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An Analytical Approach for Effective Location Marking of Landmine Using Robot.

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ABSTRACT

Positioning or localizing the mobile nodes has recently evolved in the technical arena, to incorporate effectiveness and efficiency in every field so as to consummate user necessities. Design of human - machine interface is well appreciated in the critical fields that are jeopardized, including the demining of field. There arises requisite requirement for localizing such robots to detect the nearness of fault. The aim of the work is to develop a mine hunting robot, which detects and localizes the antipersonnel as well as the antitank mines for safety unplugging. A potential coverage path is used for proper coverage of the demining area, therefore reducing the failure of hitting crucial points in the scanning area. An efficient analytical approach based on received signal strength and trilateration is implemented. Simulation analysis assures the proposed approach for locating the mine is less complex and effective. A user friendly GUI is developed, enabling the operator to plot the position of landmines and to monitor the scanned / left over area remotely. The key advantages of the design are cost effectiveness and highly reliable solution lasting for a long run.

Keywords: Localization, RSSI, Trilateration, Mine detection, Anchor nodes, Robot.

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INTRODUCTION

Determination of position is an essential factor to be considered in the thriving technological world. However the deployments of sensor networks have been seldom visualized to be totally static. Mobility plays a predominant role in establishing a wireless sensor network, but has several challenges to deal with. Localization has been deemed to be a primary challenge. To perceive the sensor data in spatial context, the position estimation needs to be evaluated. In mobile wireless sensor networks, localization is perhaps a cardinal feature to be concentrated while implementing protocols based on geographical routing and applications including Military surveillance, Monitoring the habitat, Infrastructure diagnostics, Disaster management, Tracking or locating the target. When the nodes equipped with a transceiver are randomly positioned /dropped, there exists feasibility for interaction between the nodes within the communicational range. This network behaves as an undirected grid using its connectivity and information about the range. Nodes can now be localized with the information available from the other nodes and hence can communicate through the network.

A major factor to be enhanced is a well grounded technique for localization and efficient target estimation. The developed solution must aid in effective positioning and confining the target location so as to pull up the ability to deal with any environmental issues including defense and industrial observance. The aim of this work is to detect, identify and accurately locate the presence and position of the land mine for destruction or deactivation postwar.

RELATED WORK

Mines laid on war are hardly removed at the end of conflicts, since the proper mine maps and markings are not available. In the arena of defense operations, there has been several mine detecting robots developed using various detection technologies which includes GPR, NQR, EMI, Electrical Impedance, X- Ray backscattering [1][2][3]. The land is carefully probed by the mine detector, when mounted in a vehicle. This is usually referred as 'breaching' [4]. For locating the mine detector, there arises the requirement of additional supplementary hardware like position encoders to calculate the current position of the robot with the preceding determined position. This method is subjected to cumulative errors, which in turn necessitates the additional navigational aids like compasses [5] to localize through dead reckoning method [6]. In order to overcome the problem of accumulation of errors and to get rid of the cost for supplementary hardware, the localization technique is implemented for spotting the position of the robot, considering the robust structure and cost to employ.

Localization could be implemented either as Source/Target-based or Node self-localization. There are several categories in Source/Target-based localization including Single-sensor and multiple-sensor localization. Range-based and Range-free techniques are classified under Node self-localization. Range-free method employs the connectivity or pattern matching approach. The distinctive Range-free localization algorithms [7] [8] [9] include Centroid, APIT, SeRLoc, Amorphous, APS, MDS-MAP, DV - Hop, HDV- Hop and so on, which are complex for a resource constrained nodes when compared to Range-based algorithms. Range-based method calculates angle/distance for location estimation utilizing the neighboring anchor nodes and has several advantages including accuracy and less complexity. Such Range-based algorithms [10] [11] do need some physical information between the anchor nodes and the blind node such as time, distance etc. With this information the formulated algorithm has to locate the blind node.
For a mobile robot/node to self localize, it exploits range based algorithms using distance/ angle to estimate the location. Such location estimation model includes the Time of the signal Arrival (TOA). The signal can be either acoustic or RF signal to calculate the distance using signal propagation velocity and propagation time [12] to estimate the distance between the robot and reference point. The drawback is the transmitter that infers the distance using the round trip delay of signal fails to include the computing latency at the receiving end. Time Distance of Arrival (TDOA) [13] has the same pitfall, but uses two different signals at different propagation velocity.

