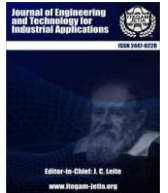




ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.12 n.60, p.28-38, July/August, 2026.

DOI: <https://doi.org/10.5935/jetia.v12i60.3182>

RESEARCH ARTICLE

OPEN ACCESS

SIX AXIS MAGNETOMETER/ACCELEROMETER ASSISTED MOBILE ROBOT INDOOR NAVIGATION

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ARTICLE INFO

Article History

Received: December 22, 2025

Reviewed: May 20, 2026

Accepted: June 21, 2026

Published: July 31, 2026

Keywords:

Arduino,
Autonomous,
Mobile robot,
Yaw/heading,
Navigation,
Magnetometer

ABSTRACT

Yaw/Heading measurement is an important parameter for the pose determination of the mobile robot. Yaw/heading can assist the mobile robot in localization much needed for autonomous navigation. There are various sensors available to measure the Yaw/heading that may require pre or post-processing of the data. This paper presents a low-cost and efficient six-axis magnetometer/accelerometer LSM303DLHC (GY 511) sensor for direct measurement of the Yaw/heading. The yaw values were recorded in real time with a data logger while the mobile robot was tracking a line with the help of IR sensors. It establishes that the change in yaw values due to turns on track corresponds to real-time movements/navigation of the mobile robot. Additionally, experiments were performed that demonstrate that the mobile robot can navigate autonomously, fetching yaw values from LSM303DLHC, and avoiding obstacles. The heading values from the LSM303DLHC sensor were found to be consistent with time and suitable for educational/research projects.



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I. INTRODUCTION

Mobile robots have been increasingly popular in recent decades due to their ease of maneuverability. They find numerous applications indoors and outdoors, such as cleaning. [1], warehousing [2], [3], agriculture [4], [5], search and rescue [6], [7], healthcare [8-10], security and patrol [11], environment monitoring [12], etc. Wheeled mobile robots among locomotive robots are the chosen ones due to their lower power consumption and simple design. In some cases, it is manually controlled, and in some cases, it is autonomous. However, the autonomous navigation depends on the localization task of the mobile robot [13]. The position of the mobile robot is very important as it tries to locate itself in an unknown environment. The position can be expressed in Cartesian coordinates (x, y) for a planar region along with its heading or yaw angle (θ) [14]. Hence, in the indoor environment, the mobile robot can rely on its own sensors and calculate its position using dead reckoning [15]. Hence, sensors like encoders, Inertial Measurement Unit (IMU), LiDAR are used in conjunction with beacons such as ultrawide band (UWB), Bluetooth, and WiFi for indoor positioning [16]. The heading can be obtained with the Global Positioning System (GPS) [17], but sometimes it doesn't work or provides inaccurate readings indoors [18], [19]. Also, the dependency is not reliable using Global Navigation Satellite Systems (GNSS) [20] due to restricted coverage and hindered signal propagation [21]. Magnetometers can provide absolute heading based on the Earth's magnetic field, provided there are no external magnetic disturbances [22]. To remove electromagnetic interference and heading correction, magnetometers need calibration and a filter or post-processing of data that may be computationally expensive [23], [24]. The remainder of this paper is organized as follows: Section 2 discusses the materials and methods; Section 3 presents the results and discussions; Section 4 discusses the limitations of the present work; and Section 5 concludes the paper.

II. RELATED WORK

There are some commonly used sensors found in the research articles for heading measurements. Mostly, the authors applied filters/post-processing to get stabilized readings and make them error-free even in the presence of magnetic disturbances. For example, a recent work reported the use of MPU 6050 (accelerometer and gyroscope) for yaw angle determination on an inclined plane for a mobile robot. It used the golden section search method with the mean squared error metric to mitigate drift effects. [25]. MPU 6050 was also used to stabilize the camera position of the gimbal smartphone to improve the quality of captured images and videos. The average error in the yaw angle was reported as 0.78° without any filter. [26]. A low-cost prototype consisting of MPU 6050 and HMC 5883L (magnetometer) can provide accurate headings with an error of 2.9° after proper calibration. It can be beneficial for pseudo-tethered devices when used while driving, leading to portable navigation. [27]. Fusing the data of multiple MPU 6050 to suppress the random drift error can prove beneficial. Four MPU 6050 were taken into consideration, on which the effect of calibration shows a trend of steady enhancement. [28]. LSM303DLH is also a common and low-cost sensor used for attitude and heading reference systems (AHRS). The sensor fusion algorithm using estimation of mean square error was validated on a combination of gyroscope and LSM303DLHS (accelerometer and magnetometer) sensor and found to be effective [29]. Dual magnetometers (LIS3MDL) with inertial navigation systems (INS) can be integrated with dynamic time wrapping (DTW) algorithm for estimation of motion speed for the indoor mobile robots'. The results of wheel odometry were similar to the proposed approach and comparable to dead reckoning (DR) [30]. Similarly, the LSM303D magnetometer can give yaw angle accuracy of 0.4° with the Levenberg–Marquardt (L-M) algorithm with “hard iron” and “soft iron” errors [31]. The HMC5883L can also facilitate the robot’s motion and help it to be on the intended path. But the accuracy of the heading varies from 1° or 2° [32]. Above mentioned low-cost magnetometers/accelerometers can be used as heading sensors in AHRS for autonomous navigation for path following/tracking autonomously with a mobile robot. The navigational performance was based on straight line following or circular path following using the MEMS sensor MPU 9250 (includes MPU 6050) [33]. Use of HMC5883L in the robot’s motion for path tracking can be improved with realistic tracks and the inclusion of obstacles. [32]. But in some cases, magnetometers are costly, such as in [34] Path following with the LIS2MDL magnetometer with simple calibration can also facilitate autonomous navigation with sensor fusion and reinforcement learning. Waypoint-following demonstrated in [35] Didn’t consider obstacles in between and used HMR3300 magnetometer (comparatively costlier). Similarly, track following can be facilitated by fusing the wheel odometry data with the BNO 055 compass sensor, to minimize the RMS error value of less than 0.15 meters. [36]. The comparison of reported works is shown in Table 1.

