Low-cost robotic sensor networks platform for air quality monitoring

Siti Nurmaini
Robotic and Control Research Lab, Computer Science Faculty, Sriwijaya University.
Jl. Raya-Palembang Prabumulih KM 32 Indralaya, Ogan Ilir Sumatera Selatan –Indonesia, email: siti_nurmaini@unsri.ac.id

Abstract

Building robotic sensor networks (RSNs) for air quality monitoring application is a challenging frontier for robotic research. Such systems must operate for extended periods of time in unstructured and complex domains. The implementation requires addressing numerous issues at the systems level such as energy efficiency, planning, and controlling robots' trajectories for achieving robust operation. Hence developing new algorithms is needed to overcome various issues in sensor networks, multi-robots, and multi-sensors system. In this paper, initial experiments towards air quality monitoring using RSNs are proposed. Multi low-cost mobile robots were set up as prototype RSNs for measuring temperature, humidity, and CO/CO_2 gas concentration in urban environments.

Keywords: robotic, sensor networks, air quality, monitoring

1 Introduction

Air quality monitoring of urban environments is very important to raise awareness about the environment. Nowadays, many monitoring process of air quality in the city is conducted by stationary monitoring systems which use static sensor networks (SNs) that is spread in several locations [1]. These systems can monitor the level of air pollution and record the environmental situations detaining a wide scale. The advantages of this technology have been described in many applications and literatures. In habitat monitoring applications, SNs are deployed to collect air quality parameters in terms of humidity and temperature data [2]. In

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military surveillance missions, SNs can be rapidly developed to obtain confidential data from the target safely in large location [3]. In environmental monitoring, SNs are deployed to detect what is happening in it [4]. However, they are very limited in reacting to what they detect. On the other hand, if a large area is covered sparsely, the networks may not be connected.

SNs are a collection of sensor node with a communications system which is easily deployable for monitoring physical processes and recording environmental situations at several locations. Commonly monitored environmental parameters are temperature, humidity, pressure, wind direction and speed, gas and chemical concentrations, and pollutant levels. They consist of a detection system with low-cost, low-power, working in a variety of systems and can be placed in various environmental situations. SNs system is equipped with microcontroller, multi-sensor systems, gate away, transceiver, and receiver. Therefore, SNs have not only detection systems but they can communicate with each other for data processing.

Recently, there has been a great deal of research on using mobility in SNs for assisting nodes deployment in environmental monitoring [5–8]. In some situation, many environments inaccessible and dangerous for humans, due to pollutants accumulation in confined areas because of some weather conditions and environmental situations, which produce local pollution. In such environment, SNs with mobile platform can make a significant contribution. Therefore, mobility has become important because SNs can move to several environments in range of detection.

Integration of distributed robotics and SNs produce mobile sensor networks [5, 9,10]. They can independently monitor a variety of environments, and it can collect the environmental data. Robots can act as interfaces to SNs solutions and also enhance them by providing important benefits such as sensor deployment, calibration, failure detection, and power management [5]. However, many environments are difficult to reach by the large robot due to the limited space and rugged terrain. Therefore, enabling integrated multi robots and SNs applications becomes extended challenge for both robotics and SNs research particularly, with the difficulty of understanding their unknown environment. This paper presents SNs with mobile platform introduced as a prototype robotic sensor networks (RSNs) that implements the air quality monitoring in aspect pollution monitoring. In the future, we will make RSNs for exploring hazardous environments in terms of monitoring the gas concentration in pollution conditions.

2 Low-cost robotics sensor networks

Currently, SNs have been employed for monitoring several environment and surveillance scheme. However, only a few researchers investigate how to utilize mobility for reducing the cost of monitoring and if the sensing locations are far apart. Integration mobility in SN has been intensively studied in Refs. [14–16]. Other alternative is to use multi-mobile robots as data mules to gather the data from the sensors. This approach indicates two major benefits in which the energy requirement for communication is minimized and the robots can collect additional data along the way.

RSNs can act as mobile nodes because they will be equipped with a variety of communication systems and detection systems. In this case, the robots can change the range of detection and SNs topology according to environmental conditions and it can quickly adapt to changing environmental circumstances. RSNs are expected to produce robustness when compared to static SNs when sensing environments in wide ranges. Some research groups have begun to design RSNs and have made some prototypes [9–12].

Nowadays, innovation robotic research progress makes it possible to produce such RSNs in low cost and smaller sizes [13–16]. For such RSNs, reaching a common goal is not an easy task. This is due to the constraints that come when low-cost sensors are used with small ranges detection. The RSNs design must produce minimal computational algorithm with precise locomotion. Low-cost robots typically lack in the ability to communicate over long distances for finding global information such as the position and heading. Thus, developing control algorithms for low-cost RSNs raises interesting work. This paper describes prototype design of low-cost RSNs platform for air quality monitoring in terms of temperature, humidity, and concentration of CO/CO_2. The RSNs node can communicate with static node and have the ability to move in a variety of environments. The RSNs will visit the location of each static node, take their measurements, and sends the data to the base station to be collected. In order to control the RSNs according to the desired performance in urban environment, interval fuzzy type-2 and particle swarm optimization techniques are used for RSNs navigation.

