et al., 2004a), (Corke et al., 2004b)) a sensor network deployment method along with a repairing network connectivity algorithm with the use of UAVs is presented. The authors describe how the deployment algorithm of the nodes is based on predetermined placement positions. Thus, when the UAV is within a radius of 1.5 meters from the deployment location a “drop” command is issued to deploy the motes.

Another example of multi-robot systems that include sensor nodes and aerial or ground robots networked together is cited in (Suzuki et al, 2008). The authors present a sensor network deployment method by the use of autonomous aerial vehicles. The deployment algorithm is based on a given desired network topology for the deployed network and a deployment scale. The resulting locations are the (x, y, z) coordinates where the sensors need to be deployed. Subsequently, these coordinates are given as way-points to the helicopter controller. The helicopter then flies to each of these way-points autonomously, hovers over each one of them and then deploys a sensor at the specified location.

A novel approach of using autonomous mobile robots to deploy a WSN in an unknown zone is cited in (Tuna et al., 2014). During the deployment of WSN, multiple mobile robots perform cooperative Simultaneous Localization and Mapping (SLAM) and communicate over the WSN. However, the system needs to be designed carefully considering battery life of nodes, detection range of PIR sensors, communication range and performance of wireless sensors, mobile robot exploration strategies and cooperative SLAM.

Another issue that network deployment methods must address is the problem of best network area coverage, without sensing holes, when redundant sensors are present. A solution to this problem is given in (Li et al., 2013) where the authors propose a family of localized robot-assisted sensor relocation algorithms. Robots move within the network to discover sensing holes and redundant sensors by local communication, and transfer the discovered redundant sensors to the encountered sensing hole positions.

Likewise in (Erman et al, 2008), the authors present an architecture which integrates WSN and UAVs for disaster response setting, and provides facilities for event detection, autonomous network rearrangement and repair by UAVs. In particular the connectivity repair algorithm is based on the fact that every node that broadcasts a signal ends up with a group indicator. Otherwise the node does not have an indicator and the point ends up blind. New sensor-deployment is needed whenever the helicopter observes that there are gaps in the grid of sensors.

Considering that the sensor nodes of a WSN have heavy workloads and their energy is easily exhausted in (Sheu et al., 2008) a WSN node replacement application is presented. Precisely, a group of smart mobile robots navigate towards low-energy fixed sensor nodes and replace them automatically with new ones. This node replacement strategy can be used in sensor networks consisting of toughly recharged battery-powered sensor nodes.

2. Life extension of the WSN

Because of the fact that the WSN in most applications needs to manage a large amount of data acquired by the sensor measurements, it requires large amounts of energy. This fact induces significant system constraints. To answer this problem in (Rahimi et al, 2003) the lifetime extension is held with the introduction of mobility of the nodes of the WSN. As a result, a small percentage of nodes is converted to autonomously mobile nodes allowing them to engage the energy hunting mechanism. Thus, the mobile nodes move in search of energy, recharge, and deliver energy to immobile, energy – depleted nodes.

An alternative approach is cited in (Tong et al, 2011) where the Node Replacement and Reclamation (NRR) strategy is proposed to meet the challenges of designing an efficient WSN for long-term tasks. According to this strategy a mobile robot or a human labor called mobile repairman (MR) periodically traverses the sensor network, reclaims nodes with little or no power supply, replaces them with fully charged ones, and brings the reclaimed nodes back to the energy station for recharging.

Additionally, in (Tekdas et al., 2009) a system in which the measurements of the sensor network are mulled by robots is introduced. A proof of concept implementation demonstrates that this approach significantly increases the lifetime of the system by conserving energy that the sensing nodes would otherwise consume for communication.

3. Collect and aggregate data from WSN

In (Chen et al., 2011) the authors investigate the navigation strategy of a robot in order to collect the data of the sensor nodes. The data gathering can be scheduled based on time and location by the use of three scheduling strategies: time based, location based, and dynamic moving based. The strategies are simulated with ns-2 simulator and showed improved data-collecting performance in cases of partitioned/islanded WSNs. Another example is cited in (Vasilescu et al., 2005) where a robotic submarine serves as a mobile base station to collect information from a network of underwater sensors (AquaFleck).

4. Closer and more accurate monitoring

There are applications in which the WSN measurements have low accuracy because of the topology or the range of the sensors. In these cases, the collaboration with robots can achieve a more reliable system. For example in (Freeman and Simi, 2011), the application of a hybrid WSN assisted by Robots for the detection of explosives in a given indoor environment is featured. The WSN consists of static sensor nodes and nodes embedded in mobile robots for close monitoring.

