Design and Development of MOKHTAR Wind Tracker

Ata Jahangir Moshayedi, Damayanti C Gharpure, Arvind D Shaligram

Abstract: This work presents the design and development of a wind tracker (MOKHTAR[1]) with implementation of Zigzag and Spiral algorithms for detecting the wind source. For odor tracking research the Wind tracking is important. A novel wind flow and direction sensor based on an array of Evaporative Heat Rejection Devices (EHRD) such as the ones used in cooling towers is developed during the present work. The developed sensor is installed on the wind tracker (MOKHTAR). MOKHTAR seeks the location of the wind source with Zig-Zag and Spiral tracking algorithms. Both the Zig Zag and Spiral algorithms are implemented and their performance is compared with respect to step size, time taken and the probability of reaching the wind source. Finally, results of path monitoring for comparison between the two algorithms are shown. The proposed system is used on a robot vehicle as the initial stage of plume tracking activity. Moreover, the proposed wind sensor array can be used in the meteorological and environmental studies

Index Terms—Mokhtar wind tracker, Wind sensor, Spiral movement, Zig zag movement.

I. INTRODUCTION

The wind direction and speed are important in various applications like weather monitoring, pollution direction studies, nuclear radiation and high securities in a chemical war etc. [1].

In odor tracking studies ,wind has a vital role in two aspects; First: as an Odor carrier [2], Second: changing the shape of odor plume and give some unsteady intermittent movement of odor molecules in both time and space [3].

On the other hand, wind can be one of the significant elements and parameter in addition to humidity, temperature, etc. for gas sensor changing their accuracy and performance [4].

In applications like plume tracking, researchers have tried to implement the insect behaviour [5-7]to combine the information of chemical concentration , wind speed and direction [1]. Then, knowing the wind direction ,as a reference , highlighted to use a wind sensor widely in odor tracking systems [8-9].

In Nature, creatures like insects use the direction of wind flow carrying the odor to localize the odors [9].

In implementation of odor tracking activity, knowing the direction of the wind and robot location in terms of upwind and down-wind helps researchers to copy and re-engineer the natural behavior of cockroach, Moth [10-11] etc.

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Mokhtar in Persian language means autonomous

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More than the inherent dynamic behavior of odor, the wind behavior as the odor carrier plays an important role in odor direction. In most of reported work [6] [12-14], a wind sensor seems to be essential. Nowadays, to track the wind and specify its direction, is considered a good strategy for odor tracking researchers [15-19].

The available commercial wind sensors are Pitot Probes, which measure the fluid velocity with respect to pressure change, hot films based on effective heat transfer coefficient and its relation to the overall wind vector at the sensor.

Hot wires [20] work on the principle that elements are heated up to the certain temperature, allow it to maintain its temperature in the wind. The temperature of the individual element is used to detect wind direction and measure the local velocity at a given point. In addition, some optical methods such as LDA (Laser Doppler Anemometry) and PIV (Particle Image Velocity) are available on the market [21].

Size, space, maintenance and mechanical structure of the commercial wind sensor bring usage limitation especially in plume tracking application. Researchers have tried to sort the problem by implementing their own wind sensor. Some of these sensors are commercialized and some have been used in minor application cases.

Ultrasonic wind sensor (wind vane) [22], DC motor wind sensor [23], RF thermocouple [24], pressure transducer based wind sensor [25], pulsed wire anemometer [26], have been reported.

Recently thermal based wind detector developments have been reported with smaller size and simpler principle as compared to commercial wind vane [20][24][27].There are some efforts to find the wind speed and its direction by using the temperature sensing difference with the temperature sensor type. Nguyen [20] tried to develop a wind sensor with the help of 40 thermistor, sensor types. They proposed the array with the size of 60mm , in the form of a disk. With the capability to measure the wind speeds up to 50 mm/s.

The [24] designed an array with three thermisor sensor which is capable to measure with the wind speed of 0.3 to 1 m/s. [27] Introduced a disk shape array with seven LM35 senor types with the wind range of 1 to 8 m/s .Also the insect and the human body inspired researcher to model and implement the wind sensor based on that.