Table 1: Comparison of path tracking/following with customized wheeled mobile robots.

S.N.	Magnetometer	Microcontroller	Task	Cost	Ref.
1	LIS2MDL	ATmega 2560	Path following/autonomous navigation	comparatively high	[34]
2	HMC5883L*	ATmega 2560	Path following	Low	[32]
3	HMR 3300	No details	Waypoint following	Higher	[35]
4	BNO 055	Raspberry Pi	Track following	Higher	[36]
5	LSM303DLH	Arduino Uno	Path following/obstacle avoidance	Low	Present work

Source: Authors, (2026).

But the choice of magnetometers can be difficult for mobile robot localization and autonomous navigation because they can be of different materials (Hall effect, inductive, anisotropic magnetoresistance magnetometers (AMR) or MEMS type). Even though there are many features like output frequency and operating range that have to be considered before selection. Such a review paper presented comparative insights into 42 IMU models from 7 different manufacturers [37] based on features such as structure details and connectivity. Also, three different types of AMS magnetometers were selected for a characteristics study and calibration. The HMC5893 by Honeywell, and the LSM303DLHC and LIS3MDL by ST Microelectronics were chosen, and comparative results showed that LSM303DLHC can be the best choice for heading measurements [38]. Selection can also be based on repeatability, cost and accuracy [35]. As per the above facts, it can be concluded that the selection of low-cost magnetometers as heading sensors is important. Also, autonomous path following/tracking by the mobile robot with obstacle avoidance should demonstrate the application of a low-cost magnetometer as a heading sensor is necessary. e The LSM303DLHC sensor (magnetometer/accelerometer) can find the heading of the mobile robot and get stored simultaneously in the SD card. The black line provides a well-defined path that the robot must follow, and subsequently, the heading is recorded on each turn. The main contributions of this paper are as follows:

- i) Comparison of affordable magnetometers/accelerometers for the selection of a suitable one (LSM303DLHC).
- ii) Testing for LSM303DLHC heading accuracy
- iii) Real-world experiments on autonomous path following/tracking with and without obstacle avoidance on rectangular/circular tracks.

III. MATERIALS AND METHODS

This section outlines the procedure to execute the design of experiments. The first step in methodology involves the selection of a heading sensor. As there are some affordable heading sensors available, their comparison can lead to the identification of a suitable one. Therefore, the selection criteria are discussed in subsection 3.1. Then the second step is about a customized differential drive mobile robot (DDMR) that was developed for real-world experiments. It is discussed in subsection 3.2. This subsection also includes insights into two important hardware components (Micro SD card module as data logger and LSM303DLHC sensor), with their working and interfacing with Arduino Uno. After the development of DDMR with all the hardware components integrated, an embedded C language code was developed. There were three types of experiments designed to be executed on the developed DDMR.

First, heading values were recorded from the LSM303DLHC sensor on the onboard mobile robot. Secondly, heading values were recorded in real time as the mobile robot was tracking the black line with IR sensors. It was tested in two experimental arenas (curvature and rectangular path). Lastly, it was demonstrated that the mobile robot can navigate autonomously, fetching heading values from the LSM303DLHC sensor, avoiding obstacles. The methodology of the work is provided in Figure 1.

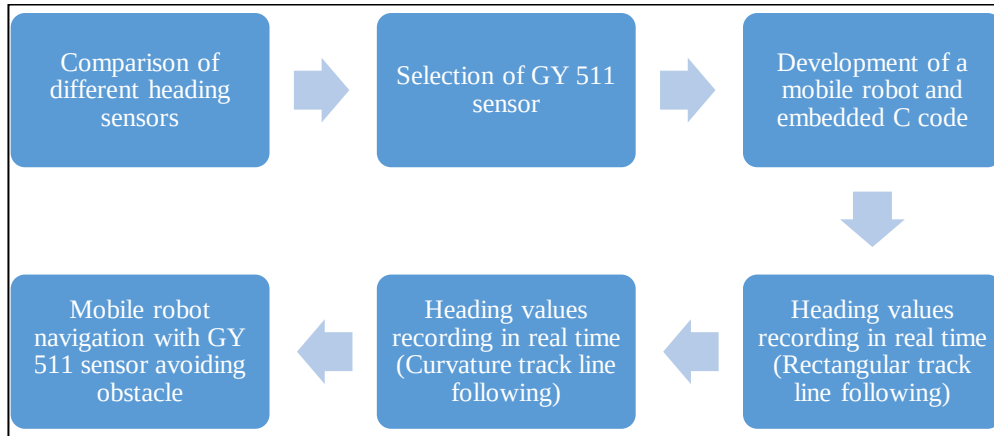


Figure 1: Methodology of the proposed work.
Source: Authors, (2026).

III.1 COMPARISON OF LSM303DLHC WITH OTHER YAW/HEADING SENSORS

This subsection highlights the comparison of three common and affordable yaw/heading sensors used for navigational purposes. These sensors are an LSM303DLHC sensor (magnetometer and accelerometer), GY 271 QMC5833L magnetometer and GY 521 MPU 6050 (accelerometer and gyroscope). The comparison parameters were provided in Table 2 below. There are other commercially available heading sensors, such as the RM 3100 3-axis magnetometer sensor [39], and DF robot fermion BNO055 [40] but not considered due to cost constraints.

Table 2: Magnetometer/Accelerometer sensor comparison.