5. Robot navigation and path planning

All the previous categories focus on WSN assistance by robots. On the other hand, the operation of robots can be enhanced by the use of a WSN. For example in (Freeman and Simi, 2011), the WSN guiding of the mobile robots in order to find their path to the desired static node is presented. An alternative is shown in (Enriquez, 2013) where a system for mobile robot navigation around static obstacles with the use of RFIDs is given. This system uses an RFID system, for precise navigation around obstacles.

On the contrary in (Batalin et al., 2004) the authors describe an algorithm for robot navigation by the use of sensor nodes as signposts for the robot to follow, thus obviating the need for a map or localization on the part of the robot. Navigation directions are computed within the network (not on the robot) by applying value iteration.

In (Cheng, 2012), a novel approach to mini-UAV localization in a WSN is presented. According to the method firstly the environmental adaptive RSS parameters are employed given from the WSN in order to estimate the range estimation model. Afterwards a particle swarm optimization-based method is proposed to solve the established objective function.

6. Enhancing Operations / Delivering a task

Thereafter representative examples of WSN collaboration with robots are given. For example in (Merino et al., 2011) a human tracking system for person guidance with WSN, fixed and robot onboard cameras is presented. The information from the aforementioned sources is fused in order to respond to a guidance request.

In (Herrero and Martínez, 2011) a system for mobile robot odometry relying on a WSN/Robot system is proposed. The robot emits RF and ultrasound signals at the same time which are captured by the nodes of the WSN. These nodes compute their distance from the robot and transmit it back to the robot. The robot computes its location based on these measurements by rejecting the inaccurate ones.

In (Marantos et al., 2008) a method for mobile robot localization in WSNs is presented. The proposed method makes use of fuzzy logic for modeling and dealing with uncertain (noisy and unreliable) information from measurements of the Radio Frequency Signal Strength of the nodes. The method succeeds in handling highly uncertain situations that are difficult to manage by well-known localization methods such as the Monte Carlo method.

In (Costa et al., 2012) the authors describe an architecture based on UAVs which can be employed to implement a control loop for agricultural applications, where UAVs are responsible for spraying chemicals on crops. The process of applying the chemicals is controlled by means of the feedback obtained from the wireless sensor network (WSN) deployed on the crop field.

Many security applications have also been developed. Amongst the latest systems, there are the collaborative WSN and Robot security systems which are equipped with appropriate sensors and deployed in a variety of environments and topologies. For example, in (Li and Parker, 2008), the authors present an indoor intruder detection system that uses a WSN and a ground mobile robot. Upon the detection of an intruder, the mobile robot travels to the position where the intruder is detected in order to investigate.

Another example is given in (Lin et al., 2008) where an intruder detection system which consists of zigbee sensor modules that detect intruders and abnormal conditions is presented. The sensor nodes transmit intrusion alarm to the monitoring center. If any possible intruder is detected, the robot moves to that location autonomously and transmits images to remote mobile devices of security guards, in order to determine and respond to the situation in real time.

In addition in (Cho et al., 2006) the researchers introduce a collaborative WSN and ground mobile robots collaboration for indoors navigation at a construction site (warehouses, office buildings, manufacturing facilities) providing security and safety.

Another home security application is cited in (Tian et al., 2009) where a WSN and ground robot household security system is proposed. The system is composed of the robot node and the sensor nodes of the WSN for monitoring temperature, humidity, gas leaking, fire and housebreaking. The robot node undertakes the task of collecting and processing sensor data from the WSN, and also acts as the interface of the system with the other users.

Figure 1 shows the Comparison of key design issues for collaborative WSN/Robot systems in experimental works as it is evident from the literature.

3 OPEN ISSUES

The WSN collaboration with Robots is a very promising perspective, indeed. However, this collaboration has already shown its drawbacks. At first, the effort of organizing a team of autonomous agents to best patrol the area is computationally expensive, even for relatively small problem instances (While et al, 2013).

In addition, from the literature review a number of open issues to be investigated are revealed considering the data gathering and processing. These processes consume large amounts of the system's energy; therefore, the investigation of new methods for energy-efficient data gathering protocols is necessary. These protocols must be oriented towards forwarding sensing data within a specified latency constraint without sacrificing energy efficiency and thus achieving longer life of batteries for WSN. Another issue is the investigation of the overall accuracy of the systems in high noise conditions. For example the infrared and ultrasonic sensors of robots often do not recognize thin-legged chairs- which make robots get stuck in one place while wheels are still running- or reflectivity of the floor surface, which often deludes robots. Another solution is to leverage techniques developed in the robotics community to build spatial models from noisy sensor information and to keep track of complex dynamic systems.

