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Robust Blimps Formation using Wireless Sensor based on Received Signal Strength Indication (RSSI) Localization Method

(Formasi Blimp Menggunakan Peranti Tanpa Wayar Berdasarkan Teknik Penempatan Penunjuk Kekuatan Isyarat Penerima (RSSI)

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ABSTRACT

This paper suggests the wireless communication technique used to determine the information of blimp localization (distance and orientation) via wireless sensor network (WSN) protocol. In cooperative decentralized system, information exchanges between the agents are crucial. Each agent is required to share data to enable individual decision making task. In this work, the WSN were used as the data communications protocol which provides robust communication using the mesh networking. In order to support the multi agent communication network, the reliability of data needs to be proved. The performances of the communication selection were studied through experimental and simulation approach. The experimental results showed that the RSSI value from the device provided good statically data fit using the R-square with value of 0.947. This paper also proposed a new mobile node arrangement with hexagonal anchor node arrangement based on water particles formation. The node arrangement was simulated using the Senelex™ and showed low absolute error position thus achieving the desired cooperative system requirement.

Keywords: Blimp; localization; RSSI; wireless; Xbee

ABSTRAK

Kertas ini mencadangkan teknik komunikasi tanpa wayar yang digunakan untuk menentukan maklumat penempatan blimp (jarak dan orientasi) melalui protokol rangkaian sensor tanpa wayar (WSN). Dalam sistem pembahagian koperasi, pertukaran maklumat antara agen adalah penting. Setiap agen perlu berkongsi data bagi membolehkan tugas membuat keputusan dilakukan secara individu. Dalam kertas ini, rangkaian peranti tanpa wayar (WSN) telah digunakan sebagai protokol komunikasi yang menyediakan pertukaran data yang mantap menggunakan rangkaian jaringan. Untuk menyokong komunikasi rangkaian bagi pelbagai agen, kebolehpercayaan data perlu dibuktikan. Prestasi komunikasi dikaji melalui eksperimen dan simulasi. Keputusan eksperimen menunjukkan bahawa nilai RSSI daripada peranti disediakan menunjukkan statistik data yang baik dengan Regresi, R^2 bernilai 0.947. Kertas ini juga mencadangkan aturan nod mudah alih yang baharu dengan susunan heksagon pada nod sauh berdasarkan pembentukan zarah air. Susunan nod disimulasi menggunakan Senelex™ dan menunjukkan ralat mutlak yang rendah sekaligus mencapai keperluan sistem koperasi yang dikehendaki.

Kata kunci: Blimp; penempatan; RSSI; tanpa wayar; Xbee

INTRODUCTION

A blimp is an aerial vehicle that looks like an ellipsoid balloon with a propeller. Technically, this vehicle is a non-rigid airship which uses gases that are buoyant in air with density lower than 1.2 kg/m^3 and 1.2 g/L ft. With the ability to hover at low altitude and speed; this vehicle is very suitable for low altitude data gathering. The blimp model were presented based on our own specification (Kadir et al. 2012).

In cooperative multi blimp system, communication between agents plays a very important role to establish data sharing during a mission (Maalej et al. 2012). The challenge in the cooperative system is to calculate the distance between the agents and accurate localization. To enable reliable data exchange, it is important to establish a good communication link between the agents. By combining measurements from *proprioceptive* and *exteroceptive* sensors permit motion monitoring of vehicle orientation, in addition to environment information. Several outdoor and indoor positioning localization technologies have been developed based on Infrared, ultrasonic, RFID, Wireless Sensor Network (WSN), Wi-Fi, WLAN and Global Positioning System (GPS).

In this work, we have consider WSN technique and Xbee as the wireless device. The Xbee will be embedded as nodes to the blimp (mobile nodes) and beacon (anchor node). The Zigbee networking provides the capability for devices to communicate with other nodes within a network. The mesh topology also enables the mobile nodes to communicate with the anchor node and between them and give more efficient signal propagation through the best available links.