Further, the estimation model encompasses Angle of Arrival (AOA) which is studied by acquiring the signal orientation sent by the anchor nodes through the array of antennas and multiple receivers' collaboration [14]. The drawback is the requirement of additional hardware like highly directional antennas/ antenna array/ an array of ultrasound receivers. Received Signal Strength Indicator (RSSI) computes the power received by the receiving node and estimates the loss in the signal propagation. It then converts the signal loss to distance using factual or empirical signal propagation loss model. Unlike other models, it requires no additional hardware but a transceiver [15], thus reducing the hardware cost and size of the nodes. Improvising the RSSI method by reducing the transmission loss model, one can appreciate the effectiveness and localization accuracy [16].

The proposed landmine detecting robot calculates RSSI data and directly maps to the distances through the signal propagation model. The result is the known distances from the anchor nodes, and the concept of Trilateration [17] can be trivially revealed as the problem of finding the intersection of three spheres, a method to discover the location of the object based on the simultaneous measurement of ranges from three anchor nodes involving a system of quadratic equations. Section 2 provides a description of the proposed model of localizing the mine using robot; Section 3 discusses the analysis of hardware model used for localization; Section 4 focuses on localization and includes principle behind RSSI.

PROPOSED WORK

Despite of variety of tools and concepts employed against mine threats, there is no foolproof match for all the situations. Method employing ultrasound or lasers reaches distinguished level of accuracy and a way forward, but every supplementary device adds the size, price, energy and additional signal processing requirements as well. The collaboration of detection and localization technology, operating in its distinctive method might be a better and cost- effective solution to achieve high performance and accuracy. The proposed system uses Metal detector to find the presence of the landmine. An affordable RF-based approach with minimal configuration requirements has been studied and an analytical approach to mark the position of the landmine/ explosive has been implemented. Once the presence of mine is detected, the location of the mobile robot is estimated using the RSSI and Trilateration concept.The Hardware description of the proposed system, Mapping of landmines, Localization are discussed further in detail.

SYSTEM DESCRIPTION

The system consists of three units: 1) Three Anchor nodes for localization, 2) A mobile robot which detects the landmine, estimates the RSSI values and calculates the appropriate distances from anchor nodes, 3) A monitoring unit runs the trilateration to find X,Y position of the robot. The block diagram of the proposed system is shown in Figure 1and 2.