S.N.	Yaw/heading Sensor	Cost under INR 300 (may vary slightly)	Calculation of absolute Yaw angle	Accelerometer	Magnetometer	Heading Accuracy
1	LSM303DLHC	Low	Easy[38]	$\pm 2g$, $\pm 4g$, $\pm 8g$, and $\pm 16g$	± 1.3 to ± 8.1 gauss	Stable with less noise [38]
2	QMC5883L	Very Low	Moderate	NA	± 8 gauss	Comparatively low due to high noise
3	MPU 6050	Very Low	Difficult [41]	$\pm 2g$, $\pm 4g$, $\pm 8g$, and $\pm 16g$	NA	Error integrates over time due to drift[41]

Source: Authors, (2026).

III.2 STATISTICAL ANALYSIS-BASED SELECTION OF LSM303DLHC

This subsection presents the statistical analysis of LSM303DLHC heading values along with other sensors QMC5883L and MPU 6050. Firstly, the LSM303DLHC sensor pin breakout and interfacing with Arduino Uno are explained. The LSM303DLHC sensor shown in Figure 2 can be interfaced with Arduino Uno/Nano. The sensor can easily calculate the heading with the help of magnetic fields. The respective connections are shown in Figure 3.

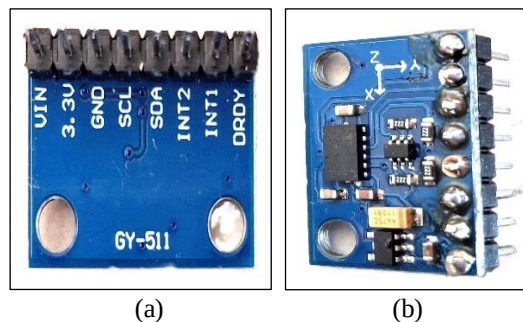


Figure 2: (a) LSM303DLHC with LSM303DLHC chip front side, (b) LSM303DLHC sensor back side.
Source: Authors, (2026).

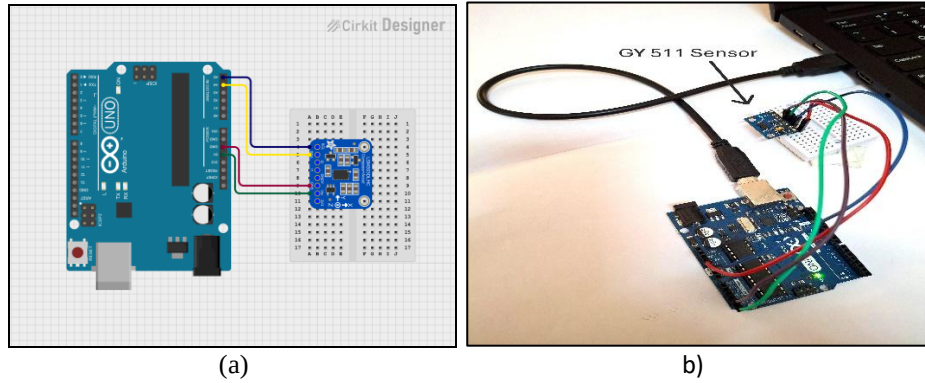


Figure 3: (a) Interfacing LSM303DLHC with Arduino Uno schematic, (b) Real picture of interfacing.
Source: Authors, (2026).

Arduino IDE and the LSM303DLHC sensor are helpful in getting the measured values from sensors in real-time and troubleshooting as required. The LSM303DLHC sensor was first calibrated with the local latitude and longitude position. The library from Github <https://github.com/pololu/lsm303-arduino> was used to calibrate the magnetometer and then record the heading data [42]. The calibration values found are below.

```
compass.m_min = (LSM303::vector<int16_t>){-426, -139, -398};
compass.m_max = (LSM303::vector<int16_t>){+530, +820, -190};
```

This was put in the program code to calculate heading and found to be accurate with the global north as per the digital compass of a standard Android smart phone. It is important to store the heading data as the mobile robot traverses from one point to another. A micro SD card module with a capacity 8 GB can be easily interfaced with Arduino Nano and can be used as a data logger for heading values Arduino Uno/Nano [43]. The respective connections are shown in Figure 4.

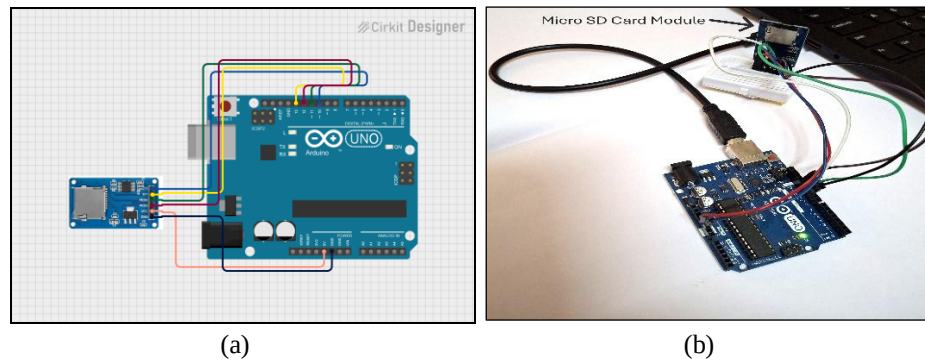


Figure 4: (a) Interfacing Micro SD card module with Arduino Uno schematic, (b) Real picture of interfacing.
Source: Authors, (2026).

Based on the sensor comparison provided in Table 2, it has been found that stable reading with less noise and tilt compensation can be best fit for heading calculations. To conclude, a hardware setup was created to test the values of heading angles logged in real time. The hardware setup (shown in Figure. 5) consists of Arduino Nano, Micro SD card and all three sensors listed above in Table 2. The logged data of heading values from each sensor is provided in Table 3.

