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Development of a Low Cost Mobile Volcano Early Warning System

Mitra Djamal[1,a], Maria Evita[1,2,b,c], Bernd Zimanowski[3,d] and Klaus Schilling[2,e]

[1]Department of Physics, Institut Teknologi Bandung, Indonesia

[2]Department of Computer Science VII, Universität Würzburg, Germany

[3]Department of Geography I, Universität Würzburg, Germany

[a] <mitra@fi.itb.ac.id>, [b] <maria@fi.itb.ac.id>, [c] <evita@informatik.uni-wuerzburg.de>,
[d] <zimano@mail.uni-wuerzburg.de>, [e] <schi@informatik.uni-wuerzburg.de>

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Abstract. A new early warning system has been developed for Indonesian volcano, which is in the second place for the most dated eruption after Japan. This low cost system consists of Wireless Sensor Network (WSN) for sensing, processing, distributing and transmitting the data; satellite technology for remote sensing data of the volcano; and mobile robot for replacing a died sensor node in emergency situation. Not only for normal condition when only small events happen, but the system is also robust to a hazard erupting volcano environment to acquire real-time data in high-fidelity operation and manages both the power and bandwidth efficiently in the same time. Simulation and laboratory experimental result show that the system consumed lower energy and utilized better the bandwidth than the current existing system. Furthermore, the mobile robot has been successfully arrived at the desired location for broken node substitution with no human involvement in a toxic dangerous area.

1. Introduction

As a country with at least 1171 eruption of 127 volcanoes since historic time, Indonesia has built a volcano early warning system to minimize the effect of this natural disaster [1,2]. Nevertheless, some problems still occur in Indonesian volcano monitoring system (the main part of volcano early warning system) regarding data (delayed, no real time, not automatically managed), bandwidth utilization, power occupation and unsafe to user, which delayed the automatic response taking for anticipating the effect of the disaster [1,3].

Therefore, here we have been developed a new monitoring system for Indonesian volcano which consists of WSN, mobile robot and satellite technology to solve some problems in existing Indonesian volcano monitoring system. This system is called MONICA – Mobile Monitoring System for Indonesian Volcano (Fig. 1) [1,3,4,5,6,7]. In a normal condition, when there is no or only small eruption happen, the system activates fixed-mode (magenta arrows of Fig. 1) to monitor the volcano. Acquired field data from WSN is sent to Base Station through Wi-Fi connection then sent to the Control Station. This Station may request some images from satellite about the volcano condition.

Furthermore, in a frequently eruption condition which breaks the fixed system or data transmission abortion, an emergency mode called mobile mode (blue arrows of Fig. 1) then be activated by the system. A mobile robot which consist the same sensor node as in the fixed system then be deployed to replace the broken highest-priority node. Afterward, if there is another highest-priority node break, the robot will move to the broken node location and replace it. The data is sent to the base station and sent to the control station using internet connection and some images from satellite also may be requested by the station.

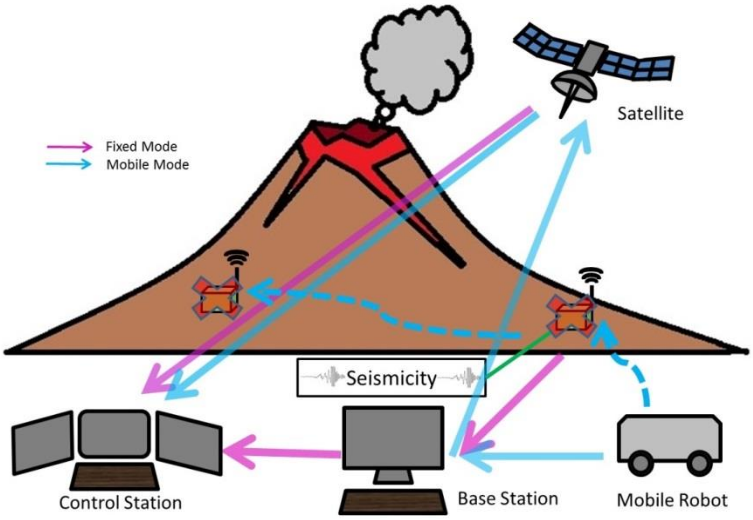


Fig 1. MONICA system consists of WSN, mobile robot and satellite technology. The system divided into 2 modes: fixed-mode (magenta arrows) for normal condition and mobile mode (blue arrows) for emergency condition

For both modes, the system is formed by sensor nodes with WSN inside. Not only easy to be programmed, WSN also not hard to get and cheap. This low power hardware can also support a large number of sensor distributed over a wide area [8,9]. Meanwhile, the mobile robot, which is only used in mobile mode has been introduced for data measurement in a hazard condition as volcano [10,11,12]. These two main sub-systems (WSN and mobile robot) will be discussed in this paper for Merapi volcano application with specifically in seismicity as the volcano's prominent characteristics.