Recent works document the wireless network technique (Ahmed et al. 2012; Ahn et al. 2010; Dang et al. 2008; Erdogan 2010; Guibin et al. 2010; Muhamed et al. 2009; Park et al. 2010; Rahman et al. 2012; Wang et al. 2010; Zheng 2011). Generally, there are four techniques that can be used for range estimation: Angle of Arrival (AoA), Time-of-Arrival (ToA), Time-Difference-of-Arrival (TDoA) and Received-Signal-Strength-Indicator (RSSI). In AoA technique, the angle of a signal arrives at a node will be recorded. However, this technique needs to be equipped with a directive antenna, which may require hardware modification. In ToA and TDoA technique, the signal arrival time or the difference of arrival times were measured. The distances were determined based on transmission times and speeds. For RSSI, the distance was obtained based on the power levels received by the device through AP or API mode. Each techniques offers different advantages, whereas there is tradeoff between data accuracy with data hardware modification. There are three localization methods that offer accurate location estimations, which are ToA, TDoA and AoA. However, they require precise synchronization of wireless nodes and direct wireless communication (LOS: Line-of-Sight) link. Therefore, some disadvantageous are introduced in terms of cost and energy consumption of sensor communication nodes. Due to no hardware modification required for implementing the 4th method, RSSI-based location estimation method offers advantageous in terms of cost and energy consumption. The RSSI method can consider the variation of measured RSSIs value, due to multipath fading and shadowing in a Non-Light-of-Sight (NLOS) link. In addition, RSSI methods produce better results compared to other method (Hara & Anzai 2008; Tiang et al. 2010).

In this work, RSSI range estimation data between nodes will be highlighted and reliable localization data were demonstrate using this method. The experimental and simulation results will highlight the advantages of our approach and clarify its limitations. The rest of the paper is organized as follows: Next, some relevant work in aerial vehicles and cooperative system will be discussed. After that, we introduced the basic concept of proposed method. Subsequently, we will discuss the networking formation for the nodes followed by the experimental and simulation result, here we will discuss the comparisons between different environments and network formation and lastly, we will discuss the conclusion and future work.

RELATED WORK

Due to cost effectiveness and persistent potential in maritime surveillance (Flight International 2013), the blimp is a resurgence technology in aerial observation (Liao & Pasternak 2009). This vehicle also offers great potential in surveillance, exploration and communications application (Liao & Pasternak 2009; Luca at el. 2011). Recent work documented the usage of the blimp in several cooperative applications such as rescue operation (Hada et al. 2008; Keith et al. 2005), searching (Guoqing & Corbett 2004) and forest fire detection (Merino et al. 2006). As mentioned by Maza et al. 2011, localization of a group of vehicles can exploit more information from multiple scenes and can be used to estimate the position of objects of interest. However, a poor communication links between agents will affect the coordination of objects of interest complete their mission, reduce the efficiency of a team and may lead to vehicles lost.

Recently, WSN had shown the solution in a diverse spectrum of applications from surveillance and tracking for forest, military, street traffic, patients supervision, atmospheric research, and hurricane tracking (Lawrence & Mohseni 2007; Cione et al. 2008; Kulakowski et al. 2012; Akyildiz et al. 2005, 2002; Baronti et al. 2007). This method also introduces a cooperative networking for a team of aerial vehicle (Cione et al. 2008; Guoqing & Corbett 2004; Hada et al. 2008; Keith et al. 2005; Lawrence & Mohseni 2007; Maza et al. 2011; Merino et al. 2006).

Due to low power wireless characteristic, the ZigBee wireless networking has gained interest from many researchers (Zheng & Lee 2006). This industry-standard IEEE 802.15.4 radios at 2.4 GHz offer minimum power and computational requirements for cooperative multi agent system. Shaw and Mohseni (2011) has applied the *Digi's*