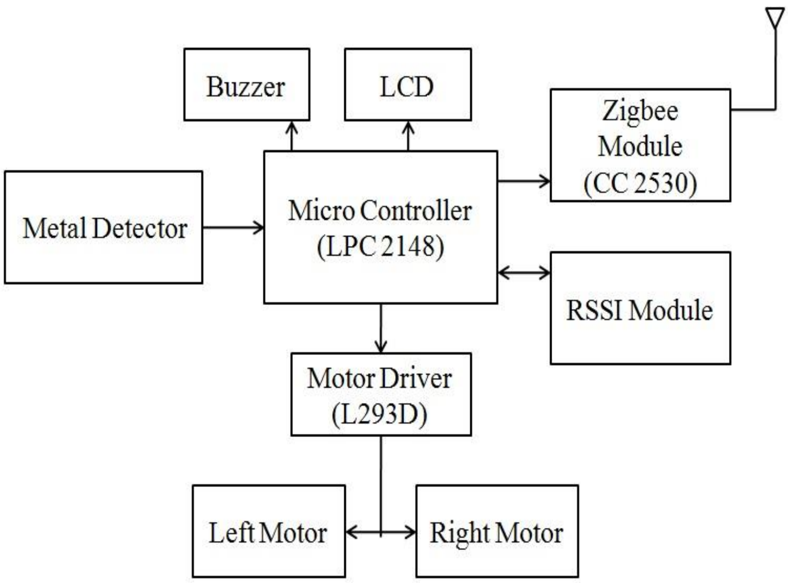

Figure 1: Block Diagram of the Mobile Robot

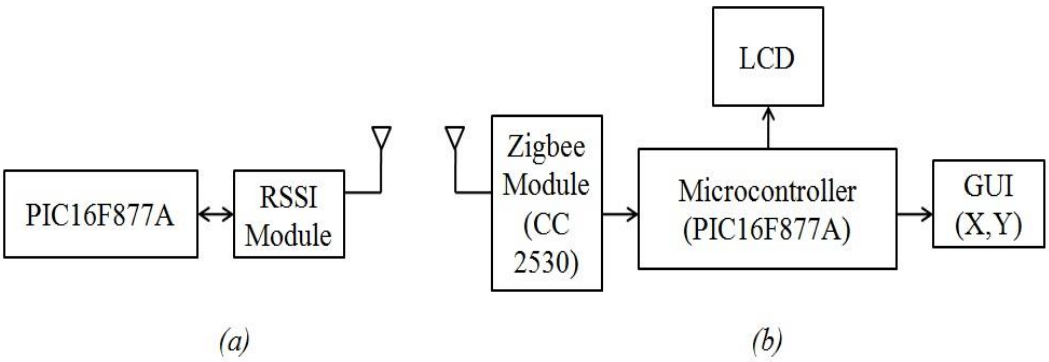

Figure 2: Block Diagram (a) The Anchor Nodes (1, 2, 3) (b) Remote Monitoring unit

ANCHOR NODES

Localization is predominantly assisted by the anchor nodes whose X, Y coordinates are known. There are three anchor nodes used in the proposed work. The Anchor nodes can be dropped for the deployment in real time, but for experimental purpose they are placed in fixed coordinates. The mobile robot detects the existence of the landmine and it broadcasts a RF signal. On receiving the RF signal from mobile robot these anchor nodes resend the RF signal. Hence the anchor nodes are assumed to be in the communicational range of the mobile robot to calculate the distances between them. The anchor nodes are built using the PIC16F877A controller with the RSSI module configured as slave.

MINE DETECTING ROBOT

The designed robot is competent enough to detect a buried landmine and to mark the location of the mine without detonating it. Figure 3 a) depicts the distance calculation using RSSI and Figure 3 b) shows applying trilateration for localization.

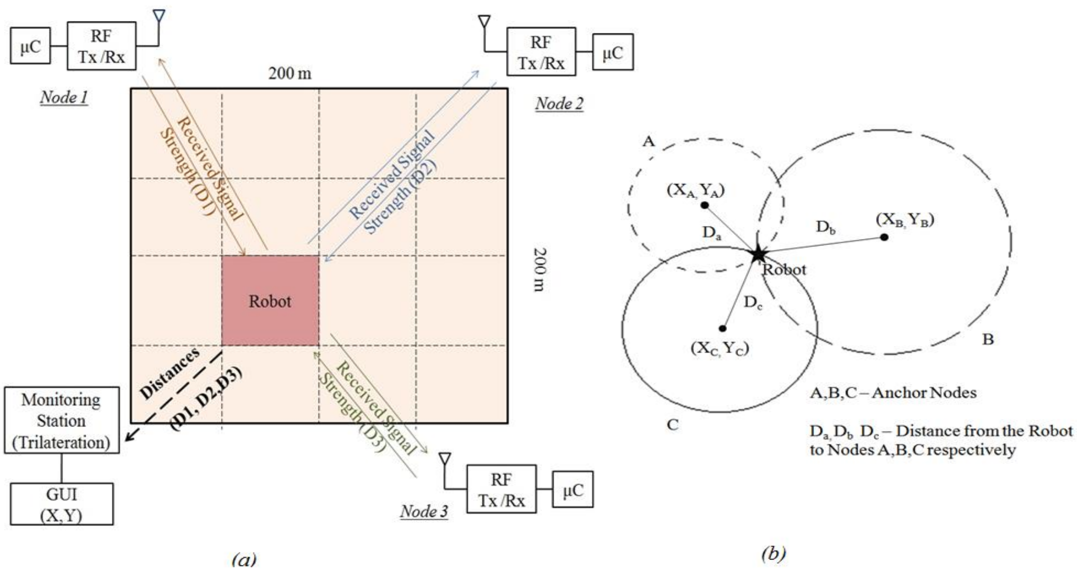

Figure 3: a) Distance Calculation using RSSI with three Anchor nodes
b) Trilateration using distances (D1, D2, D3) between Mobile robot & Anchor Nodes (1,2,3) respectively