3 Prototype system design

In our work, low-cost problem is solved by using inexpensive sensors and low-cost microcontroller which can perform the minimum tasks required to gather air quality information. An initial experiment is conducted in order to find the RSNs performance. In this section, the design of air quality monitoring robots platform including the architecture RSNs selection and set-up of sensors for measuring air quality parameter is presented.

3.1 Robotic sensor networks design

The complete system architecture of RSNs includes a group of static nodes and mobile nodes, data base node, communication systems, client's node and infrastructure as shown in Figure 1. Each node in RSNs has detection ability, especially mobile nodes in fact an enhanced sensor node using robotics technology in detection system. A data base node is used for data processing and act as base station to connect the static sensor nodes and mobile sensor nodes by using Internet platform.

Currently, the proposed architecture for experiment containing three devices: static nodes, mobile nodes, and data base system includes a single board computer as a server. All nodes consist of all the sensor nodes. In the future, the client nodes are added in the experimental such as smart phones, mobile phones, and PC tablets. Communication between the data base system and the client nodes are conducted by using Internet platform.

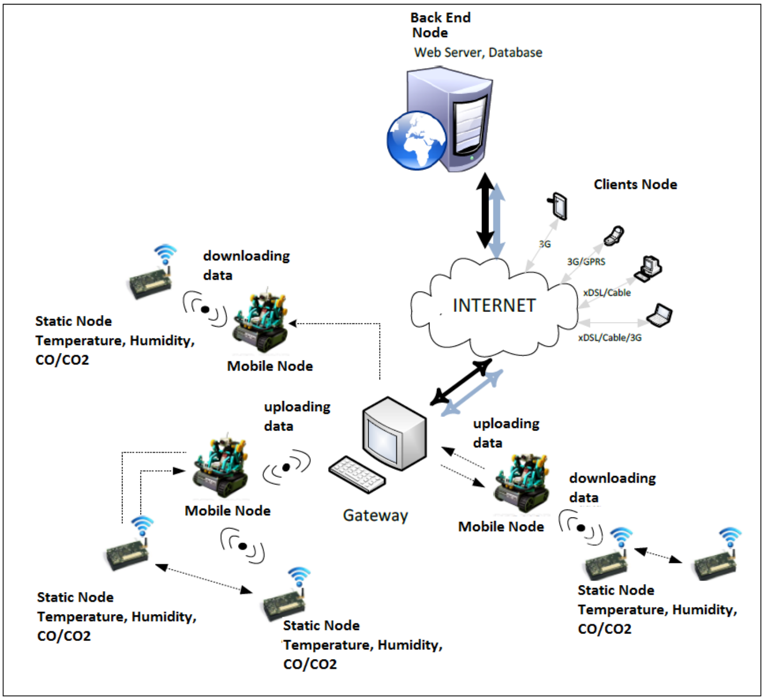

Figure 1: RSNs architecture.

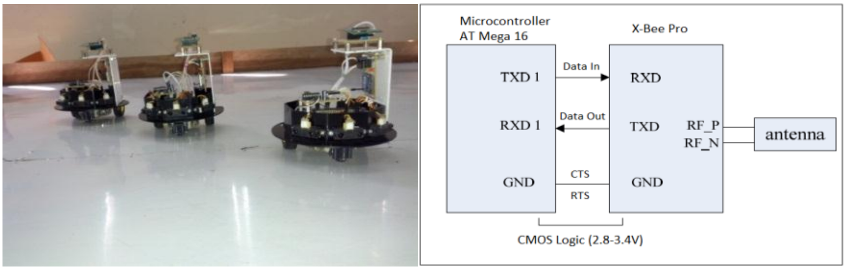

Figure 2: RSNs prototype. (a) Mobile node. (b) Mobile node platform.

In this work, a new robot platform is developed for the purpose of measuring environmental parameters by using the RSNs. The mobile sensor node is perhaps the low cost of mobile robot [17]. A prototype of the low-cost RSNs are designed and implemented by following mobile robots as shown in Figure 2. In the future, various locomotion and control modules are added to the RSNs architecture, therefore they can move everywhere.

The RSNs architecture have lithium polymer batteries, low-cost infra red sensors, TGS 2600 gas sensor, simple actuator, and low-cost microcontroller AT Mega 16 as shown in Figure 2(a). Our design uses expandable processing board and sensor board with multi-sensing capabilities, which provides a flexible basis for changing experimental needs. RSNs node uses X-Bee-Pro OEM/ZigBee. This is radio frequency transceiver and receiver serves on full duplex communication at frequency IEEE 802.15.4 2.4 GHz.