2. System and Algorithm

Seismicity data from WSN which is sent to the Base Station then to Control Station in normal condition is proceed in fixed-mode of the system (Fig. 2a). In hazard condition which causes broken fixed sensor node, the mobile mode is activated. After receiving node died notification, the system then checking the priority of this node. For the highest priority died node, the system then deploys the mobile robot to replace the node. Otherwise, the system uses the remaining alive-node for monitoring process.

2.1 Wireless Sensor Network

Wireless Sensor Network has been proposed to overcome some problems in existing system [1,3,4,5,6,7]. However, WSN has limited bandwidth and consumes much power for high fidelity and real time data process of volcano seismicity [8]. Therefore, it has been performed some techniques to tackle this matter: power management (clustering, neighbor discovering, cluster head choosing, shutdown the power, data transmission and time slot management techniques), bandwidth management (software division, information dissemination, data compression and earthquake event location techniques) and quality of service management (learning process sensor, hybridization data collection, decision making, prioritization, geographic routing, data acquisition algorithm and real time data transmission techniques) (Fig. 2b).

2.2 Mobile Robot

Mobile robot for outdoor application (L = 0.36 m, d = 0.125 m, h = 0.225 m) such as a volcano environment has been used for this research (Fig. 3).

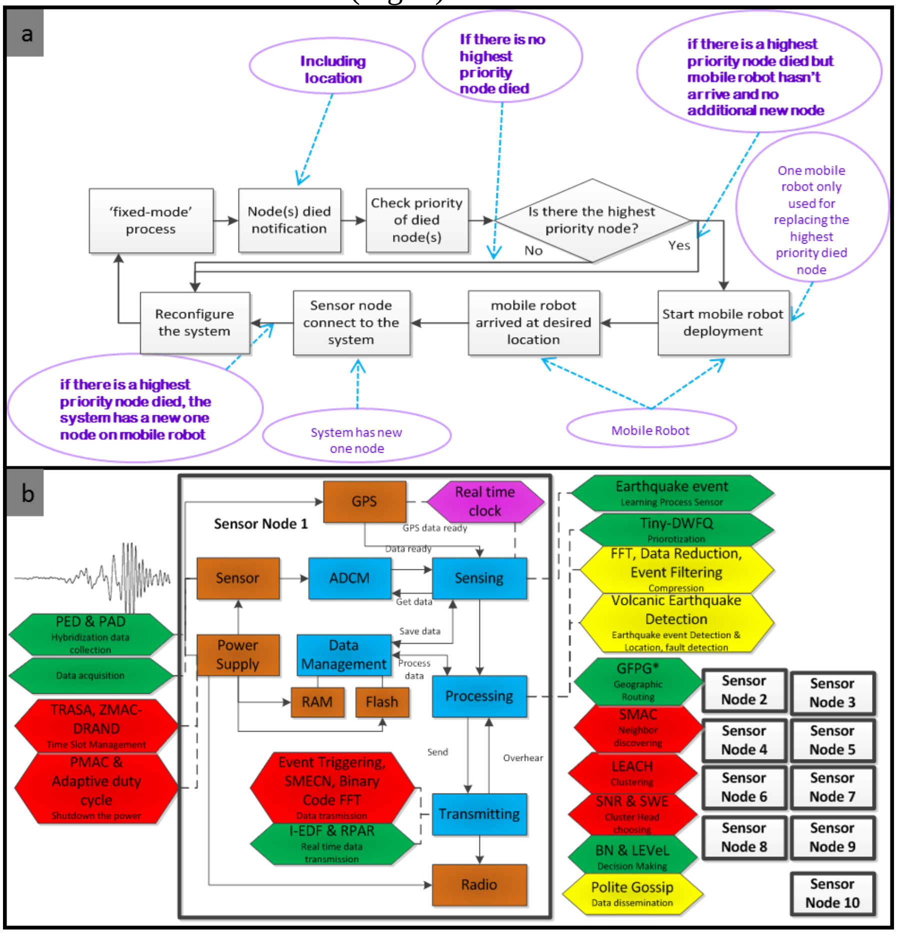


Fig. 2. The algorithm of the system for fixed and mobile modes activation (a) and WSN system including power management, bandwidth management and quality of service management techniques (b)

Mobile robot deployment process requires a navigation and control system suitable for this environment. Here we use a near optimal navigation protocol for guiding mobile robot through rough terrain and avoid hazards towards its goal in the die fixed-node location, together with PD controller for dealing with effective delay of this robot.

