Self-orientation of Directional Antennas, Assisted by Mobile Robots, for Receiving the Best Wireless Signal Strength

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***Abstract*—In our previous work, we presented autonomous, self-organizing wireless networks using multiple mobile robots, which enabled the desired wireless coverage in the form of a mesh network and a point-to-point network. Capacities to cover the desired area using multiple robots, all carrying omni-directional antennas, were demonstrated. However, the use of omni-directional antennas did not prove effective in covering a sufficiently large distance. Hence, in this paper, we introduce the use of directional antennas to increase the range of the wireless network, and later apply this concept to extending a wireless network over complex terrain. As the first step to using directional antennas, we will present a pattern-based search algorithm to address the problem of self-orientation of a Directional Wireless Network (DWN). The algorithm will find the orientation of antennas that enables them to receive the best possible Received Signal Strength Indication (RSSI). Preliminary experimental results will be shown that demonstrate the ability of the algorithm, assisted by mobile robots with pan-tilt devices for the antennas, to automatically find the maximum RSSI available. Finally, we will conclude with a discussion of findings from this paper and applications of the use of directional antennas.**

I. INTRODUCTION

RECENTLY, research on Wireless Sensor Networks (WSN) has been increasing, due to such networks' widening use in many practical applications, such as factory automation systems, transportation management, military systems, and structural diagnosis. To cover an entire factory with a wireless sensor network, for instance, a number of wireless sensors will be needed. Minimizing the number of required wireless sensors will reduce both the equipment and energy costs, as well as minimizing the man power needed to manage such a network. Therefore, research regarding problems with wireless network coverage and its optimization has been increasing. For example, in [1], the authors addressed energy efficiency and network connectivity, two important properties of a Wireless Ad-hoc Sensor Network (WASN), to accommodate a large WASN with limited resources and a dynamic topology. The authors in [2] provided efficient distributed algorithms, using the relative neighborhood graph, to optimally solve the best-coverage problem. They also extended the algorithms to find the best-coverage-path with the least energy consumption.

As WSNs can be used in a variety of applications, there may be important aspects that are yet to be considered, such as the best time and place to install a WSN. For instance, if sensor networks need to be installed rapidly in an emergency, problems with maximum wireless network coverage become more complicated and need to be redefined [4-9,10]. Moreover, if sensors are needed in areas that humans cannot access, another formidable problem of sensor network design might arise. To cope with these problems, there have been several studies introducing mobile platforms for a WSN [3-9]. These studies have used various mobile platforms, carrying sensor nodes, to form WSNs, such as mobile robots and balloons. The authors in [3] dealt with ad-hoc network coverage, using networked robots, by putting wireless network cards on top of vacuum cleaning robots and attempting to maximize the wireless coverage area using the sparsest possible deployment. The authors in [4] showed that a distributed sensor network, employing four-wheeled mobile robots, helps first responders during emergencies. In addition, the authors in [5] proposed a ballooned wireless mesh network to promptly organize communication in a disaster area. In [6-7], the authors presented sensor node deployment by means of Unmanned Aerial Vehicles (UAVs) in a disaster area.

We also showed autonomous, self-organizing wireless networks using multiple mobile robots in [8-9]. We introduced the novel concept of Autonomous Wireless Agent Robotic Exchange (AWARE) to provide the desired wireless coverage in the form of a mesh network and a point-to-point network. Although we demonstrated, in these papers, the capability to cover the desired area using multiple robots carrying omni-directional antennas, the area was relatively small. If the use of directional antennas is employed, it will increase the range of the wireless network, allowing network connectivity over a much larger area than that of omni-directional antennas.

Recently, many research groups have paid attention to Directional Wireless Networks (DWNs), due to their superior ability to cover a very long distance [11-13]. Since a directional antenna has a limited Field of View (FOV), assigning the correct orientation to the antenna plays a significant role in WSNs with directional antennas. The authors in [11] addressed the problem by selecting a minimum number of directional sensors and assigning them orientations, and designing a simple greedy algorithm for coverage maximization. The authors in [12] aimed at minimizing the overlapping wireless coverage

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area, and facing the antennas toward the area of interest to improve the coverage. In [13], the authors address the problem of self-orientation of wireless multimedia sensor networks to maximize multimedia coverage.