The Spring shape sensor like hair cells wind sensor made to simulate the cricket's hair body [28] and optical switch wind sensor based on human face skin hair [29] to measure the air flow are reported.

Knowing the wind direction is the key factor of odor carrier is one of the main aspect which inspired us to design a wind tracking system. The proposed wind sensor , with the use of EHRD is a novel idea based on using the array of LM 35.The EHRD array has been successfully integrated on the robot vehicle and satisfies the criteria of being light in weight, optimum in size

based on the limitation of size and dimension of the robot vehicle and low power consumption[1].
The wind tracker functions as the initial gate for odor tracking research and implementation of zigzag and Spiral algorithms for testing performance. The purpose of using spiral and zigzag for tracking response is better as compared to pure casting [3-4] [30-32].Along with this system, Path and Position Monitoring System(PPMS) [33] has been designed and used for this study.
The remainder of the paper is organized as follows: system description based on sensor principle, design , characterization and proposed sensor array description in section ii.: robot platform (Mokhtar), wind tracker configuration and navigation algorithms dealt with in section III. Experiment setup and results presented in section iv. Finally, paper is concluded in section v.

II. SYSTEM DESCRIPTION

A. Sensor Principle and design

The main hypothesis and basic foundation of sensor design part starts from the relation between temperature and wind direction. By changing the wind direction, the temperature in the atmosphere will vary, based on the heat exchange due to air flow [27]. By this hypothesis, the main activity was to introduce and find an array which can give the improved response and accuracy, based on change in wind direction [29].
Sensor's configuration: The LM35 is an integrated circuit sensor that can be used to measure temperature with an electrical output (mv) proportional to the temperature (in degree Celsius). It can make an output voltage in mv (millivolts) that may not require to be amplified and draws only sixty micro amps from its supply with low thermal heat.
Even this sensor is quite sensitive to temperature [34] but the sensor's response to wind directly is poor because of low temperature sensitivity. Also after heating or cooling, it takes some time to come back to the previous temperature (sensor recovery time).
The initial activity was to study and rectify above problem to give proper sensitivity related to wind direction. An augmentation based on evaporative heat rejection is developed. The new device is referred to as Evaporative Heat Rejection Device (EHRD).
Figure.1 illustrates the construction of EHRD sensor. It consists of an LM 35 integrated temperature sensor mounted inside a bonnet in a round shaped area (diameter 6cm and height of 2.5cm) shown as plastic cover_1 with the hatch (3cm×2.5 cm) covered with a 4 mm transparent acrylic sheet shown as plastic cover_2. According to Hernandez, et al [28] it is essential to maintain a humid environment near the temperature sensor. A wet wipe (a special tissue paper) (2 cm ×1. 5cm with the 0.05 cm) is used as shown in Figure. 1.
A copper chimney of diameter 0.5 cm, height 3.5cm is used to provide cooling effect improving sensor recovery time. The function of the chimney is to have a better connection between the temperature sensor and air, which helps in defining a set point for the sensor and maintain it at environmental temperature.

B. EHRD sensor behavior study:

It should be noted that, the principle of wind direction sensing is based on a change in temperature due to the wind. The EHRD sensor, is designed to make the sensor more sensitive to changes in temperature in the presence of wind as compared to bare LM 35.
Both sensors were tested under varied conditions like room temperature (30°C), cold air (26°C) and hot air (55°C) wind generated with the help of a hair dryer and a blower as well as in the presence of natural wind to assure the effective changes