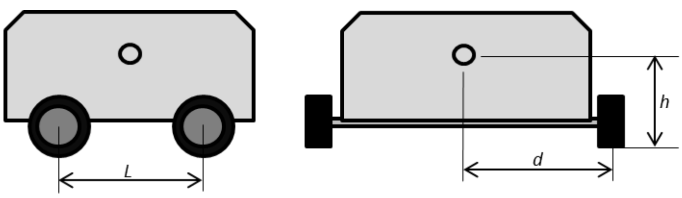


Fig. 3: Mobile robot model L is length from front wheel and back wheel, d is length from the center of the mass of robot and the wheel, h is the height from the ground to the center of the mass

3. Result and Discussion

3.1 Wireless Sensor Network

Three seismicity cases of Merapi volcano have been simulated for our WSN system (250 kbps 2.4 GHz IEEE 802.15.4 wireless transceiver; microcontroller (10k RAM, 48k Flash); and fast wakeup from sleep (<6µs)) with 3 kinds of sensor (seismic, infrasonic and lightning sensors) for 600 seconds (for slow motion and strong motion earthquakes in fixed mode activation (Fig. 4a and 4b)) and 3600 seconds (for strong motion earthquake in mobile mode activation (Fig. 4c)).

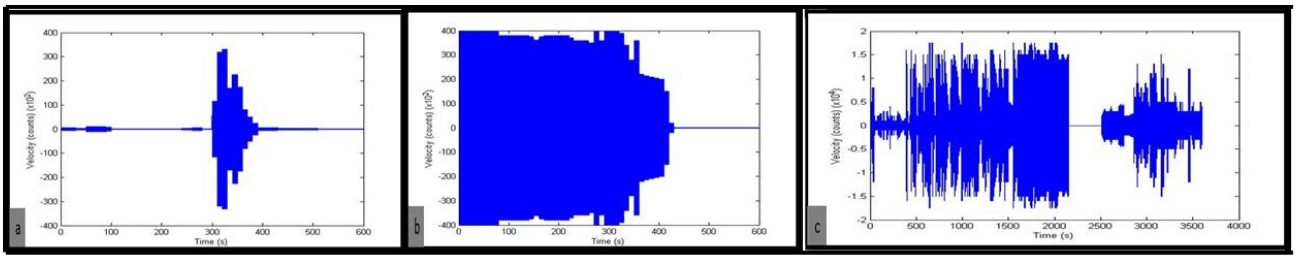


Fig. 4 Seismicity data (Velocity (counts) (*10^2)) for slow motion earthquake in fixed mode activation in 600 seconds (a), Seismicity data (Velocity (counts) (*10^2)) for strong motion earthquake in fixed mode activation in 600 s (b), Seismicity data (Velocity (counts) (*10^4)) for strong motion earthquake in mobile mode activation in 3600 s (c)

In sleep state, when there is no event detected, the system consumes the same power for the three cases (0.07 mJ/s) (Fig. 5). The power management commands the system to always sleep when there is no seismicity event coming. The power is also managed even in wake up state to acquire, process and transmit data. This state varies for different number of sensor node formed the system (Fig. 5): 0.9 mJ/s for 10 WSN in all cases, 1.3 mJ/s for 8 sensor nodes in strong motion earthquake of mobile mode cases, and 1.2 mJ/s for 9 sensor nodes in the same case. For mobile mode case (Fig. 5 green graph), it was assuming that the highest and second highest priority nodes were dead because of lightning from eruption (at t = 1000s). Number of WSN sensor node was decrease from 10 to 8. The system still running using 8 sensor nodes until the mobile robot arrived to replace the highest priority die node and add a new WSN sensor node to the system (number of sensor node become 9). These power consumption results (0.1 – 2.5 J in total) is more efficient than the existing system for the same cases (7.5 – 68.4 kJ in total).