In this paper, we introduce a pattern based search algorithm for the self-orientation of antennas in a DWN, finding the best orientation for a directional antenna to receive maximized Received Signal Strength Indication (RSSI). This paper will play an important role in achieving the final objective of our research, which is to establish autonomous, agile, scalable, self-organizing wireless networks for long distance communication in complex terrain.

The remainder of this paper is organized as follows. First, in Section II, the final objective of our research will be introduced. Second, in Section III, we will introduce a pattern based search algorithm to find the best antenna orientation for receiving maximized RSSI. Then, in Section IV, the setup for an experiment to verify the performance of the pattern based search algorithm will be described, and the results of several experiments will be given by describing the operations of the designed pan-tilt directional antenna. Finally, the conclusions and future scope of this work will be summarized in Section V.

II. AWARE: AUTONOMOUS WIRELESS AGENT ROBOTIC EXCHANGE

As mentioned above, in previous work, we presented autonomous, self-organizing wireless networks using multiple mobile robots, which enabled the desired wireless coverage in the form of a mesh network and a point-to-point network. Capacities to cover the desired area using multiple robots, all carrying omni-directional antennas, were demonstrated. However, the use of omni-directional antennas did not prove effective in covering a sufficiently large distance. Hence, in this paper, we introduce the use of directional antennas to increase the range of the wireless network. Like an omni-directional antenna, the effectiveness of a directional antenna is influenced by distance, although not nearly as much. The basic concept of using directional antennas in the proposed application is shown in Fig. 1.

As depicted in Fig. 1, the use of multiple mobile robots carrying directional antennas will allow a wireless signal to be relayed from the initial node to the final node. Each robot carries two external antennas to form a linear network for long distance coverage, as shown in Fig. 1, but additional antennas and radios can be added to create additional multipoint connections. The number of robots and antenna is determined by the requirements of the system. Their relationships can be expressed as follows,

$$\left\{ \begin{array}{ll} N_a = N_r, & N_r \leq 2 \\ N_a = N_r + 1, & N_r = 3 \\ N_a = N_r + 2, & N_r \geq 4 \end{array} \right\} \quad (1)$$

where N_a is the number of needed antennas and N_r is the number of mobile robots to form a link.

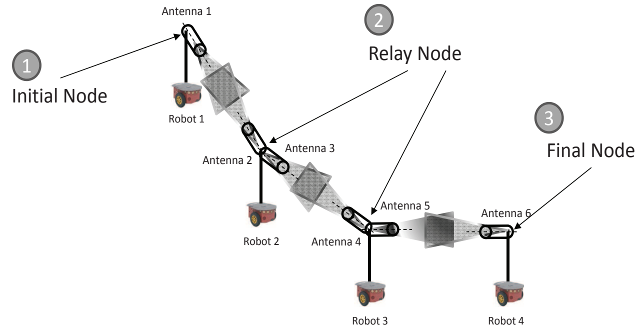


Fig. 1. A configuration of self-configurable wireless networks using multiple mobile robots carrying antennas.

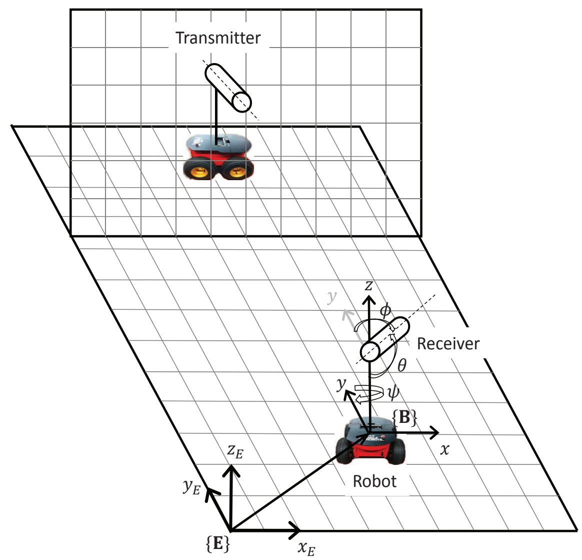


Fig. 2. A simplified model for self-configurable wireless networks.

