JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# Study of Magnetic and Microwave Sensors role in Defense Field

**Amrita Sajja[1], Madhu Priya Padarthi[2], John Munigala[3], Yuvasree Boini[4], M Kiran Kumar[5]**

*Department of Electronics and Communication Engineering, Anurag University, Hyderabad, Telangana, India*

**Abstract:** The defense sector plays a critical role in safeguarding a nation's sovereignty and protecting its citizens. By maintaining a strong defense, a country can deter potential aggressors, prevent conflicts, and respond effectively to emergencies. Microwave and magnetic sensors play crucial roles in the defense sector for detecting various objects and threats. Microwave sensors utilize electromagnetic waves [17] in the microwave frequency range to detect objects by measuring changes in the reflected waves. These sensors are adept at detecting movement, such as approaching vehicles or aircraft [12], and can also identify concealed objects [1]. On the other hand, magnetic sensors detect changes in magnetic fields, allowing them to locate metallic objects like weapons [6], [7], vehicles [9], [10], or submarines. By combining the capabilities of microwave and magnetic sensors, defense systems can effectively monitor and secure areas, providing early warnings and enhancing situational awareness against potential threats. Microwave and magnetic sensors offer distinct advantages in the defense field compared to other sensors due to their unique capabilities and properties like Versatility, All Weather Performance, Stealth Detection, Long-range Detection, etc. This study reviews Microwave and Magnetic sensors approach to detect things in defense field and gives an outline of the progress made in this field. This study also goes through a number of research papers and compare numerous microwave and magnetic sensing techniques. In conclusion, this study highlights the best sensor's [3], [4], [7], [8] applications, challenges, and potential areas of detecting weapons in defense field.

**Keywords**: National sovereignty, Microwave sensors, Magnetic sensors, versatility, Stealth detection.

## I. INTRODUCTION

In safeguarding sensitive areas and identifying potential threats, the defense field heavily relies on a diverse arsenal of sensors. Microwave and magnetic technologies play a critical role in this multifaceted approach. Theyoffer a range of capabilities beyond the limitations of human perception. Microwave sensors like Pulse radars [1], [2], [5] and Microwave Doppler's [32] utilize electromagnetic waves [17] to track moving objects, allowing for long-range detection regardless of visibility conditions. Infrared sensor cameras [5] passively detect heat signatures, providing valuable information in low-light environments or through concealment. Swept-frequency continuous wave sensors [3], [4], [6] employ varying frequencies to identify disturbances caused by movement or changes in the environment. Magnetic sensors, encompassing various types like Magnetometers [6], [7], [10], [23], Magnetoresistive sensors [24], Giant Magnetoresistance sensors [15], [22], Hall effect sensors [39], and Fluxgate magnetometers [26], [24], are highly sensitive to magnetic fields. This allows them to detect the presence of metal objects, individuals carrying concealed weapons [6], [7], or even specific types of explosives, even when hidden from sight. Microwave sensors in weapon detection [3] aren't like metal detectors. They act more like advanced motion detectors [34]. The sensor blasts out microwave waves and analyzes the echoes bouncing back. Any movement disrupts this pattern, and the sensor flags the change. This might indicate someone carrying something, but it can't tell the difference between a weapon and a laptop! The fabrication process of CMOS- MEMS Magnetic Microsensors [39], shedding light on their comprehensive design, fabrication, and characterization through the integration of CMOS processes and MEMS technology [38], [39]. These microsensors, leveraging Lorentz force actuation, respond to a magnetic field, inducing a change in capacitance, a phenomenon meticulously explored in the study. A pivotal phase of the sensor's development involves a post- CMOS process [39], wherein anisotropic and isotropic dry etching techniques are skillfully applied to release the suspended sensor structure. The culmination of these techniques allows for the sensor's efficient operation. A vital aspect of the research lies in the sensing circuit, adeptly converting the capacitance variation induced bythe Lorentz force [39] into a measurable output voltage. The experimental findings demonstrate a discernible voltage range, spanning from 0.05 to 1.94 V, in response to a magnetic field within the range of 5–200 mT, thereby highlighting the practical applications and performance capabilities of these innovative CMOS-MEMS magnetic microsensors [38], [39].