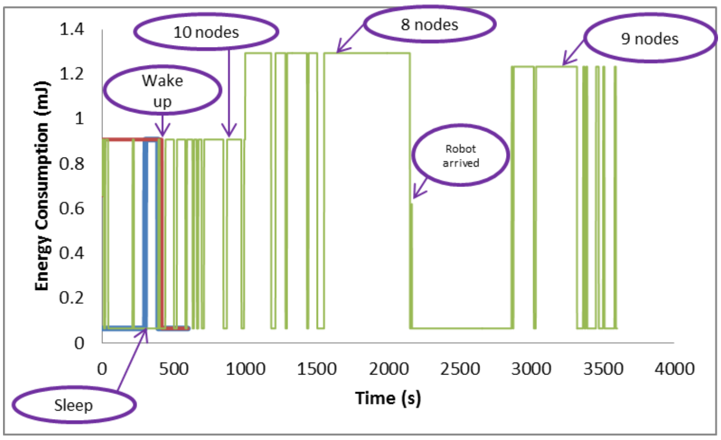


Fig. 5 Energy consumption system for slow motion earthquake in fixed-mode activation (blue), strong motion earthquake in fixed-mode activation (red) and strong motion earthquake in mobile mode activation (green)

The system also utilized efficient bandwidth in the same time. Bandwidth management allows the system to inform the highest priority node by locating the earthquake event and compress its data into smaller size to be sent to the Base Station as requested. The data is 85% - 100% delivered using 10 sensors node formed the system, for slow motion (Fig. 6 blue graph) and strong motion (Fig. 6 red graph) earthquake of fixed-mode activation and strong motion earthquake of mobile mode activation case (Fig. 6 green graph). In this mobile mode, the system still running with 65% throughput (in average) after 2 sensor nodes broke and 83% (in average) after getting new additional node from deployed mobile robot, while the existing system (Fig. 6 purple graph) can’t send the data anymore as before (0.4% throughput).

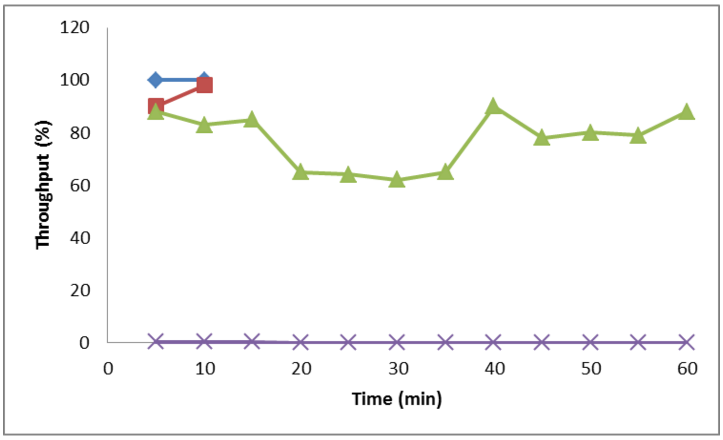
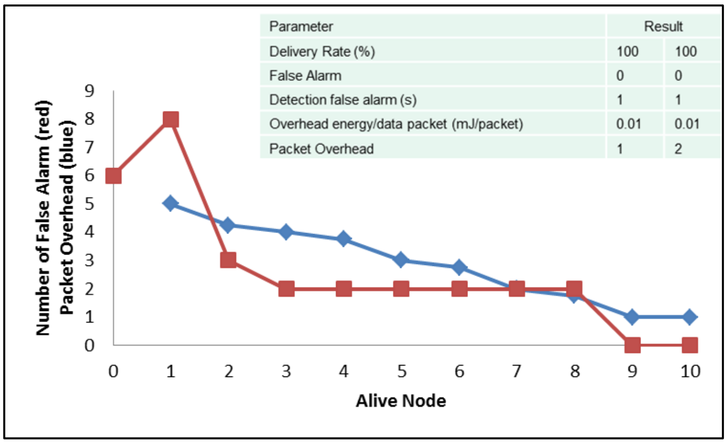


Fig. 6 Throughput system for slow motion earthquake in fixed-mode activation (blue), strong motion earthquake in fixed-mode activation (red), strong motion earthquake in mobile mode activation for the design system (green) and existing system (purple)

Different from the existing system, the designed system manages its quality of service to ensure the system is aware and robust to its environment and work efficiently with prioritization. In normal volcano condition with no eruption or only rare earthquake (both for slow and strong motion’s), the data could be 100% delivered to the Base Station (Fig. 7. inset table) with 1 – 2 packet overhead and 0.01 mJ/packet overhead energy/data packet. In additional, these earthquakes could be detected in 1 second with no false alarm of detection.