Moreover, an issue that must be successfully addressed is false alarms. The increased rates of false alarms not only affect the accuracy of the system but also the overall energy consumption of the system and make it very energy intensive. An idea that could be explored is the continuously distributed calibration of the sensed quantity in order not to be sent for further processing unreliable data.

In general terms what is missing from the literature is to conduct long-term experiments. In most of the cases the experimental test-beds are conducted only to execute a series of experiments for different conditions. This prevents the system from being simulated in real work conditions and from bringing all the points for improvement to the surface.

4 CONCLUSIONS

While WSNs are perfect in monitoring the environment and in detecting any kind of abnormalities, they are very limited in reacting to what they detect. Robots, on the other hand, can reduce the workload and enhance the capabilities of WSN. Some of the important benefits that robots can provide to WSNs are sensor deployment, calibration, power management, closer monitoring and active reaction to the deviations of the system. This robot assistance advocates the augmentation of the robots' communication and interaction capabilities with those afforded by the WSN and services embedded within the environment. Meanwhile WSNs can contribute to more accurate localization, navigation and path planning of the robots. In this paper a min-review of this collaboration and its prospects are analysed and discussed.

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APPENDIX

Work	*Sensor platform*	*Nodes*	*Sensors used in WSN*	*Robots*	*Type of Robots*		*Robots' sensors*	*Type of collaboration*	*Indoor / Outdoor evaluation*
LaMArca et al., 2002	Mica / TinyOS	N/A	Photoresistor, thermistor, irrometer, current	1	On ground	Pioneer 2-DX	Laser scanner, recharging, environmental	Bi-directional	Indoors
Corke et al. 2004a	Mica / Tiny OS	50	N/A	1	Aerial	USC's autonomous helocopter	GPS	Bi-directional	Outdoors
Tuna et al. , 2014	N/A	N/A	PIR, light, acoustic	4	On ground	N/A	laser and ultrasonic range finders, cameras, infrared, bumber	WSN →Robot	Outdoors
Freeman and Simi 2011	MicaZ /TinyOS	N/A	Environmental and ultra sound	1	On ground	Pololu 1060	Gyro, accelerometer	Bi-directional	Indoors
Batalin et al., 2003	Mica 2 /TinyOS	9	-	1	On ground	Pioneer 2DX	-	WSN →Robot	-
Enriquez, 2013	MICAz	N/As	No extra sensors	1	On ground	Pioneer 3-DX (Chamuko),	RFID reader	WSNc and RFID system → Robot	Indoors
Li and Parker, 2008	Crossbow motes	N/A	Light, sound	1	On ground	Pioneer 3-2DX	Camera	WSN →Robot	Indoors
Sheu et al., 2008	MICA2, MICA2DOT / TinyOS	12	-	3	On ground	Custom	-	WSN →Robot	Indoors
Caballero et al., 2008	Mica2 / TinyOS	25	-	1	On ground	Romeo (4-wheel)	DGPS, gyroscope, compass	WSN →Robot	Outdoors
Merino et al., 2011	Mica2 /TinyOS	30	-	1	On ground	Romeo (4-wheel)	Cameras, laser range-finders, localization, navigation and perception	WSN and camera network →Robot	Outdoors
Herrero and Martínez, 2011	Custom (IEEE 802.15.4) /Contiki OS	N/A	N/A	1	On ground	UPAT's Rover	Compass, encoders	WSN→Robots	Indoors
Cho et al., 2006	Ultra Wide Band sensors	N/A	Motion, sound, light, temperature, smoke, humidity	5	On ground	N/A	Encoders, infrared	WSN→Robot	Indoors
Mester, 2009,	iMote2 / TinyOS	N/A	Accelerometer,analog and digital temperature, humidity, light	1	On ground	Pioneer P3-DX	N/A	WSN→Robot	N/A
Tian and Geng, 2009	Custom (Zigbee)	N/A	Temperature, humidity, infrared, smoke, gas	1	On ground	Custom	N/A	WSN→Robot	Indoors
Qiao et al., 2013	Custom	N/A	Camera, PIR, temperature, light	N/A	On ground	Transmote module	Camera. PIR, temperature, light	Bi-directional	Indoors
Lin et al., 2008	Custom (Zigbee)	3	Pyro, microphone, accelerometer	1	On ground	UBOT	Encoders, ultrasonic, infrared, camera	WSN→Robot	Indoors

Figure 1: Comparison of key design issues for collaborative WSN and robot systems in experimental works.