## II. METHODOLOGY

| References | PulseRadar | Radar Holography | CW sensor | YOLOv3 Algorithm | MIMO Radar System | Real-Time Imaging | 3D-SAR Technique |
|---|---|---|---|---|---|---|---|
| Weapon Detection Using Microwave And Millimeter Wave Sensors [1] | ✓ | ✓ | X | X | X | X | X |
| Anti-Tank Projectile Detection by Means of CWSensors [2] | ✓ | X | ✓ | X | X | X | X |
| MIC for Dynamic and Automatic Detection of Weapons [3] | X | X | ✓ | X | ✓ | ✓ | X |
| MIC of Weapons Using 3D-SAR Technique [4] | X | X | ✓ | X | ✓ | ✓ | ✓ |
| Concealed Object Detection Based On YOLOv3 Algorithm [5] | ✓ | ✓ | X | ✓ | X | X | X |

**Table 1:** *Comparing different algorithms from different papers on weapon detection*

| Sensor | Description | Advantage |
|---|---|---|
| Pulse Radar [1], [2], [5] | A pulse radar sensor uses short pulses of electromagnetic energy to detect and measure the distance to objects by analyzing the time it takes for the pulses to reflect back. | Pulse radar sensors has ability to providehigh range resolution, allowing them to distinguish between closely spaced objects. |
| wave DopplerRadar [32] | It detects motion by measuring changesin the frequency of reflected microwaves caused by the Doppler effect. | Their ability is to detect motion accurately and at a distance, making them ideal for applications like speed detection and motion sensing. |
| Infrared Sensor Camera [5] | It is using infrared radiation, which is emitted by objects based on their temperature, allowing it to create images even in low-light or no-light conditions. | To see in the dark, as they can detect infrared radiation emitted by objects,making them useful for surveillance and night vision applications. |
| SFCW [3], [4], [6] | An Swept Frequency Continuous Wave (SFCW) sensor uses a continuous wave signal with a frequency that changesover time to measure distances and properties of objects based on thesignal's reflections. | Their ability is to provide high-resolution measurements in radar and imaging applications due to their precise frequency control and processing techniques. |
| CW [2], [3] | A Continuous Wave (CW) radar sensor emits a continuous signal to detect the presence, distance, and speed of objects by measuring the phase shift of the reflected signal. | Their ability is to provide continuous measurements, allowing for real-timetracking of moving objects. |

**Table 2:** *Methodologies of different microwave sensors from different papers*

| Parameter | Pulse Radar Sensor [1], [2], [5] | CW Sensor [2], [3] | Microwave Doppler Sensor [32] | Infrared Sensor [5] | SFCW Sensor [3],[4], [6] |
|---|---|---|---|---|---|
| Sensitivity | -100 dBm to -80 dBm | -50 dBm to -30dBm | -7 dBm to -50dBm | 10μW/cm³ Thermal) | -80 dBm to -60 dBm |
| Range | 10 meters to 10 kilometers | Upto 10 meters | 0.1 meters to 10 meters | Upto a fewmeters | 0.5 meters to 50 meters |
| Accuracy | ±1 meter to ±10 meters | ±0.1 to ±1% | ±1cm/s to ±10cm/s | ±0.5°C to ±2°C | ±2cm to ±10cm |
| Resolution | 1 centimeter to 1 meter | Millimeter | Millimeter to centimeter | 0.1°C to 1°C | Centimeter |
| ResponseTime | Microseconds to ms | Continuous | Microseconds toms | rosecondsto ms | Microseconds to ms |
| Signal-to- Noise Ratio | 10 dB to 30dB | 15 dB to 25 dB | 10 dB to 20 dB | Depends on temperature and background radiation | 20 to 40 dB |

**Table 3:** *Values of different parameters of different sensors used in microwave detecting technique*

| Sensor | Description | Advantage |
|---|---|---|
| Magnetometer [6], [7], [10], [23] | A magnetometer sensor measures the direction, strength, or change of a magnetic field | Magnetometer sensors invisibly sense magnetic fields, making them useful in metal detection, navigation, and more. |
| Magnetoresistive [24] | A magnetoresistive sensor detects changes in a magnetic field by measuring the resulting shift in electrical resistance of a special material. | Magnetoresistive sensors offer high sensitivity for magnetic field detection, making them ideal for applications like precision positioning and current monitoring. |
| Giant magnetoresistance [24], [15], [22] | Giant magnetoresistance (GMR) is a quantum mechanical effect observed in multilayers composed of alternating ferromagnetic and non-magnetic conductive layers, resulting in a significant change in electrical resistancebased on the alignment of adjacent ferromagnetic layers' magnetization | Giant Magnetoresistance (GMR) sensors include their small dimensions,low power requirements, and high sensitivity. |
| Hall effect[38] | A Hall Effect sensor is a type of magnetic sensor that detects the strength and direction of a magnetic field produced by either a permanent magnet or an electromagnet. | Hall Effect sensors offer several advantages, including robust solid- state components, miniaturization for surface mount applications, low cost,fast response, and durability with almost unlimited lifetime |
| Fluxgate Magnetometer [26], [24] | A Fluxgate Magnetometer is an advanced type of magnetometer designed to measure the intensity and direction of magnetic fields | Fluxgate magnetometers are very sensitive, and accurate magnetic sensors able to detect weak fields bothAC and DC |