Parameter	Result	
Delivery Rate (%)	100	100
False Alarm	0	0
Detection false alarm (s)	1	1
Overhead energy/data packet (mJ/packet)	0.01	0.01
Packet Overhead	1	2

Fig. 7 Packet overhead for slow motion earthquake in mobile mode activation (blue graph), number of false alarm for slow motion earthquake in mobile mode activation (red graph), and inset table: simulation result for slow motion earthquake in fixed-mode activation (second column) and simulation result for strong motion earthquake in fixed-mode activation (third column)

This high performance is decrease in emergency case where the nodes die because of the volcano eruption. We can see that the more the nodes die, the more the false alarm of earthquake detection (Fig. 7 red graph). Combination of neighbor choosing, geographic routing and real time data transmission techniques which required optimal number of nodes results in the more packet overhead as the more die nodes (Fig. 7. blue graph).

An experiment had been conducted to confirm the simulation result. Ten sensor nodes were connected to each other with 100 m distance from a computer as the base station (Fig. 8a). The data (25 packet) was been generated by the computer to the system. An oscilloscope connected to each node to measure the current and voltage for power consumption of the system.

The system woke up after receive a message from base station at t = 1s that there were some (packet) data will be received, it was shown by about 9 µJ/s power consumed by each sensor node (Fig. 8b). The data was first received by Sensor Node 1, and also realized by its neighbor (Sensor Node 2, 3 and 4) which shows increment in energy consumption about 0.1 mJ (at t = 1s) for this node and its neighbor (Fig. 8b). Other sensor node which didn't receive the message continued its work in sleep state. The closest and the lowest energy sensor node then acted as a sink which sent the data to the base station. This sink happened to be Sensor Node 1. This transmission process continued until all data has been sent and received by the base station for 10 second with 0.8 mJ/s energy consumption.

The data was sent and successfully received by the base station with 100% delivery rate (normalized throughput = 1) start from second 2 (Fig. 8c) which was also indicated by increment of (transmission) energy system (Fig. 8b).

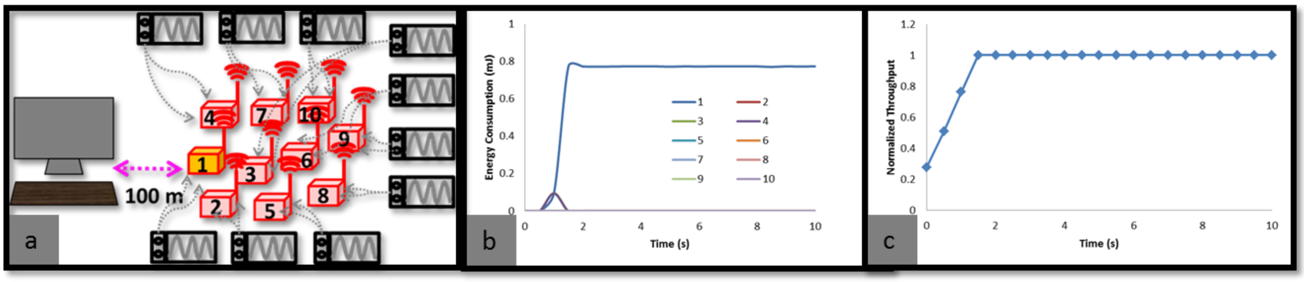


Fig. 8 Experiment setup (a) for WSN sub-system and the result: energy consumption of the system (b) and normalized throughput (c)

3.2 Mobile Robot

Mobile robot deployment for replacing the highest priority died node has been simulated on a given Merapi volcano terrain map (Fig. 9a). Mobile robot is successfully arrived at the desired location through some waypoints (white filled circle) while avoiding hazard. The high-level planner generates the path between waypoints (red line) while the low-level navigation layer guides the robot to move through this path (blue line).

The actual robot velocity (Fig. 9b blue graph) is always below the computed (by model-base look-ahead) velocity limit (Fig. 9b green graph). Meanwhile, the roll and slip angles are no more than 0.01^{o} with the highest peak occurs during hazard avoidance (Fig. 9c and d).