The mobile robot is made to move in the planned path on the scanning area which uses LPC2148 microcontroller for its computing capability and simplicity. Code Composer Studio is used for moulding the prototype. The mobile robot broadcasts an RF signal, when the presence of landmine is detected using the metal detector. The RSSI module of robot is configured as master. It in turn receives the signal from the three anchor nodes, thereby distances of anchor nodes (D_{SA}, D_{SB}, D_{SC}) from mobile robot are calculated based on Received Signal Strength Indicator (RSSI). These calculated distances using RSSI are sent to the monitoring station through Zigbee (CC2530) to run Trilateration technique to find the location/ position of the mobile robot. The mobile robot uses L293D driver for running the right and left motor. The robot is given a preplanned path to move, in order to cover all the critical points while scanning the mine field.

MONITORING UNIT

The monitoring unit renders an unobtrusive environment for real time marking of landmines and considers the safety of the operator to reduce the associated risks of demining. The monitoring station computes the exact location of the mobile robot in the scanning area using the Trilateration using the distances (D_{SA}, D_{SB}, D_{SC}) that is received through Zigbee from mobile robot. It uses PIC16F877A controller for running trilateration technique.

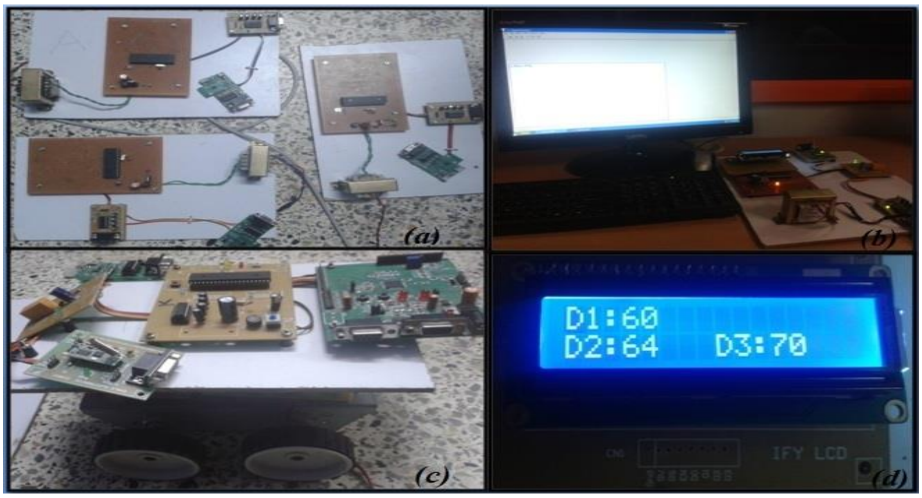

Figure 4: Hardware Snapshots: a) Three Anchor Nodes b) Monitoring Unit with output Terminal c) Mine Detector d) LCD output of RSSI distances between Robot and Anchor nodes

The technique involves the process of estimating the location using the geometry of circles and spheres. The output is seen through any terminal software like the hyper terminal via RS232 port and the snapshots of hardware modules are shown in the Figure 4.

MAPPING OF LOCATION

The relevant information including location must be available about the specific conflicts in prior to Mine clearing process. The process of gathering potentially relevant information about the mine, say the scanning area, location, terrain etc., would be the first step. This preliminary information must be mapped so as to proceed with the demining process. The proposed intuitive system offers flexible data to be mapped. The data could be seen in any terminal software as shown below in the Figure 5.