Radio frequency transceiver is a module which is composed of RF receivers and RF transmitter with UART asynchronous serial interface system. Mobile node communication use UART 1 interface circuit to connect the Zig-Bee module and AT Mega 16 is shown in Figure 2(b).

3.2 Navigation algorithm

In this work, simple cooperation algorithm between Interval Type-2 Fuzzy Logic and Particle Swarm Optimization (IT2FL-PSO) is implemented in the RSNs navigation strategies for robust implementation. In this strategy, IT2FL algorithm is used for navigating in dynamic environment while PSO algorithm for finding the source of target. Signal from static node is a direct indication of a certain data presence such as temperature, humidity, and CO/CO_2 concentration.

In general, PSO formula can describe as follows [18]:

$$v_i^{k+1} = v_i^k * w_i + c_1 * rand * \left(p_i^k - x_i^k\right) + c_2 * rand * \left(p_g^k - x_i^k\right) \tag{1}$$

In simple form, PSO formula in Eq. (1) can be seen as

$$v_i^{k+1} = v_i^k * \underbrace{w_i + c_1 * rand * (0)}_{\text{Cognitive}} + \underbrace{c_2 * rand * \left(p_g^k - x_i^k\right)}_{\text{Social}} \tag{2}$$

One advantage of PSO algorithm is a very simple algorithm and it can be implemented in just a few lines of code. This algorithm also requires only primitive mathematical operations and it's computationally not large in terms of speed of processing and memory utilization.

While interval type-2 fuzzy logic system (IT2FLS) is constructed using interval type-2 fuzzy sets to discriminate them from type-1 fuzzy logic system (T1FLS). Interval means that the input/output domains are characterized by interval type-2 fuzzy sets [19]. Triangular membership function with uncertain mean is represented in each fuzzy input *k* and each rule bases *i*. In this work, the type-2 singlet on fuzzifier is used to simplify the calculation process and the defuzzification layer approximates the type-reduced set using the Karnik-Mendel algorithm.

4 Experimental

In this work, RSNs will perform predetermined tasks and they will depend on the network infrastructure in an unknown environment. Communication systems between mobile node and static node based on two directions from point to multipoint, the Robotic nodes must be able to download environmental data from static node and send such data to data base node. Hence, X-Bee is used as a

Table 1: X-Bee Communication Results.

No	Transmitter	Receiver 1	Receiver 2	Results
1	50	50	50	Right
2	100	100	100	Right
3	150	150	150	Right
4	200	200	200	Right
5	260	4	4	Wrong

Table 2: PWM Duty Cycle Results.

Duty Cycle PWM (%)	Hexa Decimal Value
0	00_H
10	$1A_H$
25	40_H
30	$4D_H$
50	80_H
75	BF_H
80	CC_H
90	$E6_H$
100	FF_H

means of communication between static node and robotics node. In the implementation, process of X-Bee communication system is done by testing the sending and receiving of data that can be seen in Table 1. Transmission data of X-Bee system must use 8 bits. X-Bee communication system test results are shown in Table 1. The measurement error is 0% when data transmission is 50, 100, 150, and 200, respectively. When the transmitter data is 260, the communication system produce the data error to 100%, due to X-Bee performs only 8 bits data transmission, while the 260 has exceeded the data 8 bits of data (255).

For RSNs movement experiment, actuators performance tests are conducted by regulating the pulse width modulation (PWM) of direct current (DC) motor for producing duty cycle in hexadecimal value. Based on the data shown in Table 2, the smallest PWM duty cycle data is 0% or 00H, while the biggest PWM duty cycle data is 100% or FFh. The result shows that DC motor speed can be controlled by adjusting the PWM duty cycle percentage.

In the simulation is given three inputs from proximity infra red sensors such as S1 is 25 cm, S2 is 30 cm, and S3 is 35 cm respectively. The value of PWM output for left motor is 80 % and right motor is 70%. Based on the simulations that have been done, it can be concluded that the proposed algorithm produces according to desired value.

5 Conclusion and future works

Mobile sensor nodes based robotic networks architecture has been proposed in this paper. Multiple mobile robots were set up as robotic sensor nodes (RSNs) as prototype of pollution monitoring robots and initial results of experiments towards air quality monitoring with mobile platform is presented. In the future, experiment is conducted in three different unknown environments with very different properties such as an open space, a long corridor with windows, and an outdoor environment. A lot of extensions are developed, such as implementing measures wind direction will change the concentration of gas. Various other sensor modalities are used such as temperature and humidity sensors to measure air quality if there is an indication of a change in the environment.

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