**Table 4:** *Methodologies of different magnetic sensors from different papers*

| Parameter | Hall Effect Sensors [38] | Giant Magnetoresistance (GMR) Sensors [24], [15], [22] | Fluxgate Magnetometers [26], [24] | Magnetometer Sensor [6], [7], [10], [23] | Magnetoresistive Sensor [24] |
|---|---|---|---|---|---|
| Range | Several cm | Several mm to cm | Several Gauss | 10m | Several cm |
| Accuracy | ±0.5% to ±5% | ±0.01% to ±1% | ±0.01% to ±1% | ±1% | ±1% |
| Sensitivity | 1 to 100 mV/G | 1 to 100 mV/VT | 0.01 nT | 500mV/G | 0.1 nT |
| Resolution | <10 µT | <10 µT | 0.01 nT to 0.1 nT | 0.01nT | 0.01 nT |
| ResponseTime | Microseconds to ms | Microseconds toms | ms to seconds | econds toms | rosecondsto ms |
| Signal-to-Noise Ratio | 50 dB to 80 dB | 50 dB to 80 dB | 70 dB to 90 dB | 30 to 60 dB | 20 to 50 dB |

**Table 5:** *Values of different parameters of different sensors used in magnetic detecting technique*

| Method | Algorithm Design | Simulation Results | Experimental Results |
|---|---|---|---|
| MEMS Fabrication [38], [39] | - Utilizes microfabrication techniques to create miniature sensors. | - Simulated behavior of MEMS sensors in various conditions. | - Validated sensor performance in controlled laboratory settings. |
| Inductive Sensors [38] | - Based on electromagnetic induction. Detects metal objects by measuring changes in inductance. | - Simulated response to different metal targets and distances. | - Experimentally verified detection accuracy using metallic objects. |
| Magnetic Sensors [38] | - Utilizes Hall effect or magnetoresistive principles.Measures magnetic fields. | - Simulated sensitivity to magnetic field variations. | - Conducted experiments with known magnetic fieldsto validate sensor output. |
| Electrochemical [38] | - Measures chemical reactions at electrode interfaces. Common in gas sensors, pH sensors, and biosensors. | - Simulated sensor response to varying analyte concentrations. | - Tested sensor performance with known chemical solutions or biological samples. |

**Table 6:** *Results of sensors used in paper Magnetic sensors and their applications* [38]

## III. CONCLUSION

By comparing all the papers both microwave and magnetic sensors offer distinct advantages and disadvantages for weapon detection. Magnetic sensors excel at detecting ferrous metals but are blind to non-metallic threats. Conversely, microwave sensors hold potential for broader object detection [11], [12] but face challenges withinterference and accuracy. Microwave sensors are good for detecting weapons [1] ,[2], [3] made of various materials due to their penetrability and ability to operate over a range of frequencies but their limitations include issues with material composition of the weapon [4], [5], operating range, and attenuation factors. Magnetic sensors are highly effective for detecting metallic weapons [7], [8]; the Giant Magneto-Resistive (GMR) sensor [6], [22] array developed at Newcastle University shows potential for automatic weapon detection and classification but can be affected by the human body's presence, which may give a stronger signal than the material of a low- conductivity or small weapon, potentially leading to undetected items. Ultimately, the "best" sensor depends on the specific application's priorities**.** For cost-effectiveness and reliable ferrous metal detection [23], [28], magnetic sensors shine. However, for broader detection needs**,** even with potential drawbacks, microwave sensors might be a better choice. In crucial scenarios, combining both sensors or integrating them with other security measuresprovides the optimal approach for comprehensive weapon detection [5], [10].

## IV. REFERENCES


[1] R. W. McMillan, N. C. Currie, D. D. Ferris and M. C. Wicks, "Concealed weapon detection using microwave and millimeter wave sensors," *ICMMT'98. 1998 International Conference on Microwave and Millimeter Wave Technology. Proceedings (Cat. No.98EX106)*, Beijing, China, 1998, pp. 1-4, doi: 10.1109/ICMMT.1998.768213.