III. PATTERN BASED SCANNING ALGORITHM

A. Formulating Problems

Unlike omni-direction antennas, directional antennas rely on a specific orientation to receive a quality RSSI. Hence, we are formulating this problem to maximize the use of directional antennas. FOVs of a directional antenna, on both the horizontal and vertical planes, are narrower than those of an omni-directional antenna. Because of this, a directional antenna can transmit a wireless signal much further than an omni-directional antenna, using the same amount of energy. For the extended range to be beneficial, the antenna must be oriented in a specific angle and direction. Therefore, the problem of finding the best orientation is taken into consideration here, with the following assumptions:

- Two antennas, one configured as a transmitter and the other as a receiver, are deployed randomly so they do not know each other's location and orientation information. (However, they are deployed within operational range.)
- The orientation and location of the transmitter is fixed.

If a mobile platform can move across both the x-axis and y-axis, as well as rotate, it enables the directional antenna to have three degrees of freedom (DOF): x, y,and ψ, as depicted in Fig. 2. The robotic platform itself cannot orient the antenna to receive the best RSSI. For that reason, two more DOF are needed: pan angle ϕ, and tilt angle θ, and they are supported by a pan-tilt device.

With these five supportive DOF, we are simply formulating the self-orientation problem. Fig. 2 shows a simplified model for a self-configurable wireless network. In Fig. 2, a mobile platform carries a directional antenna with the goal of finding the location to get the best RSSI from the corresponding antenna. In addition, the directional antenna, with a pan-tilt device, finds the necessary orientation to get the best RSSI. Since the objective of this coordination is for the mobile platform to find the best location and for the antenna to find the best orientation to receive the highest quality RSSI, we can formally extend this problem to a minimization problem in the following notation:

> **Problem**: Find a minimized objective $f(\mathbf{X})$ indicating the location and orientation to receive the best RSSI.
> **Subject to**: $x_L \leq x \leq x_U; y_L \leq y \leq y_U; \phi_L \leq \phi \leq \phi_U; \theta_L \leq \theta \leq \theta_U$

$$,\text{where } \mathbf{X} = \begin{bmatrix} \phi & \text{(roll angle of the antenna)} \\ \theta & \text{(pitch angle of the antenna)} \\ x & (x\text{-positon of the robot}) \\ y & (y\text{-postion of the robot}) \\ \psi & \text{(heading angle of the robot)} \end{bmatrix}$$

where $\mathbf{X}$ is the vector of design variables, x_L and x_U represent lower and upper boundaries of the operation of the mobile robot in the x-axis of the earth frame $\{\mathbf{E}\}$, and y_L and y_U represent lower and upper boundaries of the operation of the mobile robot in the y-axis of the earth frame $\{\mathbf{E}\}$. In addition, the antenna can move to pan angle ϕ from ϕ_L to ϕ_U, and it can move to tilt angle θ from θ_L to θ_U. These angles are defined in the body frame $\{\mathbf{B}\}$.

B. Pattern Based Search Algorithm

Due to the ever-changing RSSI patterns and insufficient information, which arises from the fact that antennas are deployed randomly and have no information on each other's location and orientation, generating an objective function $f(\mathbf{X})$ for predicting an optimal solution is impossible. This eliminates the possibility of using traditional optimization techniques that could be applied to this problem, such as the Steepest Descent Method and the Broydon-Fletcher-Goldfarb-Shanno (BFGS) Method, which generally require knowledge of the objective function gradient to find the minimum [14]. Since all design variables are related to each other for the objective function, a nonlinearity problem arises. Thus, simultaneously solving all the variables in this problem is almost impossible. Therefore, in this paper, we approach this problem with the univariate method that changes only one variable at a time, while fixing the other variables.