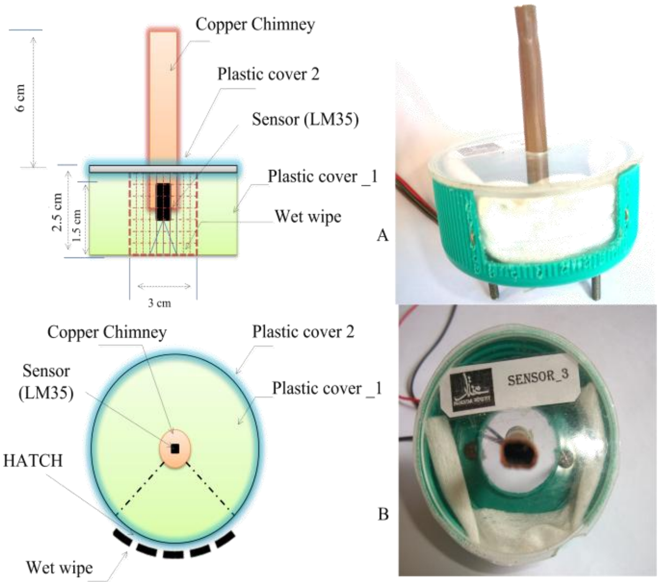

Figure 1 Propose Sensor configuration , A) Sensor side elevation B) Sensor top elevation , and sensor real implementation on EHRD sensor.

The EHRD and Bare LM 35 sensors response for the room temperature and cold wind generated by Blower are presented in figure 2.

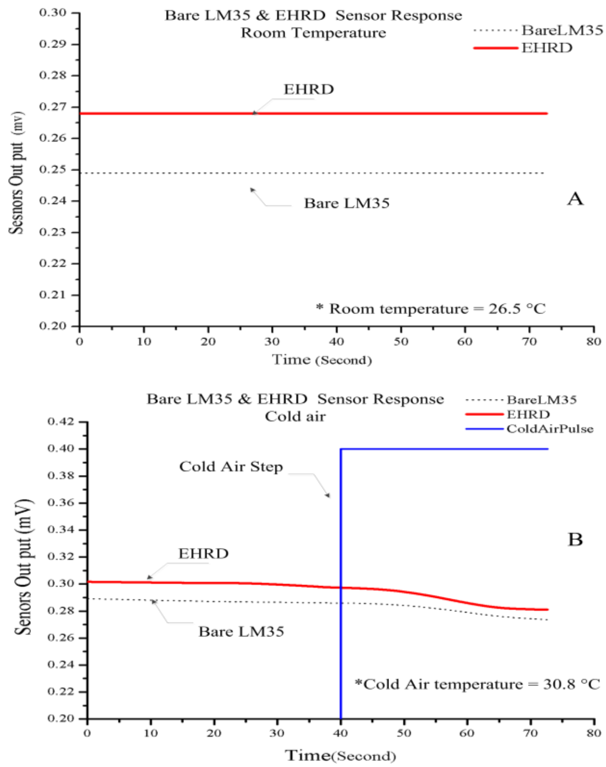

Figure 2 A) Room temperature, B) Cold air conditions for EHRD and LM 35

As seen in Figure. 2A the EHRD sensor showed 0.02 mili volts (1.5 to 2 degrees (°c)) difference as compared with bare LM35 in room condition. Figure 2B shows the sensor performance from the room temperature to cold air (by a blower). As the figure shows the EHRD Sensor have 3 second faster response, with the response slope ramp of -8.439e-6 for the EHRD sensor and -4.99e-6 as the slope response of bare LM35. . In the case of blower the sensor reached the baseline with the least fluctuation and shows the faster stability in sensor response.

For transient study in the hot air *condition*, 25 second hot air pulse from a hair dryer is injected towards the EHRD sensor. Figure 3 shows the response of the EHRD sensor in comparison with the bare LM 35**.** The graph shows the better response with compare to bare LM 35.

As the figure shows Initially, at $t=0_-$ the EHRD is at room temperature.as soon as the 'HOT' air pulse is rushing in at $t=0_+$, the evaporative heat rejection results in cooling. This is seen in the plot (C_ point).

Then, the 'HOT' air , starts showing its effect by way of rise in temperature.