Furthermore, in experiment the mobile robot also successfully avoided the hazards (blue circles) at (x,y) = {(2.0,0.25), (3.5,0.75)} with radius 0.2 m and successfully navigated between waypoints (green dots) at (x,y) = {(2,0), (3,1), (4,1)} (Fig. 10).

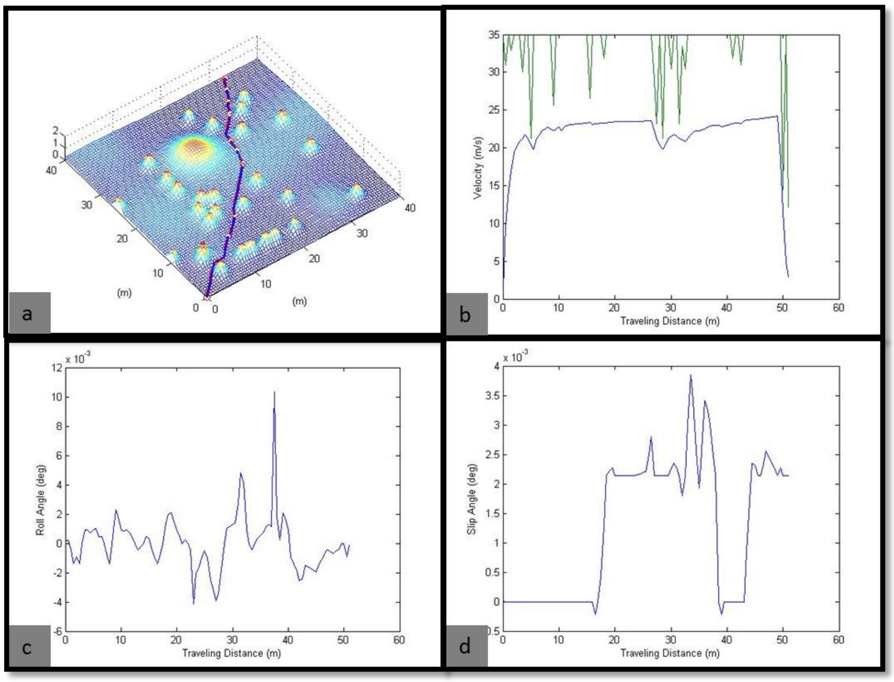


Fig. 9 Simulation result for mobile robot deployment: plan trajectory (red) and real trajectory (blue) (a), robot velocity (blue graph) and computed velocity limit (green graph) (b), roll angle (c) and slip angle (d)

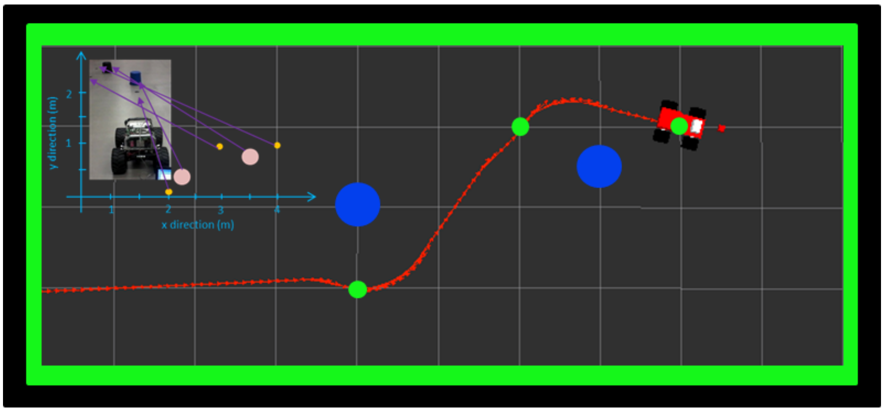


Fig. 10 Experiment result for mobile robot deployment for 3 waypoints (green filled circle) and 2 obstacles (blue filled circle); robot experiment in progress and the position for the waypoints and obstacles (inset picture)

4. Conclusion

A low cost system which consists of WSN, mobile robot and satellite technology has been developed for Indonesian volcano monitoring system as the main part of the Volcano Early Warning System. To solve the problem in power and bandwidth utilization for high-fidelity real-time data, the designed system performed power, bandwidth and quality of service managements effectively in both simulation and laboratory experiment. A mobile robot which has a new sensor node on it is deployed to replace the highest priority died node for better performance of the system. Simulation and laboratory experiment show that the mobile robot successfully arrive at the desired location while avoiding hazard through some waypoints generated by its trajectory planner.

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