In the use of directional antennas, if we assume that, in a given time period, there are minor multipath and interference

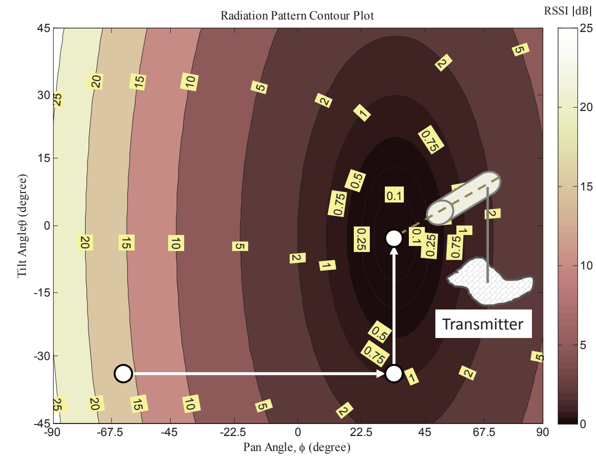


Fig. 3. An example of radiation patterns of a directional antenna on $\phi - \theta$ axis.

effects and the line of sight (LOS) is guaranteed between a pair of antennas (e.g. in Fig. 2), then the changes in radiation from the transmitter will be relatively small. In other words, its original shape will be kept, even though the radiation pattern is slightly distorted. In this case, the minimum point can be found by searching for the minimum along directions parallel to the coordinate axes, since the changes in the objective function with the directions provide a favorable search direction towards the minimum point. For instance, if the receiver searches for the minimum along directions parallel to the coordinate axes (ϕ and θ), it eventually approaches the minimum point as depicted with the white lines in Fig. 3, where the radiation pattern of the transmitter is plotted on the receiver's view.

We approach this problem with a pattern based search algorithm, using the assumptions described above. First of all, the pattern based search algorithm samples points in the domain, and uses the information it has obtained to decide where to search next. By means of this approach, the pattern based search algorithm requires no knowledge of the objective function gradient. Then, with the univariate method, the algorithm changes only one variable at a time to move from an initial guess point in a favorable direction (positive or negative), and seeks to produce a sequence of improved approximations to the minimum point. If a search in one variable (direction) is completed, the search is continued in a new direction. This new direction is obtained by changing any one of the other variables that were fixed in the previous search. There are 5 design variables in this problem, so we set the search in ϕ, θ, x, y, ψ direction order, with a search direction vector $\boldsymbol{S}$ and fixed step sizes α, which are updated with respect to the current i value. The search procedure is continued by taking each coordinate direction in turn. After all the directions are searched sequentially, the first cycle is complete and the next cycle is repeated until a stopping criteria is satisfied. This is based upon how much the objective function is decreasing for each cycle. The pattern based search algorithm can then be summarized as shown in Fig. 4.

In this algorithm, especially, the step sizes should be care-

/*Pattern Based Search Algorithm*/

Choose $\mathbf{X}_0$
$i = 1, n = 5$ /* *Number of directions* */
/* *Repeatedly scanning in* ϕ, θ, x, y, ψ *direction order*
until requirement is satisfied */
Repeat each cycle C
Set $\mathbf{S}_i$ and α_i
$\mathbf{X}_1 = \mathbf{X}_0 + \alpha_i \mathbf{S}_i$
/* *Determine favorable direction* */
If $f(\mathbf{X}_0) < f(\mathbf{X}_1)$; $\mathbf{S}_i = -\mathbf{S}_i$
Repeat each loop j
$\mathbf{X}_j = \mathbf{X}_{j-1} + \alpha_i \mathbf{S}_i$
$j \leftarrow j + 1$
Stop $f(\mathbf{X}_{j-1}) - f(\mathbf{X}_j) \leq \varepsilon_1$ or $\mathrm{X}_{j_i} \leq \mathrm{L}_i$ or $\mathrm{X}_{j_i} \geq \mathrm{U}_i$ /* *Stop loop j**/ /* *where* X_{j_i} *is current design value and* L_i, U_i *are its lower and upper boundaries**/
$f_C(\mathbf{X}) \leftarrow$ Best $f(\mathbf{X})$
$\mathbf{X}_0 \leftarrow f_C(\mathbf{X})$
$i \leftarrow i + 1$ /* *Search* $\phi \rightarrow \theta \rightarrow x \rightarrow y \rightarrow \psi$ */
If $i = 5$; $i \leftarrow 1$ /* *Reset order of searching* */
$C \leftarrow C + 1$
Stop $f_C(\mathbf{X}) - f_{C+1}(\mathbf{X}) \leq \varepsilon_2$; /* *Stop cycle C* */