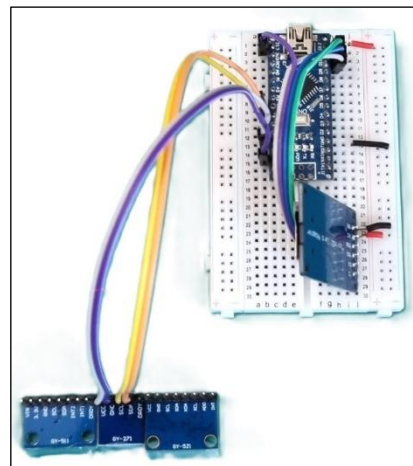


Figure 5: Hardware set up for comparative analysis of LSM303DLHC, QMC5883L and MPU 6050 with Arduino Nano.
Source: Authors, (2026).

Table 3: Statistical analysis of data values obtained from three heading sensors.

S.N.	No. of data values(degrees)	Min	Max	Mean	Median	Mode	Std	Range
LSM303DLHC	510	343.6	344.54	344.03	344.03	343.98	0.1684	0.94
QMC5883L	523	344	346	344.40	344	344	0.496	2
MPU 6050 with drift	495	1.04	359.5	165.31	106.73	95.88	110.56	358.46
MPU 6050 with processing	356	345.18	345.86	345.45	345.47	345.47	0.099	0.68

Source: Authors, (2026).

It is evident from the statistical analysis of Table 3, that LSM303DLHC sensor gives the best mean of 344.03° with respect to reference value of 344° . Out of the three sensors, the performance of LSM303DLHC seems to suit the requirement and selected finally.

III.3 DEVELOPMENT OF DDMR

The hardware assembly of the DDMR in the paper comprises components such as LSM303DLHC as heading sensor, Micro SD card module as a data logger, HC SR 04 as an ultrasonic sensor for obstacle avoidance and IR sensor (two) for black line tracking. Also, the other components are L293D motor driver, two BO motors, two wheels, Arduino Uno, rechargeable LiPO battery 11.4 V. The simple DDMR was built with the low-cost and affordable components mentioned above with Arduino Uno as the main controller. The pin connections for LSM303DLHC and Micro SD card are already discussed in the next subsections. The IN1, IN2, IN3, IN4, ENA, and ENB pins of L293D motor driver are connected to pin no. 4,9,6,7,3 and 5 respectively of Arduino Uno. IR sensors on the front right and front left of the mobile robot are connected to pin no. 2 and 8 respectively of Arduino Uno. Trig and Echo pin of HC SR04 are connected to 1 and 0 pin of Arduino Uno respectively. The complete circuit diagram is shown in Figure 6 below (drawn with cirkuit designer website). The full software developed for this problem statement has been shared in GitHub. <https://github.com/kg Singh555/Autonomous-mobile-robot-navigation-using-Magnetometer-as-Heading-Sensor>. The DDMR setup is shown in Figure 7 below.

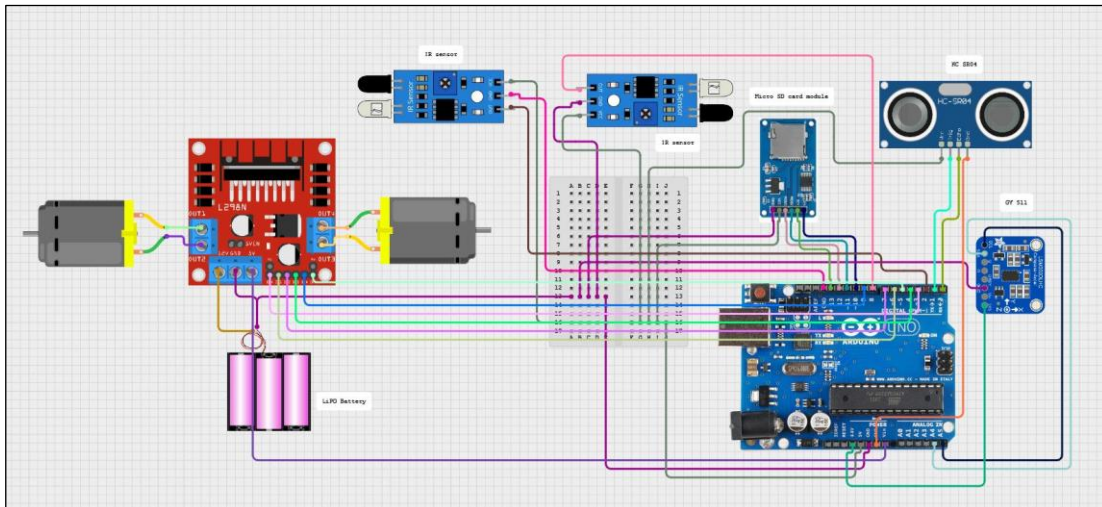


Figure 6: Circuit diagram of autonomous line follower mobile robot with Micro SD card module and LSM303DLHC sensor.
Source: Authors, (2026).

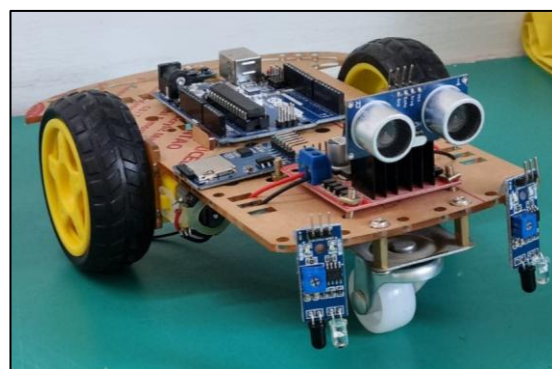


Figure 7: Complete setup with mobile robot.
Source: Authors, (2026).

IV. RESULTS AND DISCUSSIONS

This section highlights the types of experiments conducted to demonstrate the navigational feature of the DDMR using LSM303DLHC sensor. There are three types of experiments conducted. Subsection 4.1 explains the preliminary results of the heading values recorded from the onboard data logger of the DDMR while it is rotating about z-axis.