After the hair dryer is switched off (after 25 second) it is seen that the temperature falls off quickly and the sensor recovers back to its original condition. The step rise and quick recovery of the EHRD sensor is easily evident. The10%-to 90% rise time for EHRD is observed to be 31.064 Second and that for bare LM 35 is 61.04 Seconds . Similarly, the peak of 37% of the peak recovery time , for EHRD is 53.1971 Second and that for bare LM 35 is 104.531 Seconds. Compared to bare LM 35 the recovery is seen to be 13.8639 Seconds quicker, due to the presence of the copper chimney.

As the graph in figure 2 and 3 shows , in both cases of hot and cold air the EHRD sensor will show the improvement in sensor response

C. EHRD Wind Sensor configurations:

The wind direction detector consists of an array of three EHRD sensors. The insects use their moveable antenna to catch the odor signal in different directions [26]. Inspired by the insect antenna positions, of the three EHRD sensors , two sensors are placed in left and right side of the robot with one in the front, as shown in Fig.4 , at a distance of 18cm from each other.

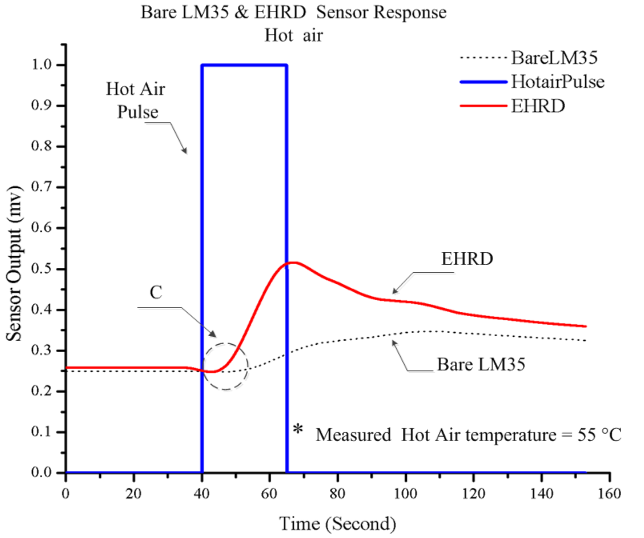

Figure 3 EHRD and LM 35 response for 25 second hot air , C point is the initial contact point with hot air

D. EHRD Sensor array working principle :

The sensor array works on the principle of detecting the less temperature on any side of the array. The sensor values of summation of S1(EHRD_1) , S2(EHRD_2) and S1(EHRD_1), S3 (EHRD_3) are compared with each other and wind direction is identified as right or left based on less temperatures. In the case of equal values, the direction is recognized as the straight direction . The array wind direction algorithm is shown in figure 5.

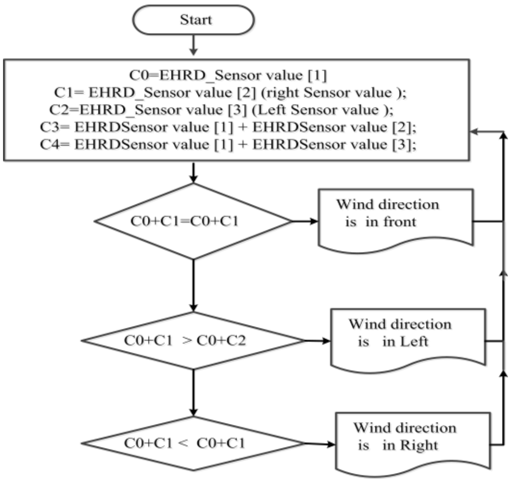

Figure 5:EHRD Wind sensor algorithm

Table 1 comparison between pervious wind sensor

NO	Wind speed range sensing(m/s)	Sensor array Specification			Sensor_ type
		Number of sensors	Sensors distance	Size / shape	
1	0 to 50 mm/s	40	5 mm	60mm Disk type	Thermocouple
2	1 m/s to 8 m/s	7	5 mm	20 cm Disk type	Lm 35
3	0.3 m/s to 1 m/s	3	--	--	Thermistor
4	0.9 m/s to 4 m/s	4	18 cm	18 cm/ triangle	EHRD