Fig. 4. A pattern based search algorithm.

fully decided upon, because they confine each design variable within the lower and upper boundaries, limiting the time required to solve the problem, as well as guaranteeing the final accuracy desired. Furthermore, based on these fixed step sizes, the entire space is divided into a grid. For example, if the antenna scans ϕ direction with $22.5°$ intervals (fixed step size), subject to ϕ's constraint, $-90° \leq \phi \leq +90°$, then the number of total points in this direction will be 9, such that $(9-1) \cdot 22.5° = 180°$. This grid search space is used to increase the speed of convergence, although it finds an approximate minimum. Conversely, a step size for ψ angle can be chosen with relative ease. Because this angle overlaps with the ϕ angle to some extent, and the angular speed of ψ is far slower than that of ϕ, ψ angle is not generally used when the antenna needs to rotate. However, when the antenna requires an orientation angle out of its allowable range (± 90 degree), the ψ angle plays a vital role in searching for a quality RSSI that is out of view. One example of the search direction vector $\boldsymbol{S}$ and step size α set to the scanning algorithm is as follows:

$$
\begin{aligned}
\alpha_1 &= 22.5, & \boldsymbol{S}_1 &= [0,0,1,0,0]^T \\
\alpha_2 &= 10, & \boldsymbol{S}_2 &= [0,0,0,1,0]^T \\
\alpha_3 &= 0.5, & \boldsymbol{S}_3 &= [1,0,0,0,0]^T \\
\alpha_4 &= 0.5, & \boldsymbol{S}_4 &= [0,1,0,0,0]^T \\
\alpha_5 &= 90, & \boldsymbol{S}_5 &= [0,0,0,0,1]^T
\end{aligned}
$$

where $\alpha_{i,i\in\{1,2\ldots5\}}$ is a step size and $\mathbf{S}_i$ is a search direction, and each element indicates $[\phi, \theta, x, y, \psi]^T$, respectively, and their units are $[°$(degree), $°$, m(meter), m, $°]^T$, respectively.

IV. EXPERIMENTAL SETUP AND RESULTS

A. Experimental Setup

For initial experimentation, an Alfa AWUS036H USB Wireless Adapter was used as the receiver/scanner. The adapter has a transmit power of 1 Watt over the 2.4 GHz frequency band. A homemade antenna, commonly known as a "Cantenna", was constructed as an inexpensive means to create a directional antenna for the scanning device. This assembly was then attached to an Asus Eee PC laptop computer running the Ubuntu Lucid Kernel 2.6.38 in the form of BackTrack5.

```
iwconfig wlan0
wlan0     IEEE 802.11bgn  ESSID:"          "
          Mode:Managed  Frequency:2.462 GHz  Access Point:
          Bit Rate=54 Mb/s   Tx-Power=20 dBm
          Retry  long limit:7   RTS thr:off   Fragment thr:off
          Encryption key:off
          Power Management:on
          Link Quality=61/70  Signal level=-49 dBm
          Rx invalid nwid:0  Rx invalid crypt:0  Rx invalid frag:0
          Tx excessive retries:0  Invalid misc:0   Missed beacon:0
```

(a)

```
iwconfig wlan0 | grep Signal| cut -d '-' -f2 |cut -d ' ' -f1
50
```

(b)

Fig. 5. (a) A simple command line operation. (b) Additional command line parsing a single instruction.