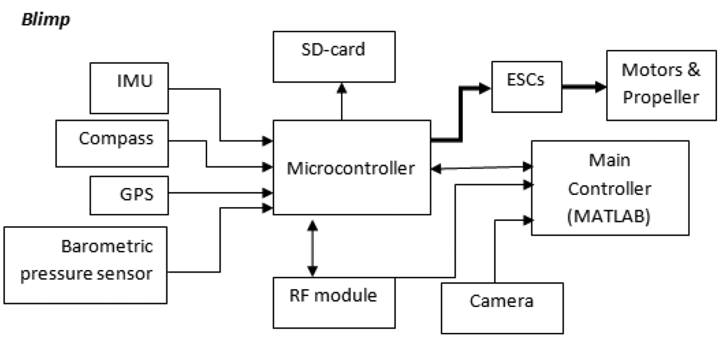


FIGURE 1. Blimp architecture

Xbee Pro radios to a 32-inch Delta-wing UAV using the Packet error rate (PER) and received signal strength (RSS), but the communication range were limited to the size of targeted region depending upon the number of vehicles. In Goddemeier et al. (2012) and Le et al. (2012), the collaborative UAVs communication was presented. They discussed details of network dimension analysis based on realistic aerial channel capacities deployment. An optimal communication chain using a team of unmanned aircraft was proposed by Tan et al. 2012 to improve and optimize the communication capacity. They reported that the RSS values were affected by the dynamic changes in the RF environment. However, this issue can be solved by taking multiple signal measurements. Hence, in our work, we would like to consider multiple signal measurement using the anchor nodes and mobile nodes to deal with the variation of measured RSSIs value due to constraint arise from multipath fading and shadowing in a Non-Light-of-Sight (NLOS) environment.

Proposed Method

In order maintain accurate wireless communication link, the nodes signal and network testing are crucial to avoid losing contact between agents. Therefore the issues are discussed as follows:

DECENTRALIZED COOPERATIVE BLIMP SYSTEM

As illustrated in Figure 1, the WSN nodes will be integrated with the blimp system attached with several devices such as sensor, actuator, controller and power supply. The wireless communication between agents relies on *Xbee s2* with 2.4 GHz frequency. The development of the blimp can be found in [34]. As mentioned before, the RSSI technique will be used on 3 mobile nodes with speed of 2 m/s. We use the same agent module for 3 moving nodes. In order to analyze the multi agent data exchange capability, we have considered several environments indoor, under building, outdoor surround with building and outdoor. The agent's were named Agents 1, 2 and 3. These agents will also be able to retrieve the RSSI value from available fixed link to help achieve accurate localization (Figure 2).

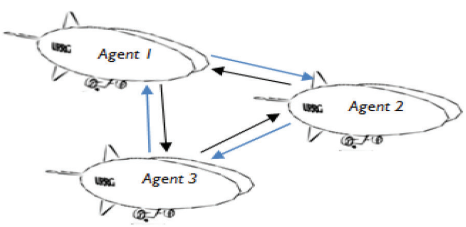
Note that the agents were able to retrieve the RSSI value between them. This networking concept is called complex point to multipoint network. The agents are set to be a router.

RSSI METHOD

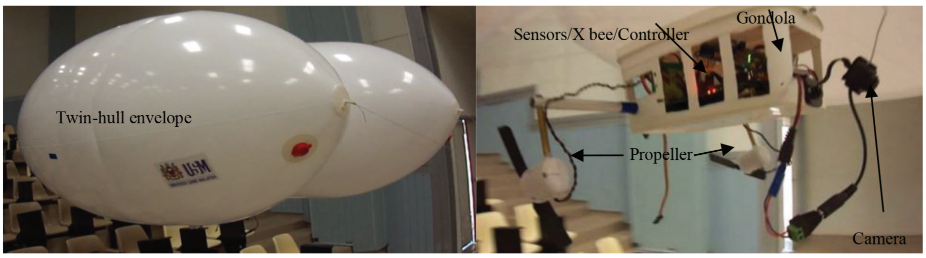
The basic idea of RSSI method lies on measuring the received signal strength (RSS) for each receiving data packet from Zigbee nodes. The RSSI value was read via Application Programming Interface (API) command. For our device, the signal levels were in -0 to -104 dBm, where the -104 dbm represent the poorest signal value. In order to acquire the RSSI value, there are two types of method, using the Xbee module to obtain the pulse width modulated signal or via AT or API command.