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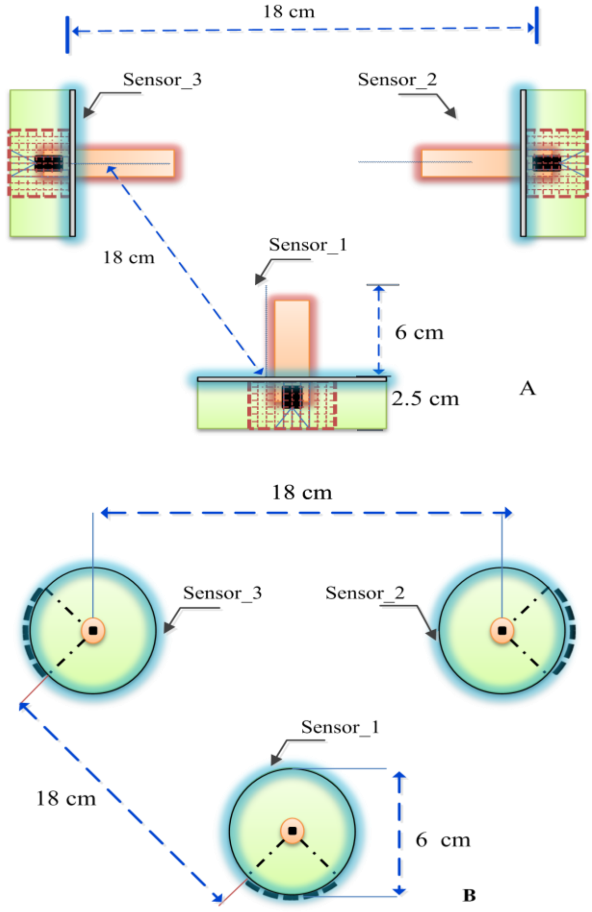


Figure 4 Propose Sensor array elevation and its dimension A) Sensors side sectional elevation B) Sensors top elevation.

E. EHRD Sensor array characterization:

Various experiments were carried out to study the response of the sensor array. In order to characterize the EHRD sensor array the experimental set up as shown in figure 6 was used. The variation in sensor response with change in the distance between the sensor array was studied. The response of the sensor array to wind generated due to fan and a blower was observed. The sensor array characterization is carried out by monitoring the wind speed LutronAM4202 digital anemometer.

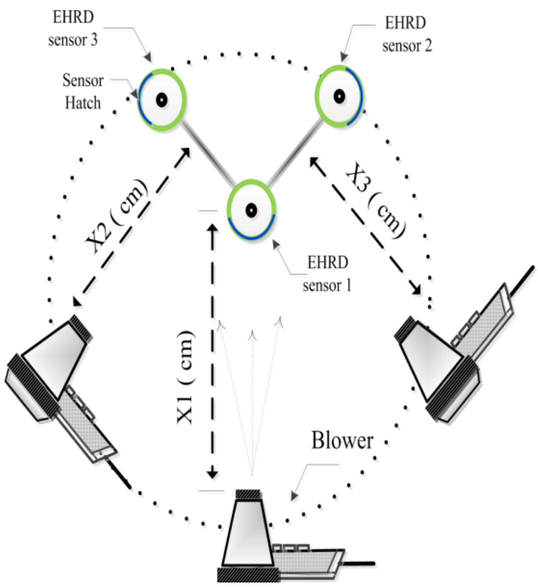
The experiments were carried out in the presence of natural wind as well as with variation in speed of wind generated, using a Blower (Figure6) and a fan . It was observed that the sensor array has a detectable differential output for wind generated using the blower at a distance of 50 cm from the source, for the wind speeds , between 2.5m/s to 6.2 m/s.

The experiments were repeated for a small fan with a height of 50 cm and maximum wind speed of 2.5 m/s. Thesensor array has the response from 1.5 till 2.5 m/s up to 90 cm away from the source. This difference may be due to the difference nature of wind generated by blower and fan. Overall the array is capable to have responded in the wind over speed ranging from 0.9 m/s to 4 m/s which is acceptable in plume tracking activity [2] [35].