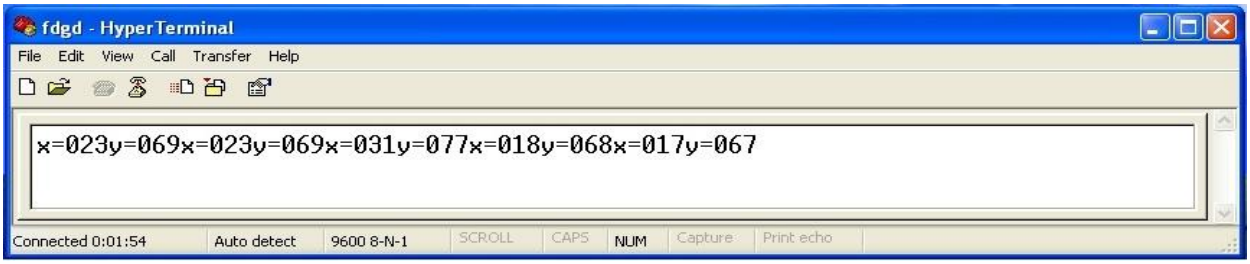

Figure 5: The X, Y Coordinates of the Mine Detector in HyperTerminal

The graphical user interface can be developed for the marking of mines in the mine field under scanning, which enhances the novice users to take part in the demining process efficiently. Handshaking of wireless serial interface has been efficiently employed between the remote terminal PC and the PIC microcontroller. The secure and trustworthy link for the communication prevails always.

PRINCIPLE OF LOCALIZATION

The RSSI technique is employed to find the distances from the mobile robot and the anchor nodes. In the free space propagation model, the received power is inversely proportional to the space separating the transmitter and receiver. RSSI measurement estimates the signal loss in the dissemination procedure or experimental loss using signal propagation model. There are several path loss models which includes free space propagation model, log-distance path loss model, Okumura- Hata model, etc., [18]. The basic principle of RSSI is to change the attenuation of strength of signal into the distance of signal transmission using the relation between the loss of signal and distance.

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d^2)}$$

Where P_t & P_r (d) are transmitting and receiving power respectively, d is the distance across the transmitter and receiver, G_t and G_r are the gain of the transmitter and receiver respectively (Generally $G_t = G_r = 1$ in embedded devices), λ is the wavelength of the signal transmitted. Hence three distances are from three anchor nodes. Considering the basic formula of a sphere and assuming the anchor nodes are on the same plane with the distances of D_{SA}, D_{SB}, and D_{SC} from mobile robot, the following equations are derived for the location estimation of the mobile robot, where X, Y are the coordinates of the mobile robot and (X_{SA}, Y_{SA}), (X_{SB}, Y_{SB}), (X_{SC}, Y_{SC}) are the co-ordinates of the anchor nodes A, B, C respectively. By calculating the distances between the anchor nodes and the mobile robot, the exact location of the presence of landmine could be calculated.

Considering the robot is at the intersecting point of three anchor nodes, The general equation of Sphere A, B, C are examined and the following equations are derived from the basic formula of sphere; thereby the intersecting point of these spheres is the exact position to be estimated [21]

Equation of Sphere A (Anchor A)

$$(X - X_{SA})^2 + (Y - Y_{SA})^2 + (Z - Z_{SA})^2 = D_{SA}{}^2 \quad (1)$$

Equation of Sphere B (Anchor B)

$$(X - X_{SB})^2 + (Y - Y_{SB})^2 + (Z - Z_{SB})^2 = D_{SB}{}^2 \quad (2)$$

Equation of Sphere C (Anchor C)

$$(X - X_{SC})^2 + (Y - Y_{SC})^2 + (Z - Z_{SC})^2 = D_{SC}{}^2 \quad (3)$$

As the proposed work is experimented in two dimensional spaces, the coordinates of Z axis (Z_A, Z_B, Z_C) are considered to be zero. Expanding and arranging the above equations, the equations (4) and (5) are obtained.

$$D_{SB}{}^2 - D_{SA}{}^2 = 2X(X_{SA} - X_{SB}) + X_{SB}{}^2 - X_{SA}{}^2 + 2Y(Y_{SA} - Y_{SB}) + Y_{SB}{}^2 - Y_{SA}{}^2 \quad (4)$$

$$D_{SB}{}^2 - D_{SC}{}^2 = 2X(X_{SC} - X_{SB}) + X_{SB}{}^2 - X_{SC}{}^2 + 2Y(Y_{SC} - Y_{SB}) + Y_{SB}{}^2 - Y_{SC}{}^2 \quad (5)$$

Rearranging the equations (4) and (5), below linear equations are obtained and are considered to be two intermediate values V_a & V_b. Solving the linear equations algebraically, the location X and Yare estimated.