The Alfa card was chosen as our primary radio due to its high power and external antenna connector. This device uses a standard SMA antenna connector, which is much sturdier than the U.FL adapters found on many other lower-power USB wireless devices. With an overall weight of 38.5g and its ability to draw all necessary power from the host laptop, the Alfa is perfect for use with this mobile robotic system.

Linux was chosen as the operating system for testing, due to its easily accessible wireless connectivity data. In Microsoft Windows, wireless network configuration is run and monitored through either third party software or the Windows Wireless Zero Configuration (WZC) service. Third party programs are slow to update RSSI information, normally doing so every 1 to 3 seconds. Writing a Visual Basic or C# program to access the WZC service would have similar lag times, dependent on the system hardware. In Linux, the RSSI information for the active connection is updated several times per second and can be gathered through a simple command line operation, as shown in Fig. 5 (a). Through additional command line parsing, a single instruction can return a highly accurate and timely RSSI value, as shown in Fig. 5 (b).

One issue with retrieving the data in this manor is that RSSI and connectivity information are only gathered on the wireless service set identifier (SSID) actively being associated to or authenticated with. Once the RSSI drops below a set threshold, the system will disassociate from the wireless network and begin scanning for another. This issue was solved by periodically forcing an association to the test network and purging all other SSIDs from the wireless configuration menu.

The "Cantenna" was constructed to replace the stock omni-directional antenna that came with the Alfa adapter. Its construction consisted of two primary components, the first being a combination wave guide and reflector. For this, a full size Pringles potato chip can was used. The second component is the combination connector and radiating element. The connector used was a standard N-type, and the radiating element a piece of non-coated copper wire (roughly 10 centimeters in length). A hole was cut 8.5 centimeters from the rear deflector

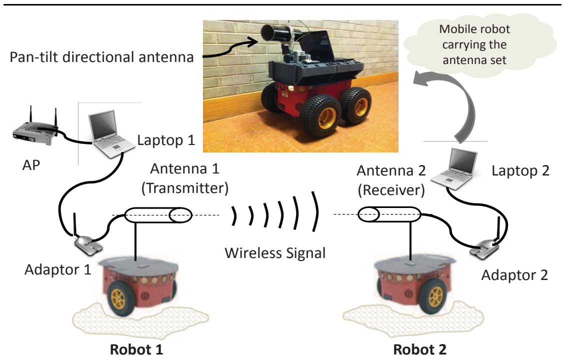


Fig. 6. A configuration of experimental setup and a mobile robot carrying the pan-tilt antenna set.

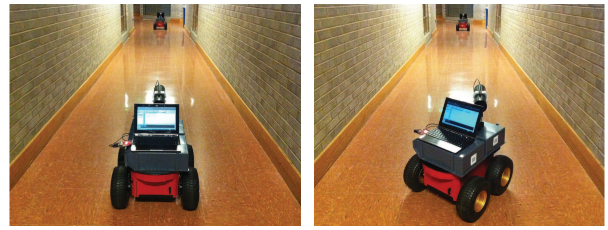
of the can, and once the copper wire was soldered into the N-type adapter, it was placed in the hole and hot glued in place. As there is no consensus as to the proper design of an antenna of this nature, its specifications are somewhat unknown, with weight being the primary consideration.

The experiment shown in Fig. 6 employs all of these devices, with the addition of the P3AT robot and the Robotis servo motor tracking arm. The first laptop in Fig. 6, referred to as "Laptop 1", has been converted into an access point and a client, in order to create a relay for the wireless signal. The internal wired network device ($eth0$) is connected to a wired network as a client. The signal is then relayed through the USB Alfa card radio ($wlan1$), which is representing itself as an access point, using "airbase-ng" of the "aircrack-ng" suite. The second laptop in Fig. 6, referred to as "Laptop 2", is using its USB Alfa card ($wlan1$) in a client mode with the access point of Laptop 1. This allows Laptop 2 to seamlessly gain network access through the wired network.