Subsection 4.2 describes the result of heading values recorded while the DDMR is tracking black line with IR sensors on rectangular and curvature path. The third experiment is presented in subsection 4.3 that explains the obstacle avoidance behavior of DDMR being guided by LSM303DLHC sensor.

IV.1 YAW/HEADING READINGS FROM LSM303DLHC WITH ONBOARD DATALOGGER ON DDMR

In this subsection, it is demonstrated that the heading values from the LSM303DLHC sensor are reliable and consistent enough to be considered for autonomous mobile robot navigation. It gives output from 0° to 360° . The DDMR has been kept in two orientations. These two orientations are 0° and 27° . Firstly, with a digital compass in Android Smartphone as a reference, 0° and 27° are marked. 0° in digital compass shows due north direction. It is shown in Figure 8. The actual experimental setup with DDMR heading due north (0°) is shown in Figure 8 a). Also, in Figure 8 b) the output on the serial monitor of Arduino IDE is shown. It prints the heading after every 1 sec. The heading was recorded for 10 mins, considering 1 sample/sec. Hence there were 600 sample values when the DDMR was in due north direction. It can be observed from Figure 9 that only at some times, the value fluctuated and recorded 359° . The circular mean for 600 samples is 0.03° .

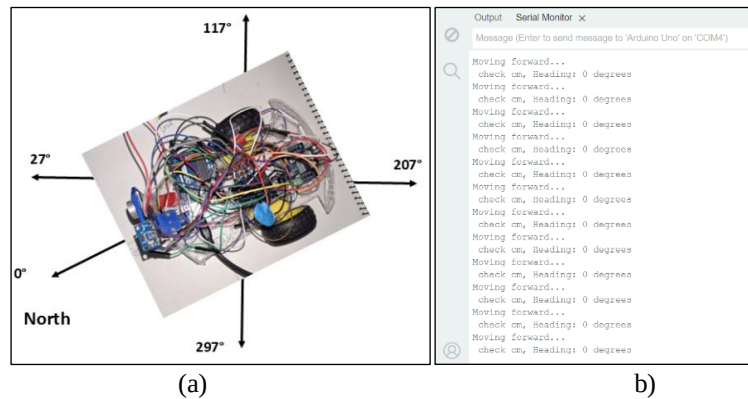


Figure 8: (a) Mobile robot heading in due north position, (b) Output in serial monitor of Arduino Uno.
Source: Authors, (2026).

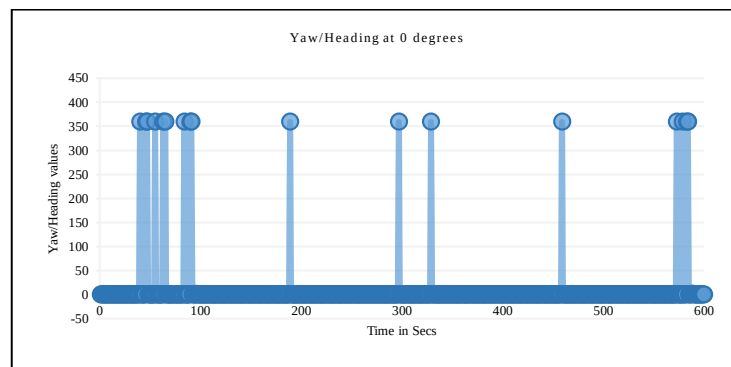


Figure 9: Mobile robot heading at 0° recorded for 10 mins (one sample/sec).
Source: Authors, (2026).

The experiment was repeated with the mobile robot orientation at 27° . It can be observed from Figure. 10 a) the mobile robot heading was oriented at 27° in the experimental setup, while the output in the serial monitor of Arduino IDE was 27° as well. It is shown in Figure 10 b). To validate the consistency of the output values in this orientation, heading values were recorded for 10 minutes. It was one sample/sec, and in total, there were 600 values. The recorded data is shown in Figure 11. The values deviation is minimal, only at one point, the value was 26° , and at some instances it was 28° . The average value for 600 samples is 27.095° .

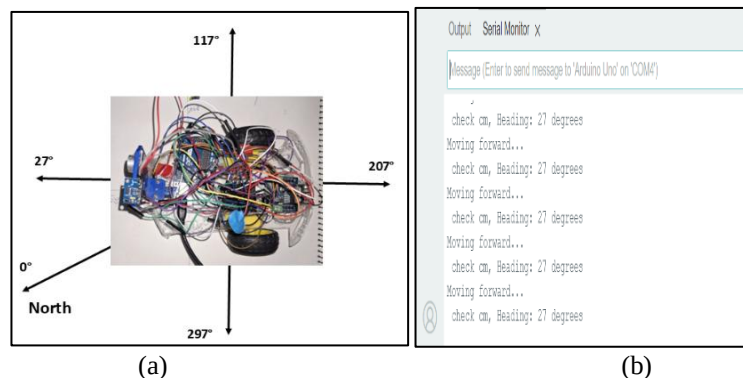


Figure 10: (a) Mobile robot heading at 27° , (b) Output on serial monitor of Arduino Uno.
Source: Authors, (2026).

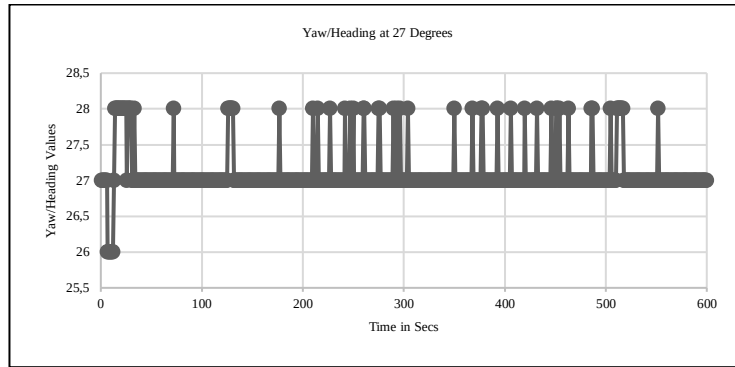


Figure 11: Mobile robot heading at 27° recorded for 10 mins (one sample/sec).
Source: Authors, (2026).