$$X(X_{SC} - X_{SB}) + Y(Y_{SC} + Y_{SB}) = \frac{(D_{SB}{}^2 - D_{SC}{}^2) - (X_{SB}{}^2 - X_{SC}{}^2) - (Y_{SB}{}^2 - Y_{SC}{}^2)}{2} = V_a \quad (6)$$

$$X(X_{SA} - X_{SB}) + Y(Y_{SA} + Y_{SB}) = \frac{(D_{SB}{}^2 - D_{SA}{}^2) - (X_{SB}{}^2 - X_{SA}{}^2) - (Y_{SB}{}^2 - Y_{SA}{}^2)}{2} = V_b \quad (7)$$

$$Y = \frac{V_b(X_{SC} - X_{SB}) - V_a(X_{SA} - X_{SB})}{(Y_{SA} - Y_{SB})(X_{SC} - X_{SB}) - (Y_{SC} - Y_{SB})(X_{SA} - X_{SB})} \quad (8)$$

$$X = \frac{V_a - Y(Y_{SC} - Y_{SB})}{(X_{SC} - X_{SB})} \quad or \quad \frac{V_a(Y_A - Y_B) - V_b(Y_C - Y_B)}{(Y_A - Y_B)(X_C - X_B) - (Y_C - Y_B)(X_A - X_B)} \quad (9)$$

The estimated location is communicated to the remote monitoring and control station using XBee module, which are later plotted in GUI for the demining detachment to execute the safety unplugging process.

SYSTEM ANALYSIS

A detailed quantitative analysis is done by evaluating the proposed localization scheme for outdoor environment. A test bed area approximately 100m width and length is used. In the performed simulation the anchor nodes are manually placed at known location in a rectangular plot in accordance to the fixed coordinates. The location of the mobile node is estimated by the coordinator and the coordinator is placed randomly within the communicational range of mobile node. The simulated result is shown in the Figure 6.

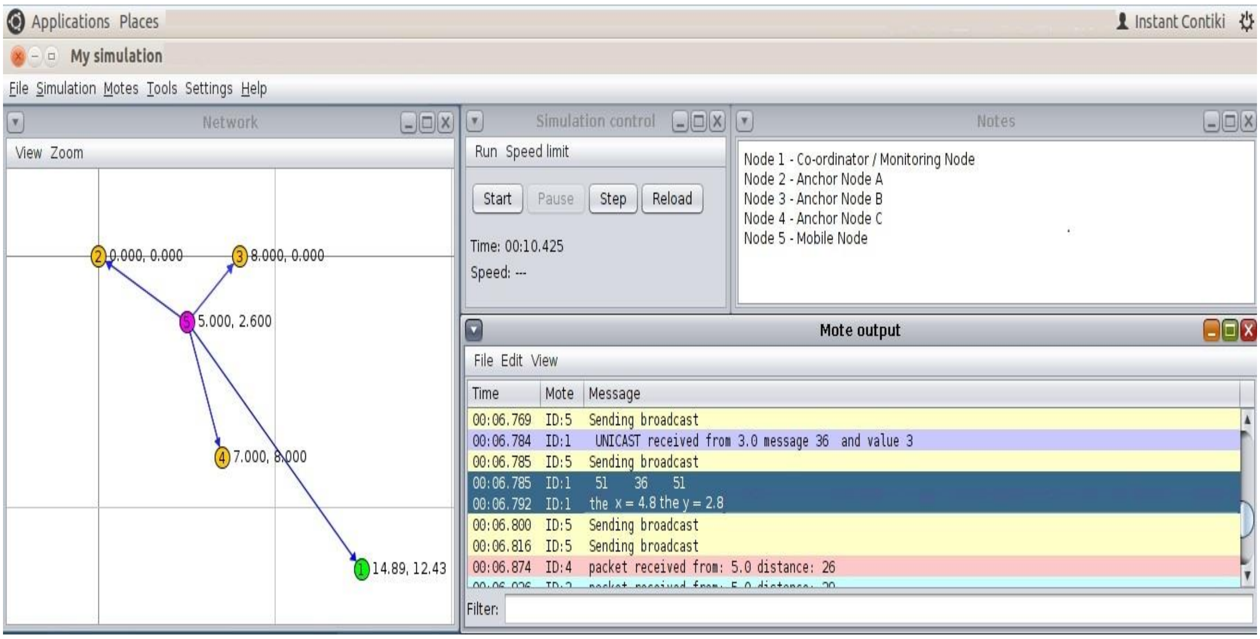

Figure 6: Simulated Result - The Location of the mobile node estimated Using RSSI and Trilateration