In order to acquire a reliable wireless connection, many parameters need to be considered such as the receiver sensitivity, transmitter output, signal frequency and signal propagation environment (Farahani 2008). For generic practical scenario, such as inside a building, in an area surrounded by building and trees where the precedent free-space is not sufficiently accurate enough, the transmitted signal will be absorbed, reflected, scattered and diffracted when blocked by obstacles. All these incidents will affect the signal power.

$$P_d = P_0 - 10 \times n \times \log_{10}(f) - 10 \times n \times \log_{10}(d) + 39 \times n - 32.44$$



(a)



(b) (c)

FIGURE 2. Blimp concept (a) Networking concept for mobile node (b) Envelope (c) Gondola

where P_d represent the signal power (in dBm) at distance d. After the blimp read the RSSI value from the nodes, the average measurement will be determined. The blimp will calculate the distances between nodes and the distances will be used for localization purposes as shown in Figure 3.

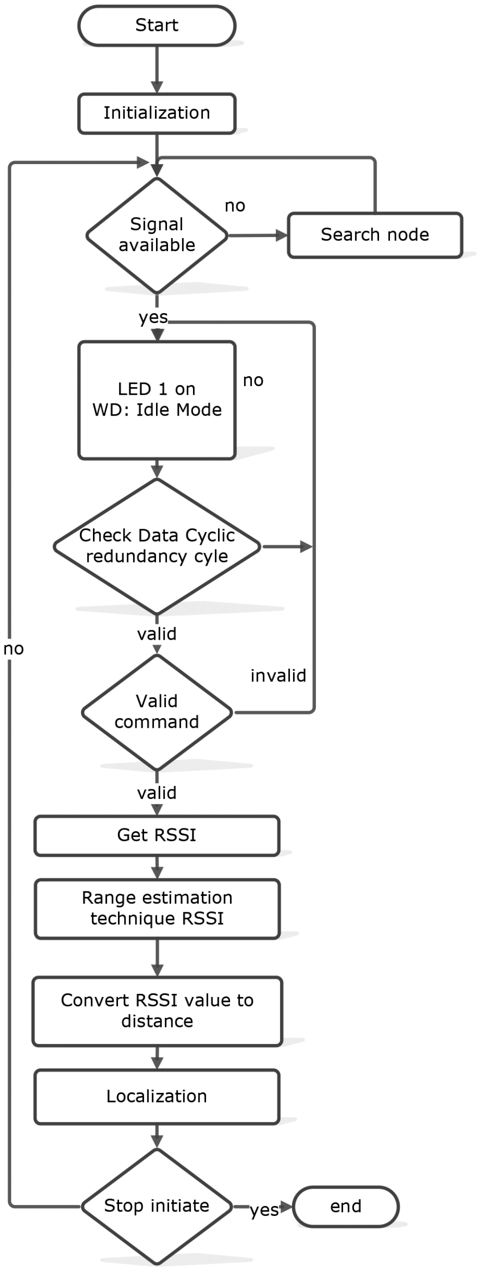


FIGURE 3. Localization via RSSI flow chart

NETWORKING FORMATION

There are three scenarios for location estimation: centralized, sectioned and distributed. We have considered to use the sectioned method in our system where this method is to divide network into sections and allocate a node capable of executing the localization algorithm for each section. The main advantage of this method is to overcome the traffic bottleneck of centralized processing and only the mobile node (the processing node) will determine its position. In this case, only the mobile platform will communicate thus minimize the fix nodes capability (e.g. hardware processing power and memory) compared to the distributed location where each nodes need to determines its own location.

In this work, the nodes formation was inspired by the water particles and bee comb as shown in Figure 4(a)-4(b) (Emoto 2007). The networking processing node in the sectioned approach was based on water molecule, H_20 concept containing 2 anchor node representing hydrogen atom and 1 mobile node representing 1 oxygen atom. When we deploy 3 mobile nodes, the most effective shape for anchor node was the hexagon. This hexagonal structure also provides the efficient area coverage compared to other shapes such as triangle, square and circle. The nodes formation was illustrated in Figure 4(c)-4(d). In order to cover large networking area, the hexagonal coverage with the shape of bee comb formation will enables efficient link throughout the navigation area. The distances between fix nodes will depend on the wireless nodes coverage.