The performance of the EHRD sensor array was compared with temperature sensors based wind detector reported in literature [20,24,27].

As summarized in the Table 1, the EHRD shows comparable performance with lesser number of sensors as well as smaller sizes.

III. Use of EHRD wind detector for implementing Wind Tracker:



The EHRD sensor was mounted on Mokhtar [36] (See figure 7) for localizing wind as a part of plume tracking exercise. Mokhtar consists of ATMEGA 32 as the controller, motor drivers, two sets of IR sensors on both sides to avoid the collision and PPMS [33] to record and monitor the robot path and positions. The EHRD wind sensor array was mounted on the top to help it move towards the source and align itself in wind direction. The wind tracker aided in testing the EHRD sensors for realizing wind source localization

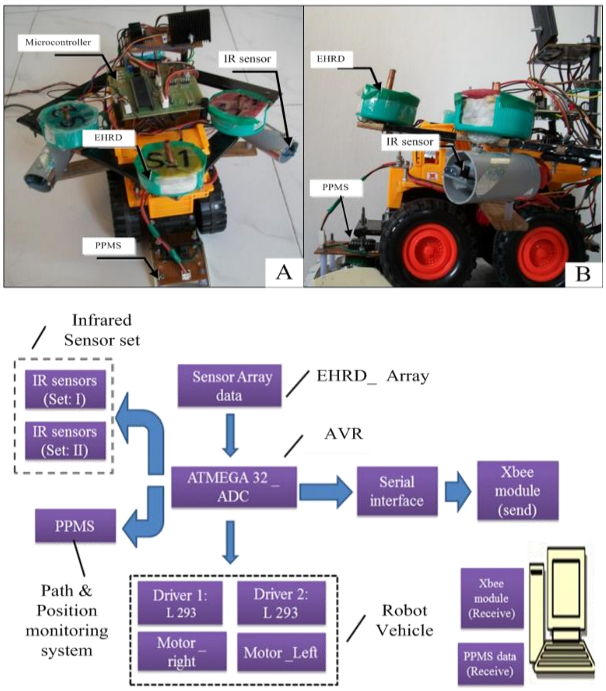


Figure 7: A,B Mokhtar Wind traker platform hardware part

A. Platform navigation strategy

Wind localization Task has been done using modified Zig Zag and Spiral by the robot controller based on the model introduced in [24] [25].

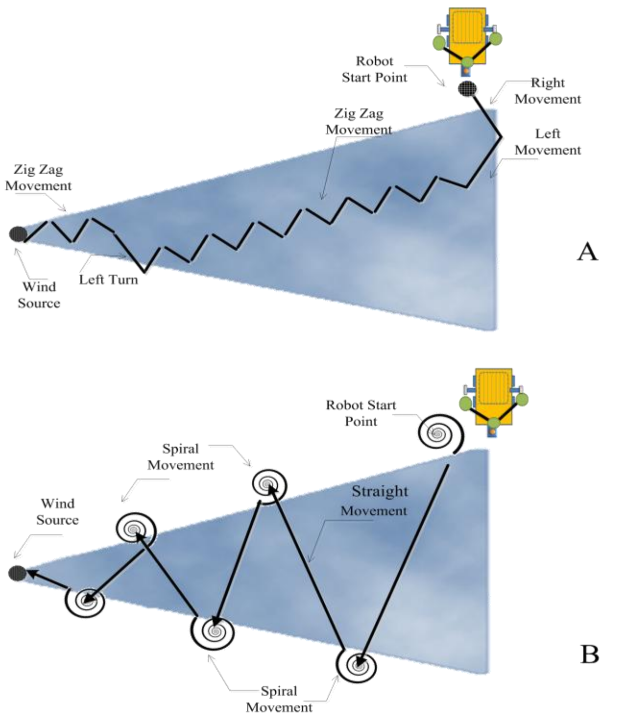


Figure 8 : Modified Zig zag movement B: Spiral Movement

Modified Zig zag algorithm: In the Modified Zig (fig 8A) Zag algorithms, the robot has three kinds of movements Left, Right and zig zag with the orientation angle of 30 degrees per turn and speed of 6 cm/s. With each step of approximately 2 seconds.