The DDMR also rotated around the z-axis clockwise to record the values of heading angles. It paused after a 90° turn in the clockwise direction, taking the reference directions shown in Figure 8 a). First, it was oriented towards 27° as the reference, then 117°, thereafter 207°, and lastly 297°. For a particular orientation, at least 28 heading values were recorded, which are shown in Figure. 12. The value dropped suddenly to 0° because it oriented towards due north again after complete rotation. It showed some spikes due to heading angle measurement at 359° and thereafter settled to 0°.

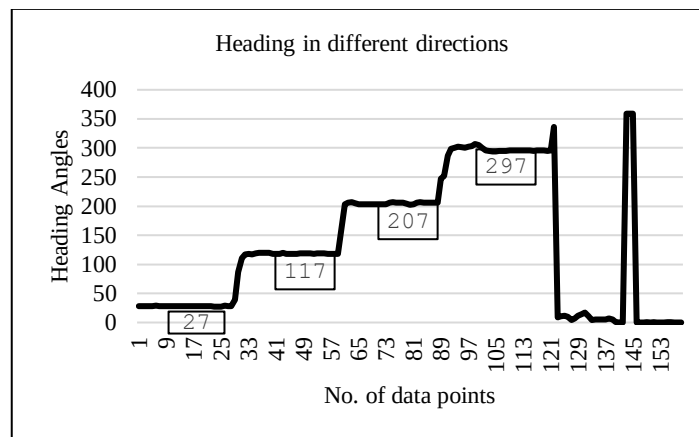
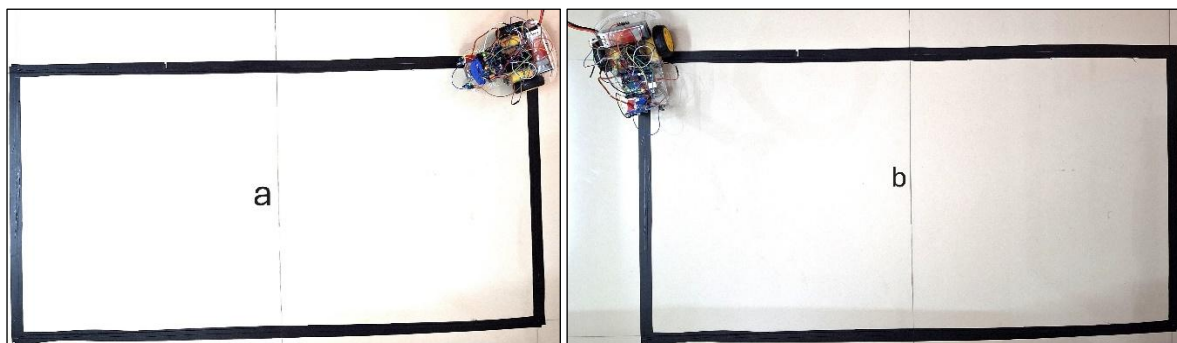


Figure 12: DDMR at each 90° turns, completing a full rotation around the z-axis.
Source: Authors, (2026).

IV.2 YAW/HEADING READINGS FROM LSM303DLHC WHILE DDMR TRACKING BLACK LINE

This subsection explains the DDMR black line tracking behaviour on a rectangular and a curvature path. There is a simultaneous recording of the heading values with the help of an onboard Micro SD card as a data logger. The Micro SD card module recorded heading values from the sensor LSM303DLHC at a rate of 1 sample/sec. The DDMR was able to follow a black line, which is rectangular in shape and measures 4 ft. × 2 ft. Approximately 15 seconds were required to complete one cycle. There were four turns of each 90°. The DDMR, while tracking the black line turns, and the Micro SD card module records the heading in the SD card. The position of the mobile robot at each 90° turn is shown in Figure 13. The mobile robot starts with position shown in Figure 13 a). Then it takes a 90° turn, and that is shown in Figure 13 b). Thereafter, the subsequent movements are shown in Figure 13 c) and Figure 13 d). It can be observed that movement is anticlockwise and the expected heading measurements will be 27°, 297°, 207° and 117° for each of the positions shown in Figure 13 a), Figure13 b), Figure 13 c), and Figure 13 d) respectively.



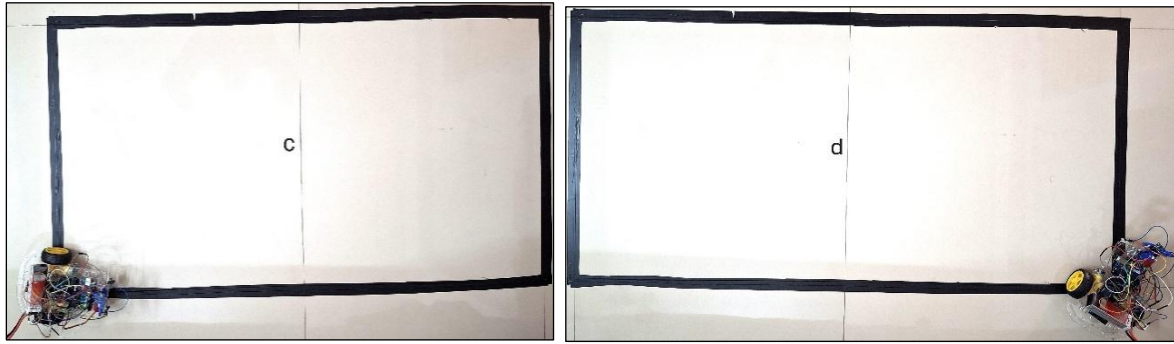


Figure 13: The DDMR heading is (a) 27° (b) is 297° (c) is 207° (d) is 117° .
Source: Authors, (2026).