A computer simulation was conducted to verify the proposed cooperative system and performances on each mobile localization task. In this simulation, we will consider the hexagonal, square and triangle formation.

RESULTS

In this section, the performances of the proposed method are demonstrated through simulation and experiment.

EXPERIMENTAL VIA RSSI

The RSSI value produce by the device varies depending on the operating environment; indoor, outdoor, LOS and NLOS will produce the different effects of signal wavelength. In order to understand the problem, we have completed several experiments to study the power signal behavior over the distance. We have performed an experiment using the Zigbee RF module by Digi international, model *Xbee2 2mW Chip antenna*.

In this experiment, wireless devices were tested on various environments; 16 distances point were considered. Each distances measurement was repeated ten times. The testing were conducted in 3 scenario: Outdoor, Indoor (LOS) and Indoor (NLOS). The performances of the device were illustrated in Figure 5(a)-5(c). In each plot; the diamond indicates the power signal value received via RSSI and the red line indicates the deviation of the samples taken where σ denoted as standard deviation. We can observe that in each figure, the plot was similar and display a decrease value of RSSI value over distances. This trend indicates that the measured signal weakens as the distance became greater, thus verify the reasonable result based on the path-loss equation trend. However, the capture signal variation depends on the path loss exponent of the environment.

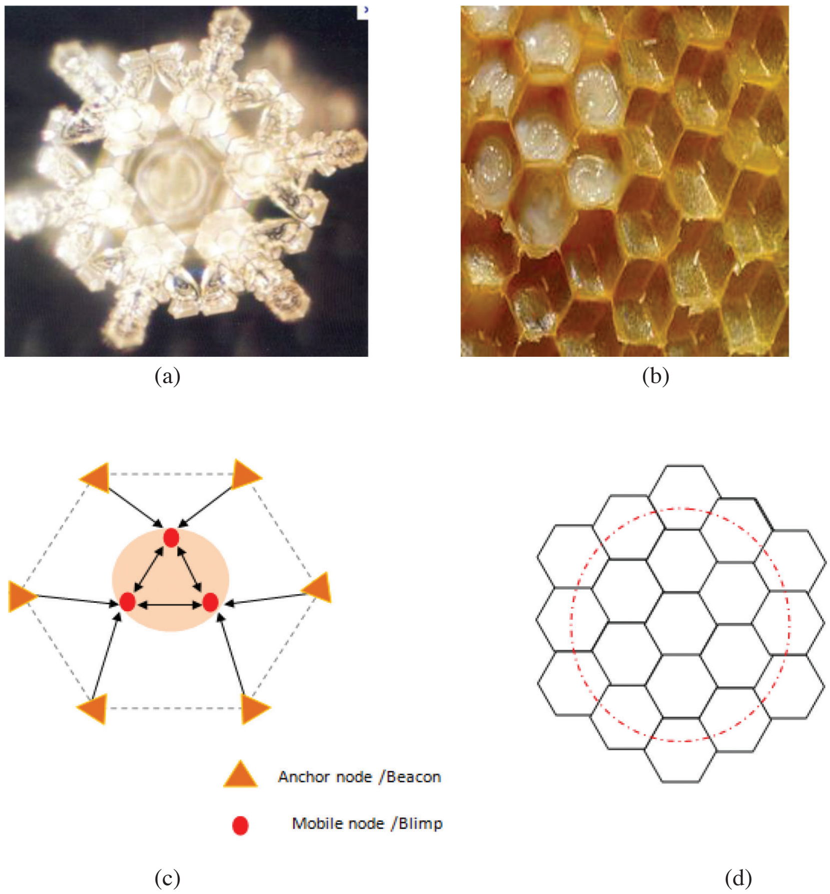


FIGURE 4. Network formation (a) Natural formation: Water particle (b) Bee comb (c) System node arrangement and (d) Bee comb anchor node arrangement