B. Results

In this sub-section, we show the results of the preliminary experiment, demonstrating the self-orienting, directional antenna automatically finding the best orientation for maximized RSSI. In this experiment, we set up Robot 2 in Fig. 6 as a static model, (x, y, and ψ DOF from the mobile robot are not needed) and assume the best location for the antenna has already been found, in order to observe the operation of the pan-tilt antenna in more detail. Thus, the pattern based search algorithm is always terminated when the algorithm scans the ϕ or θ direction. In other words, the algorithm should be terminated when i=1 or i=2 in the algorithm shown in Fig. 4.

Then, to validate the performance of the search algorithm, we prepared two different situations, as shown in Fig. 7 (a) and (b), where a P3AT mobile robot (from MobileRobots Co.) carried a directional antenna, a laptop, and the USB adaptor that is being used for this experiment. In the two situations, Robot 1 carried a transmitting antenna, configured as an access point, that was fixed at $\mathbf{X}$=$[0° ,0° ,0_m,0_m, 0°]^T$. In the first situation, then, Robot 2 carried a receiving antenna, configured as a client, that was set to face straight at the transmitting antenna, in order to set the robot's heading angle ψ is fixed at $0°$. In the second situation, Robot 2 is set to face slightly away from the transmitting antenna, with the heading angle ψ fixed at $45°$. After that, we scanned all possible points to identify the best objective in advance and activated the proposed pattern based search algorithm. In this step, for scanning in the ϕ direction (when i=1), we set the step size of α_1 to $22.5°$, resulting in 9 total points in this direction. In addition, for scanning in the θ direction (when i=2), we set the step size of α_2 to $15°$, resulting in 7 total points in this direction, satisfying its constraint $-45° \leq \theta \leq +45°$. Then, stopping criteria ε_1 and ε_2 are set to 2dBm and 0dBm. With these settings, if the designed scanning method indicates the same location as the best in all scanned points, it can be said that the scanning algorithm is validated.



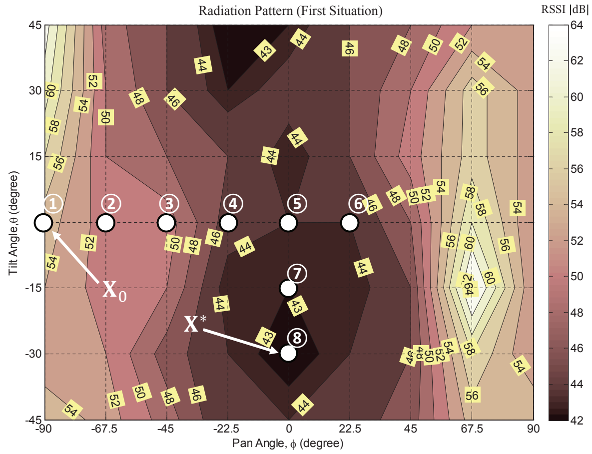
(a) (b)

Fig. 7. Two different situations. (a) Robot 2 with when its heading angle ψ is fixed at $0°$. (b) Robot 2 with when its heading angle ψ is fixed at $45°$.

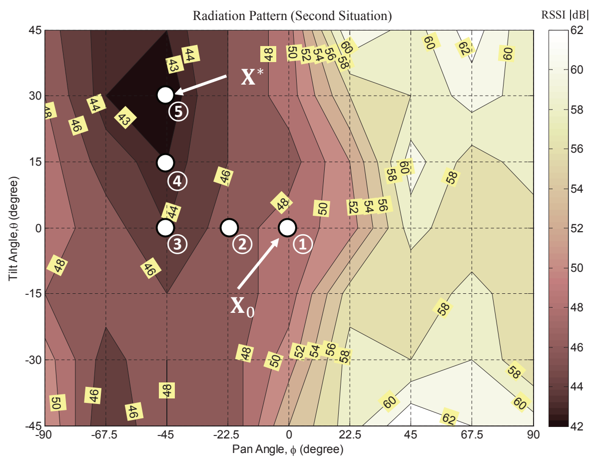
Contours in Fig. 8 (a) and (b) show all scanned RSSI values at all points in the two different situations illustrated in Fig. 7 (a) and (b). As we expected, in the contours, there are explicit patterns showing convex shape around the minimum, although there is some distortion to these patterns that can be seen away from the minimum. This implies that the minimum can be found by the proposed pattern based search algorithm (See Fig. 3). In Fig. (8), lower values of the contours mean a better RSSI, because RSSI is measured on a scale of negative dBm, which is a logarithmic unit of decibels relative to one milliwatt. A device receiving an RSSI of -20dBm is actually receiving an amount of electricity, through the air, equal to 0.01 milliwatts. As the scale is logarithmic, due to the loss of electricity in the air, every drop in dBm is an exponential loss in received electricity (-30 dBm = 0.001mW, -60dBm 0.000001mW). Hence, this experiment shows a reverse heat map of the EM spectrum for a given SSID, as perceived by the directional antenna.