By checking the values of EHRD sensor the robot sends the movement commands to the robot's motor by implementing following algorithm

If the [sensor1+sensor 2] = [sensor 1+sensor 3] :
Zig zag movement (robot is in the wind moving towards the source)
If [sensor 2] ≠ [sensor 3]
Turn toward the lowest value.

Spiral algorithm: In this algorithm, the robot starts to search the wind with an initial radius R=2 cm until it finds wind signal to rotate the robot.

The movement consists of two types :

1. Right hand side Spiralling ,
2. Straight movement . (See fig 8B)

After finding the wind signal the robot moves 6 cm/s straight in the extended line of last direction. In this method, the following algorithm is used.

If [sensor 1+sensor 2] = [sensor 1 + sensor 3]
: Straight movement (robot is in the wind moving towards the source)
If [sensor 2] ≠ [sensor 3]
: start rotations in right side of the robot

B. Experiment environmental and Results

The system was tested in a room with dimension 3meter× 2.8 meter×2.5 meter (Fig. 9) and a small fan as the wind source has used as wind generator with the height of 50 cm and max wind speed of 2.5 m/s. Experiment environment also has provision for cross wind to observe the robot behaviour in outdoor condition.

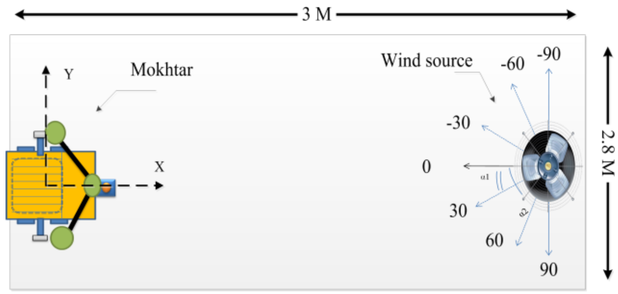


Figure 9 experiment environment

The experiments were carried out by changing the theta (source orientation) from -90 to 90 with Mokhtar at the same location at a distance of 1.15 m. Both Spiral and Zig zag movement were with the help of PPMS [33]. Also to reduce turbulence due to movement of the robot, in both algorithms, the robot is made to have a fixed speed [8]. Implemented and the robot movement was recorded Mokhtar at the same location at a distance of 1.15 m. Both Spiral and Zig zag movement were implemented and the robot movement was recorded with the help of PPMS [33]. Also to reduce turbulence due to movement of the robot, in both algorithms, the robot is made to have a fixed speed [31]. The maximum time for robot to reach the source is considered 90 second and more than this time was considered as failure in source localizing.

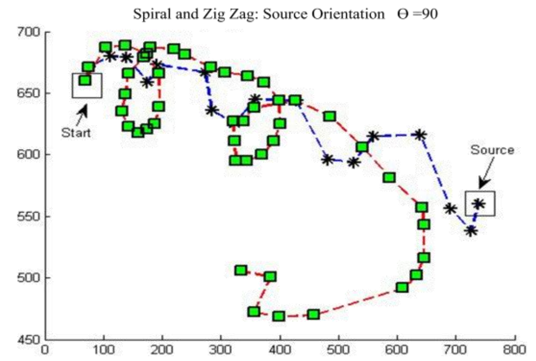


Figure 10. Mokhtar robot path monitoring by the help of PPMS

The Fig. 10 shows the robot movement in the forms of Zigzag (star-line) and Spiral (Box-line) as a sample of PPMS plot [33]with theta (degree of source orientation) 90 degree. PPMS samples the location every second and the plot shows the data acquired.

As it can be seen that the robot reaches the source with The modified zigzag in 10 movements

Whereas Spiral movement is unable to detect the wind source which is also shown in figure 11.

The performance of wind tracker was evaluated based on three parameters

- The number of “movements”
- Time for reaching the source and
- The probability of reaching

By repeating the experiments a number of times. The Figure (11) shows the results with spiral and Zig zag movement based on average values of time, the number of movement and probability of reaching the source within 90 seconds.