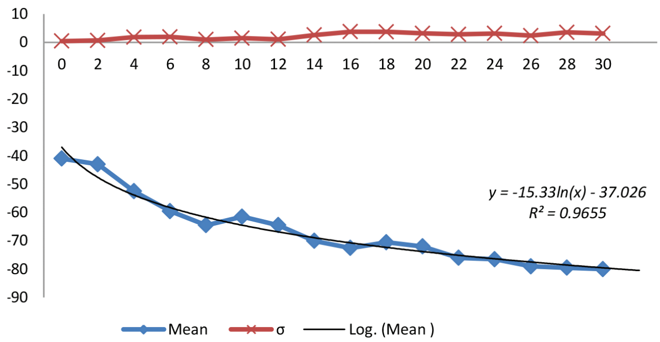
As illustrated in Figure 5(a), the case of free space (outdoor with LOS), the collected sample deviations are small approximately 1~5% from the average value. The R^2 value of 0.9655 indicates that the output fits the real data well. Figure 5(b)-5(c) shows the indoor results, the sample deviations were approximately 0~3% from the average value with R^2 value of 0.8927. This indicates that although the deviations were small, the sample suffered from greater signal loss. This showed that transmitted signal were affected by obstructed path thus reduce the signal propagation efficiency. Moreover, Figure 5(c) also supports the claim in denser environment with NLOS characteristic. The overall deviation was approximately 0~5.7% greater than previous data with R^2 of 0.8571 less than indoor with LOS setup.

In order to use data for localization purposes, the average values were used. The results are reasonable due to regression analysis that shows the R^2 value were 0.9647 shows good data fits. Figure 6 shows the results for average value based on 7 samples of data. We also analyze the error percentage based on path loss equation as shown in Figure 7 where e1 represent outdoor error, e2 represent indoor and e4 represent average value. It can be concluded that the outdoor scenario contributed to the lowest error percentage approximately 5% compared to Indoor. However, the indoor with NLOS contribute to the highest error approximately 7% compared to the references value.

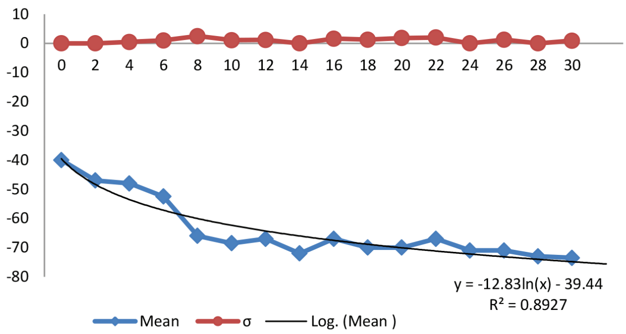
SIMULATIONS- NETWORK FORMATIONS

In order to set the network density and selecting the optimize networking; we have performed an analysis using *Senelex*. The algorithm is simulated in *Matlab 7.0™* using the *Senelex* provided by the University of Ohio [37-39]. Three different topologies are considered in the network's coverage area of 200 × 200. The selected network topology is a square, triangles and hexagonal. The RSSI value used were average connectivity values based on the collected sample. The received signal strength parameters are reference distance, power at reference distance, P0 =40 dBm, path loss exponent, n =2 and standard deviation of noise sigma = 6 dB. The anchor and mobile node formation results were shown in Figure 8 where ☐ representing anchor node and ▣ representing the mobile node.

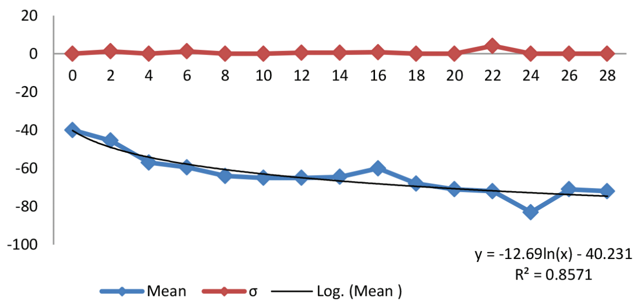
The proposed cooperative blimp system positions which represent the mobile node were shown in Table 1. This mobile node will required an anchor node formation for localization purposes. Therefore, we have tested the formation as mentioned. The performances of node using four formations are shown in Table 2. Figure 8 shows the detail networking formation of nodes estimation for a