We set the initial value $\mathbf{X}_0$ to $[-90°, 0°, 0_m, 0_m, 0°]^T$ for the first situation and $[0°, 0°, 0_m, 0_m, 45°]^T$ for the second situation, respectively. As results in Fig. 8 (a) and (b) show, in both cases, the search direction to the minimum was correctly determined by the pattern based search algorithm (depicted by the white dots and corresponding numbers). Accordingly, the outputs indicate the exact same locations that were found each time all points were scanned, and final values are $\mathbf{X}^*$=$[0°, -30°, 0_m, 0_m, 0°]^T$ for the first case, and $\mathbf{X}^*$=$[-45°, 30°, 0_m, 0_m, 45°]^T$ for the second case, respectively.

As a result, it was proven that the search algorithm could successfully search for the location to receive the best RSSI. In this result, as the change in the objective function was smaller than ε_2, the search algorithm was terminated in two cycles.



(a)



(b)

Fig. 8. Results of two different situations. (a) First situation: contours of scanned data with $\mathbf{X}_0$=$[-90°\ ,0°\ ,0_m,0_m,\ 0°]^T$. (b) Second situation: ontours of scanned data with $\mathbf{X}_0$=$[0°\ ,0°\ ,0_m,0_m,\ 45°]^T$.

V. CONCLUSIONS AND FURTHER WORKS

The objective of this paper was to design a search algorithm that enables a directional antenna to find the location and orientation for receiving the best possible RSSI. To begin with, we explained about some inherent characteristics of DWN problems. For instance, the objective function is not obtainable in advance, and this is a non-linear problem, which prevents the use of some traditional optimization techniques. To cope with these characteristics, we introduced the pattern based search algorithm, along with the univariate method that uses a fixed step size.

To validate the proposed search algorithm, we built a custom pan-tilt system, having 2 DOF, with two servomotors. Then, this system was incorporated into a mobile platform having 3 DOF. Finally, the directional antenna ended up having 5 DOF: x-axis, y-axis, ψ angle from the mobile robot, and ϕ and θ angles from the pan-tilt system. Then, we formally extended our search algorithm by introducing these 5 DOF as variables of the objective function of the minimization problem. As a result, this objective function was minimized, with some iteration, to find the orientation for receiving the best possible RSSI.

The minimum was successfully found in the first situation with $\mathbf{X}_0$=$[-90°,\ 0°,\ 0_m,\ 0_m,\ 0°]^T$. However, if the search started with a different initial point, for instance $\mathbf{X}_0$=$[-90°,\ 30°,\ 0_m,\ 0_m,\ 0°]^T$, the search direction would be determined toward the local minimum at $(-22.5°,45°)$. The search direction being toward a local minimum shows that choosing an appropriate $\mathbf{X}_0$ plays a significant role in the patterned based scanning algorithm for finding a global minimum.

The final goal of this research is to create a self-configurable wireless network using multiple robots. However, in this paper, we have only dealt with a standalone system, the link robot (Robot 2), and the use of the pan-tilt directional antenna in Fig. 6. Therefore, in order to achieve our final goal, we need to create the all-inclusive system by incorporating Robot 1 with Robot 2 to find the best position, relative to each other. In addition to the type of network coverage, placement of the robots, and direction of antennas, the different combinations of robots and antennas should be determined by considering the given task and environment.

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