As The Fig. 11 A show`s the steps require reaching the source versus Theta for both movement types. It shows the Spiral has the least steps than

Zigzag motion. The time to reach the source versus Theta for both movement algorithms is shown in Fig. 15 B. It shows that time of reaching the source for the Spiral is less than Zigzag.
The Fig. 11 C shows the probability of reaching the source in a Zigzag is more than a Spiral.

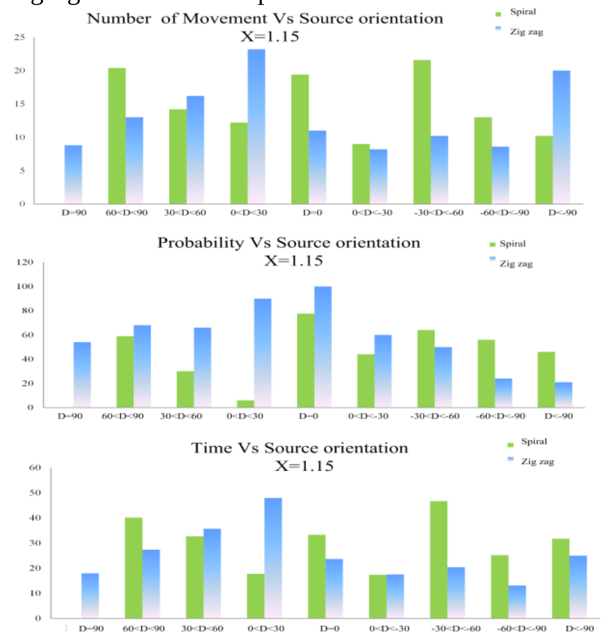


Figure 11: Zig zag, Spiral mapping movement comparison by source orientation between -90 to 90

On the other hand , as the figure 11 shows, the -30degree result is not good in the case of spiral algorithm. This may be caused by two facts of initial turn of robot in right side which is positioned robot on the border line of the wind flow, then the robot cannot receive a proper signal and track the wind proper. Some parts of experiment demonstration are available at [37].

IV. CONCLUSION AND FUTURE WORKS

This paper reports a novel wind detector based on Evaporative Heat Rejection Device (EHRD). Construction details of EHRD are given in the paper along with test results for individual devices. Further, for the formation of an array of the EHRD sensor and wind direction sensing based on the same is tested.
In comparison with the reported wind sensor as mentioned in Table 1, the designed EHRD sensor array uses a less number of sensors and is smaller in size. Also the array offers an advantage of being maintenance free with no movable and mechanical part. The EHRD sensor array is acceptable in plume tracking activity with speed range of 0.9 m/s to 4 m/s. This work implements and compares two algorithms viz. Zig-zag and Spiral tracking algorithm, for source localizing activities to localize the wind source by mounting EHRD array sensors on the robot . The system performance was tested with experiments carried out at room temperature. It is observed that the Zig-zag movement takes more steps than the Spiral. This is in agreement with literature reports [38].
However, from the observations reported in section Experiment environmental and Results it is seen that the probability of reaching the source is higher for Zig-zag compared to Spiral. In almost all the cases, 100 percent probability is observed in the case of Zigzag movement when the wind source is facing the robot ‘head on’ (D=0), whereas, the Spiral algorithm results in a nearly 75 percent probability. Specifically, for the case of $0<D<30^{o}$ one can observe the probability of reaching the target is seen to be significantly larger for Zig-zag compared to the Spiral algorithm. Thus, concluding the superiority of the Zig-zag algorithm compared to the Spiral algorithm.
One of the main aspect of this research has been the development of a simple, light weight, optimum size, low power consumption [4] , wind vane sensor and its successful use for wind source localization.The Future works would deal with the use of the EHRD Sensor array along with gas sensors for Plume tracking application.

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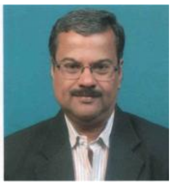

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