(a) Outdoor (LOS): Distance, m vs RSSI dBm



(b) Indoor (LOS): Distance, m vs RSSI, dBm



(c) Indoor (NLOS): Distance, m vs. RSSI, dBm

FIGURE 5. Received signal strength power for various environments

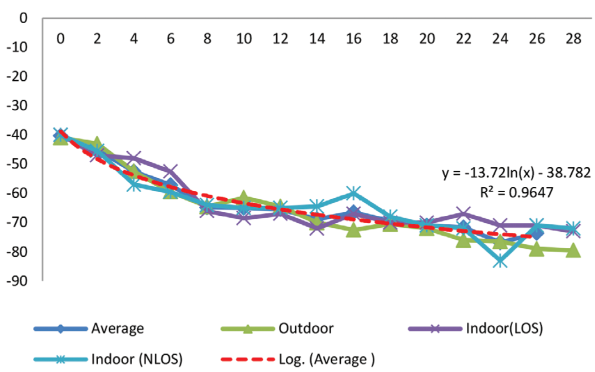


FIGURE 6. Comparison and average data for RSSI

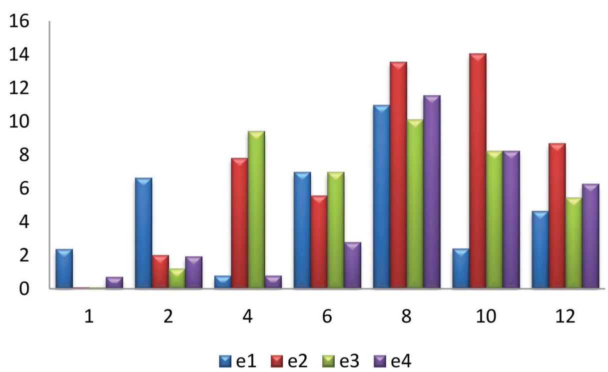
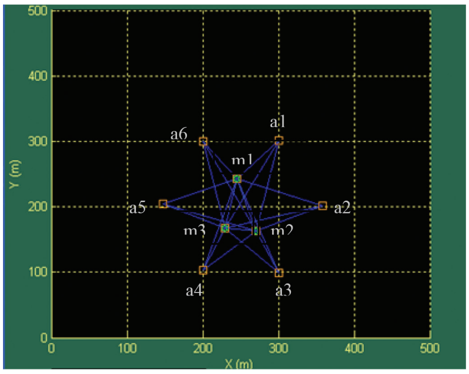


FIGURE 7. Error between RSSI value based on path loss equation, Pd

TABLE 1. Mobile node location (m_1,m_2,m_3)

	1	2	3
		Mobile nodes	
x	245.18	270.48	229.52
y	242.88	163.11	167.38
θ	138.60	71.59	110.38



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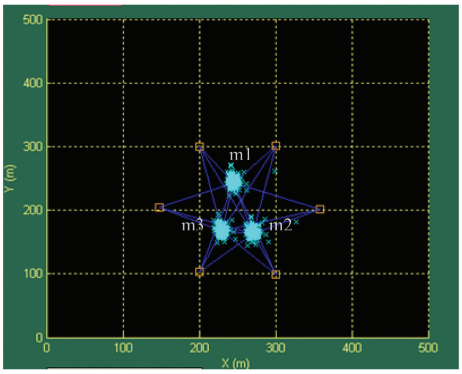

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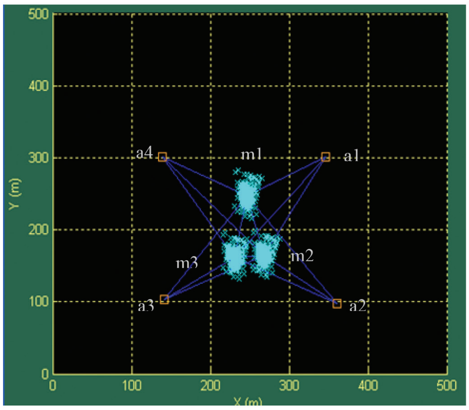