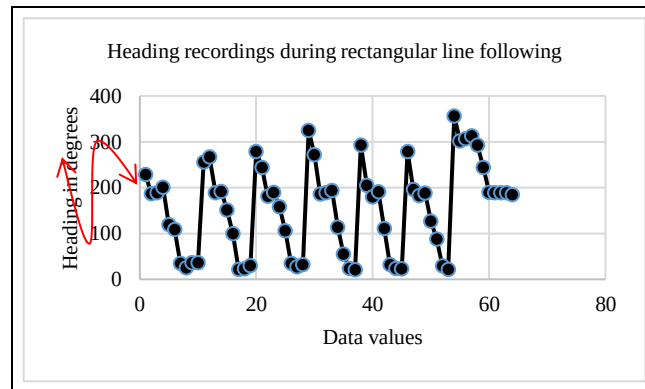


Figure 14: Heading recorded at each 90° turn (six repetitions) while DDMR tracking the black line.
Source: Authors, (2026).

Above Figure 14 shows the consistent record of the heading sensor for the DDMR. The line following was repeated six times and concludes at position Figure. 13 c) and remains there for some time. The red curved arrows mark the start and completion of the first cycle of the mobile robot movement. Similarly, a curvature path was created for the mobile robot to track. This time, the number of heading values recorded was 30 samples/sec. The run time of the mobile robot was approximately 15 seconds, and 450 heading values were recorded. Figure. 15 a) and Figure. b) below show the curvature path with mobile robot tracking and the graph with heading values recorded during the run, respectively.

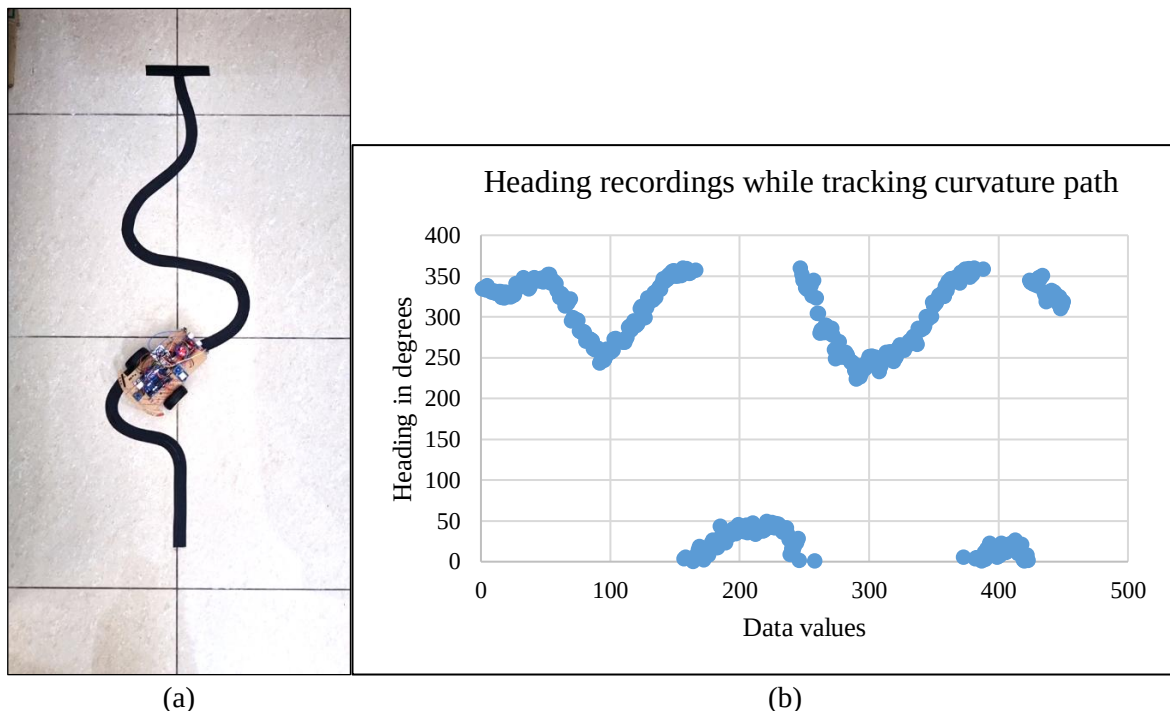


Figure 15: (a) DDMR tracking curvature path, (b) heading recorded with LSM303DLHC sensor while tracking curvature path.
Source: Authors, (2026).

IV.3 YAW/HEADING READINGS FROM LSM303DLHC WHILE DDMR AVOIDING OBSTACLES

The third experiment was performed to demonstrate that DDMR can fetch the heading values from the LSM303DLHC sensor to avoid obstacles and autonomously navigate. As per Figure. 16, DDMR senses the obstacle with an ultrasonic sensor and, with reference to its present heading, turns 30° to the right and goes straight for a while. It then turns left again to catch up to the black line to resume line-following behavior. Hence, it can complete its run after reaching the end of the line.