The mobile robot determines the distance based on the signal strength values from the anchor nodes and transmits the information to the coordinator, which in turn determines the location values using Trilateration. The increase in quantity of anchor nodes is directly proportional to the accuracy of localization.

The aim is to evaluate the accuracy of the location system employed for mine detection. Table 1 shows the summary of every instant (i) of data recorded by measuring the actual position (X_{act}, Y_{act}) and the estimated position (X_{estm}, Y_{estm}) of the mobile robot employing RSSI and Trilateration in a test bed area.

No of Mines Placed	Actual Position (m) (X_{act}, Y_{act})	Estimated Position (m) (X_{estm}, Y_{estm})	Localization Error (m)
Mine 1	(5.0 , 2.6)	(4.8 , 2.8)	0.28
Mine 2	(3.0 , 2.0)	(2.9 , 1.9)	0.14
Mine 3	(4.0 , 2.0)	(4.1 , 1.8)	0.23
Mine 4	(6.4 , 4.6)	(6.7 , 4.5)	0.31

Table 1: Experimental Summary

The Localization error is calculated so as to prove the system is accurate. The accurate coordinates of the mine is at (5.0, 2.6) in meters, and the estimated position is at (4.8, 2.8) in meters which is shown in the Figure 6, for which error in localization for this instant is 0.28 m (using equation 10 to estimate localization error). The location of the actual and estimated value is depicted in the graph in Figure 7, using the data recorded on experimentation.

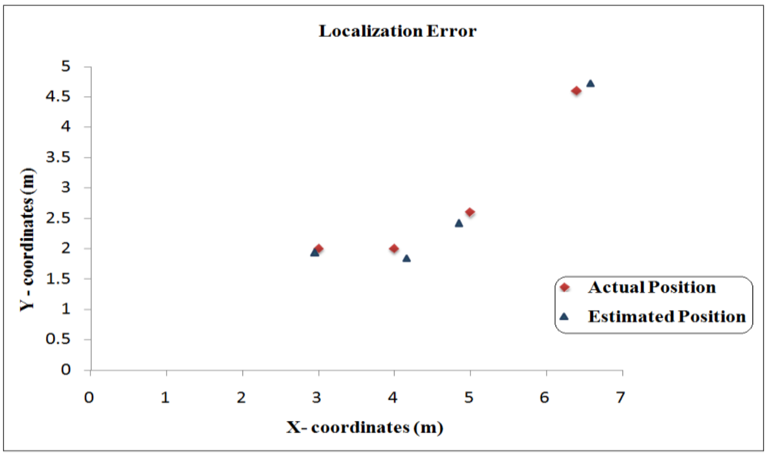

Figure 7: Analysis on the Localization Error

$$\text{Localization Error} = \sqrt{(X^i_{estm} - X^i_{act})^2 + (Y^i_{estm} - Y^i_{act})^2} \qquad (10)$$

From the Table 1, the average Localization Error calculated in the experimental setup is 0.24(m). This Localization error is negligible which generally occurs due to the error in distance which depends on RSSI values in between the nodes that communicate with the mobile node.

CONCLUSION

In recent decades, several innovative ideas and solutions have evolved to solve the problem of localization in military surveillance and sensor networks. The proposed work is found to be a solution for localizing and mapping a mine for the safety mine hunting operations. It quantifies the effectiveness of implementing RSSI and trilateration in mine hunting operations to estimate the location of mine and justifies through simulation analysis. High accuracy is observed on increasing the number of anchor nodes. In addition to the present work, the feasible hot areas to concentrate are: 1) The effective plan for path in which the mobile robot can travel across the entire terrain to cover every critical point 2) The security of the localization technique 3) Implementing this technique in any terrain like hills, plains, desert, which are possibly interesting issues in future to deal with multipath propagation.

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