[2] A. Rutkowski, A. Kawalec and C. Rećko, "Anti-tank projectile detection by means of CW microwave sensors and portable pulsed radar," *2018 22nd International Microwave and Radar Conference (MIKON)*, Poznan, Poland, 2018, pp. 315-316, doi: 10.23919/MIKON.2018.8405211.

[3] Baqué, R.; Vignaud, L.; Wasik, V.; Castet, N.; Herschel, R.; Cetinkaya, H.; Brandes, T. MIC: Microwave Imaging Curtain for Dynamic and Automatic Detection of Weapons and Explosive Belts. *Sensors* 2023, *23*, 9531. https://doi.org/10.3390/s23239531.

[4] Rezgui, Nacer-Ddine & Andrews, David & Bowring, Nicholas. (2015). Ultra-wide-band 3D microwaveimaging scanner for the detection of concealed weapons. 10.1117/12.2197581.

[5] Pang, L.; Liu, H.; Chen, Y.; Miao, J. Real-time Concealed Object Detection from Passive Millimeter Wave Images Based on the YOLOv3 Algorithm. *Sensors* 2020, *20*, 1678. https://doi.org/10.3390/s20061678.

[6] Al-Qubaa, Abdalrahman & Wilson, John. (2012). Design of an electromagnetic imaging system forweapon detection based on GMR sensor arrays. Sensors and Actuators A: Physical. 174. 75–84. 10.1016/j.sna.2011.11.034.

[7] Kotter, Dale & Roybal, Lyle & Polk, Robert. (2002). Detection and classification of concealed weapons using a magnetometer-based portal. 10.1117/12.479303.

[8] Y. Huang, P. Mather and M. Sibley, "Open Area Concealed Weapon Detection (CWD) Sensor System and Algorithm Development," *2019 PhotonIcs & Electromagnetics Research Symposium - Spring (PIERS-Spring)*, Rome, Italy, 2019, pp. 4078-4085, doi: 10.1109/PIERS-Spring46901.2019.9017665.

[9] Bugdol, Marcin & Miodonska, Zuzanna & Krecichwost, Michal & KASPEREK, Paweł. (2014). Vehicle detection system using magnetic sensors. Transport Problems. 9. 49-60.

[10] R. Berešík, J. Puttera, J. Kurty and J. Jurčo, "Magnetic sensor system concept for ground vehicles detection," *2017 International Conference on Military Technologies (ICMT)*, Brno, Czech Republic, 2017, pp. 710-715, doi: 10.1109/MILTECHS.2017.7988849.

[11] Dala, A.; Arslan, T. In Situ Sensor for the Detection of Oil Spill in Seawater Using Microwave Techniques. *Micromachines* 2022, *13*, 536. https://doi.org/10.3390/mi13040536.

[12] Jenik, Vojtech & Hudec, Premysl. (2012). Microwave multi-sensor system for estimation of positionsof fast-flying objects. 1917-1919. 10.1109/EuCAP.2012.6206077.

[13] Brandin, M.(2003). Classification of ground objects using laser radar data.

[14] Chen, S.; Wang, J.; Zhang, C.; Li, M.; Li, N.; Wu, H.; Liu, Y.; Peng, W.; Song, Y. Marine StructuralHealth Monitoring with Optical Fiber Sensors: A Review. *Sensors* 2023, *23*, 1877. https://doi.org/10.3390/s23041877.

[15] C. Guo, Li Anliang, H. Cai and Yang Huabo, "Algorithm for geomagnetic navigation and its validity evaluation," *2011 IEEE International Conference on Computer Science and Automation Engineering*, Shanghai, China, 2011, pp. 573-577, doi: 10.1109/CSAE.2011.5953286.

[16] Fingas, Merv & Brown, Carl. (1997). Review of oil spill remote sensing. Spill Science & Technology Bulletin. 83. 199-208. 10.1016/S1353-2561(98)00023-1.

[17] O. P. N. Calla, H. K. Dadhich and S. Singhal, "Oil spill detection using multi frequency microwave sensor onboard satellite; SSM/I and AMSR-E," *2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS*, Melbourne, VIC, Australia, 2013, pp. 3710-3713, doi: 10.1109/IGARSS.2013.6723636.

[18] P. Ripka, M. Janosek, M. Butta, S. W. Billingsley and E. Wakefield, "Crossfield effect in magnetic sensors," *SENSORS, 2009 IEEE*, Christchurch, New Zealand, 2009, pp. 1860-1863, doi: 10.1109/ICSENS.2009.5398405.