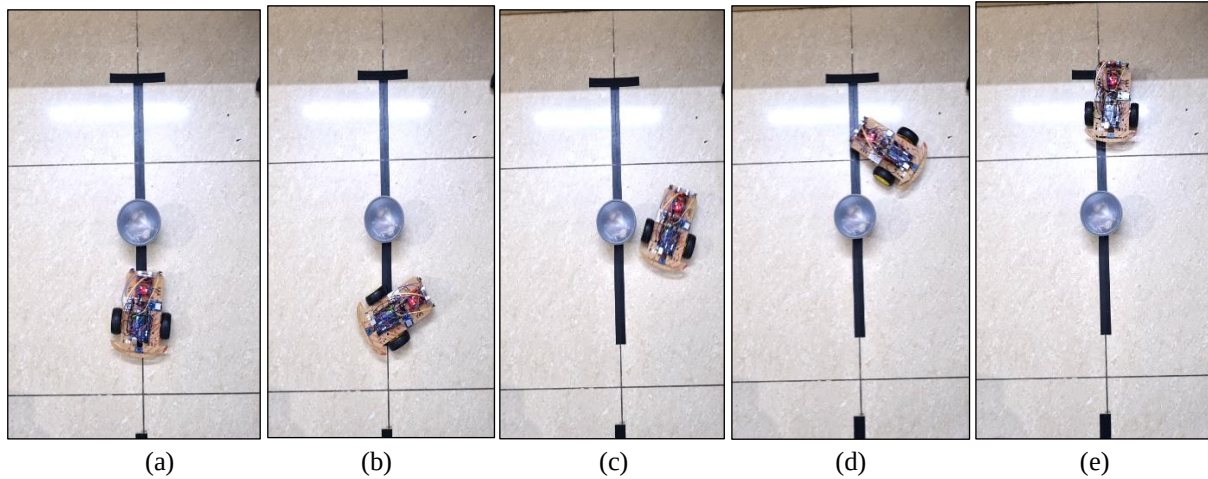


Figure 16: The DDMR (a) starts following the black line b) senses the obstacle and turns 30° to the right, c) avoids the obstacle, d) gets back to the black line, e) resumes line following behavior and stops.

Source: Authors, (2026).

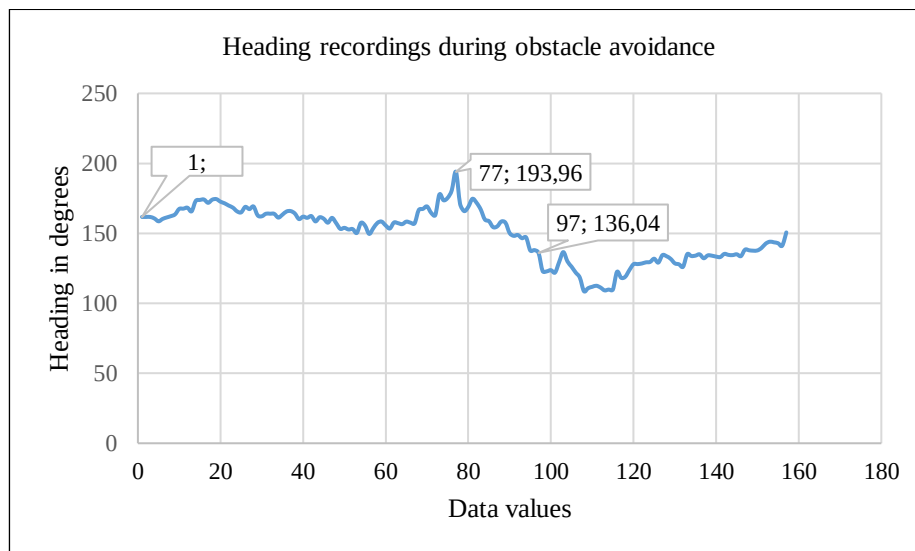


Figure 17: Mobile robot heading recorded with LSM303DLHC sensor while autonomously avoiding obstacles.

Source: Authors, (2026).

The mobile robot autonomously avoided the obstacle by turning 30° to the right and obtaining its heading angle from the LSM303DLHC sensor. The mobile robot turned 30° from the reference, which can be seen in Figure 17 above as data point 1. The value is 161.7° . After turning the heading recorded is 193.96° , which means the difference of angle is 32.26° . Hence, an error of 2.26° was there. Also, when the mobile robot returned to the black line after avoiding obstacles, its heading recorded was 136.04° ; hence, the true value of the turn was 60° , but it was actually $193.96 - 136.04^\circ$, equal to 57.92° . Hence, an error of $60 - 57.92 = 2.08^\circ$ was there.

IV.4 LIMITATIONS OF THE WORK

There are some limitations of the work presented in this paper. Firstly, there can be few replacements for the used LSM303DLHC sensor that can be processed with Mahony or a low-pass filter. For example, the recently launched magnetometer MMC 5603NJ sensor may be relatively cheap and highly accurate, but it needs an accelerometer for tilt compensation. The experiments conducted are subject to environmental conditions, hardware components and software setups used. Only the orientation of DDMR was considered; hence, including odometry and dead reckoning can enhance the results.

V. CONCLUSIONS

In this paper, a low-cost six-axis magnetometer/accelerometer LSM303DLHC sensor was used for Yaw/heading measurement. The LSM303DLHC sensor was selected after comparison with its counterparts on defined parameters. A simple DDMR was developed with an onboard Micro SD card module as a data logger. The first experiment performed suggests that heading values are consistent over a period. Secondly, the DDMR was able to track the rectangular and curvature black line with IR sensors. These experiments were performed so that heading values can be stored in real time while the DDMR is traversing. The stored values can be compared with the fixed turns on the black line (90° turn in a rectangular path) as a reference. The third experiment confirmed that DDMR can use the heading values from the LSM303DLHC sensor to avoid the obstacle successfully. Hence, the selection of LSM303DLHC as a heading sensor can be a good choice for low-cost navigational applications in robotics. In future, fusion of sensors with different combinations of magnetometers, gyroscope, and accelerometer will be explored for autonomous navigation. It will also include the calibration and data filtering process.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Kumar Gaurav.

Methodology: Kumar Gaurav.

Investigation: Guransh Singh Arora, Kumar Gaurav.

Discussion of results: Kumar Gaurav.

Writing – Original Draft: Kumar Gaurav.

Writing – Review and Editing: Kumar Gaurav.

Resources: Guransh Singh Arora, Kumar Gaurav.

Supervision: Kumar Gaurav.

Approval of the final text: Guransh Singh Arora, Kumar Gaurav.

VII. ACKNOWLEDGMENTS

The author acknowledges the provision of research facilities by Manipal University Jaipur.

VIII. REFERENCES

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