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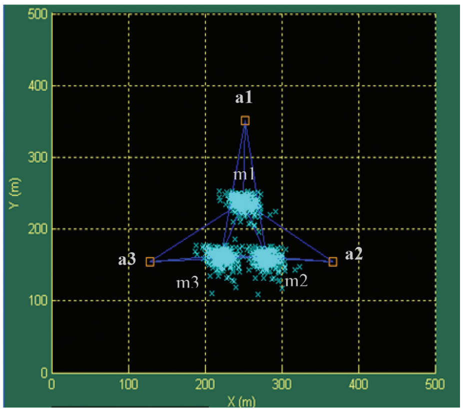

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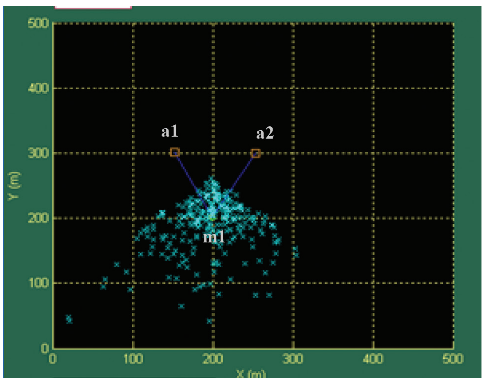

(e)

FIGURE 8. Network formation (a) Hexagon fix node sample (b) Hexagon (c) Square (d) Triangle and (e) Simple: one mobile node with two anchor node

TABLE 2. Mobile node location

Shape	Simple	Hexagon	Square	Triangle
Mobile node	1	3	3	3
Anchor node	2	6	4	3
Average absolute position error(m)	49.70	7.03	10.41	11.71
Samples	317	249	303	365

number of repeating samples with RSSI data and time. The accuracy of the nodes formations were evaluated by the average absolute position error. The maximum likelihood method was used to compute the estimated node position. The error was determined by calculating the true position with estimated positions of nodes based on the received signal strength model. The log-distance path loss and log shadowing were considered. Referring to the result for minimum shape consisting of 1 mobile node with 2 anchors node, the average absolute error in the result was 49.70 with data samples of 317 sets. It can be seen that with fewer nodes were in the area, with localization method resulting in poor results.

The main idea was to propose the hexagonal shape to the node allocation for an area for 1 sampling interval by this mobile node. From the analysis, the hexagonal shape gave quite good results of average absolute position error = 7.03 for data sample of 249 set. The square shape contributes to 10.41 where it represented 48% of error compare to hexagon. Whereby the triangle = 11.71 represent 67% of error compared to hexagon. Therefore, the hexagon shape gives the best solution compared to other. This shape also claims to be the second efficient shape compared to circle but better in terms of area coverage. It also introduces to more compact network area and able to compensate with poor signal problems due to 6 anchor node availability in one-sample time.

CONCLUSIONS AND FUTURE WORK

This paper describes the wireless sensor network for cooperative multi agent blimp system. These inter robot and beacon communication network must enable the robot to localize itself. The devices were tested experimentally and verify the proposed concept. It was demonstrated here that the device selected produce the desired RSSI value to be used in localization purposes. However, the signal accuracy depends on the path loss value in an environment. To enable the cooperative multi blimp system, the decentralized system needs to have good arrangement of anchor node/beacon to help the localization and strengthen the communication between agents. Therefore, the Senelex was used to analyze the proposed arrangement thus proposed good network density on the node. Based on the simulation result, the hexagon shape showed a low value of position error compared to the square and triangle. This shape also has good area coverage with minimum overlapping compared to circle.

Future work will focus on the hexagonal networking arrangement and multi robot localization algorithms. The optimize localization algorithms will also be considered in terms of accuracy of mobile robot localization and data reliability.

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