*[19]* J. T. Bono, D. J. Overway and W. M. Wynn, "Magnetic sensor operation onboard a UUV: magnetic noise investigation using a total-field gradiometer," *Oceans 2003. Celebrating the Past Teaming Toward the Future (IEEE Cat. No.03CH37492)*, San Diego, CA, USA, 2003, pp. 2018-2022 Vol.4, doi: 10.1109/OCEANS.2003.178209.

[20] Chen, Z.; Liu, Z.; Zhang, Q.; Chen, D.; Pan, M.; Xu, Y. A New Geomagnetic Vector Navigation Method Based on a Two-Stage Neural Network. *Electronics* 2023, *12*, 1975. https://doi.org/10.3390/electronics12091975.

[21] E. Karthika, K. Amutha, S. J. Prabhu, S. J. K. Jerushia and H. Padmapriya, "Object Detection Using Radar," *2018 International Conference on Current Trends towards Converging Technologies (ICCTCT)*, Coimbatore, India, 2018, pp. 1-4, doi: 10.1109/ICCTCT.2018.8550829.

[22] Jiang Yanwei, Fang Jiancheng, Huang Xuegong and Song Yujun, "Design of GMI micro-magnetic sensor and its application for geomagnetic navigation," *2008 2nd International Symposium on Systems and Control in Aerospace and Astronautics*, Shenzhen, China, 2008, pp. 1-6, doi: 10.1109/ISSCAA.2008.4776397.

[23] A. Sheinker, L. Frumkis, B. Ginzburg, N. Salomonski and B. -Z. Kaplan, "Magnetic Anomaly Detection Using a Three-Axis Magnetometer," in *IEEE Transactions on Magnetics*, vol. 45, no. 1, pp. 160-167, Jan. 2009, doi: 10.1109/TMAG.2008.2006635.

[24] J. Hu *et al.*, "Magnetic flux regulation largely boosts magnetoresistive sensors," *2020 IEEE SENSORS*, Rotterdam, Netherlands,

2020, pp. 1-4, doi: 10.1109/SENSORS47125.2020.9278912.

[25] Canciani, Aaron & Brennan, Christopher. (2020). An Analysis of the Benefits and Difficulties of Aerial Magnetic Vector Navigation. IEEE Transactions on Aerospace and Electronic Systems. PP. 1-1. 10.1109/TAES.2020.2987475.

[26] Fischer, Gregory & Edelstein, Alan. (2010). Magnetic Modeling of a Rotating Flux Concentrator System Designed to Mitigate Noise in Large Magnetic Sensors.

[27] M. Zhai, Z. Long and X. Li, "Fault-Tolerant Control of Magnetic Levitation System Based on State Observer in High Speed Maglev Train," in *IEEE Access*, vol. 7, pp. 31624-31633, 2019, doi: 10.1109/ACCESS.2019.2898108.

[28] Huang, J.; Zheng, Z.; Zhou, Y.; Tan, Y.; Wang, C.; Xu, G.; Zha, B. Magnetic Anomaly Detection Basedon a Compound Tri-Stable Stochastic Resonance System. *Sensors* 2023, *23*, 9293. https://doi.org/10.3390/s2322929.

[29] Lu, F.; Tan, Q.; Ji, Y.; Guo, Q.; Guo, Y.; Xiong, J. A Novel Metamaterial Inspired High-Temperature Microwave Sensor in Harsh Environments. *Sensors* 2018, *18*, 2879. https://doi.org/10.3390/s18092879.

[30] Thi Phuoc Van, N.; Tang, L.; Demir, V.; Hasan, S.F.; Duc Minh, N.; Mukhopadhyay, S. Review- Microwave Radar Sensing Systems for Search and Rescue Purposes. *Sensors* 2019, *19*, 2879. https://doi.org/10.3390/s19132879.

[31] Nanzer, Jeffrey. (2017). A Review of Microwave Wireless Techniques for Human Presence Detection and Classification. IEEE Transactions on Microwave Theory and Techniques. 65. 1-15. 10.1109/TMTT.2017.2650909.

[32] Karaev, V.; Titchenko, Y.; Panfilova, M.; Ponur, K.; Ryabkova, M.; Meshkov, E.; Kovaldov, D. On the Problem of the Sea Ice Detection by Orbital Microwave Doppler Radar at the Nadir Sounding. *Remote Sens.* 2022, *14*, 4937. https://doi.org/10.3390/rs14194937.

[33] Z. Feng *et al*., "Efficient drone hijacking detection using onboard motion sensors," *Design, Automation & Test in Europe Conference & Exhibition (DATE), 2017*, Lausanne, Switzerland, 2017, pp. 1414- 1419, doi: 10.23919/DATE.2017.7927214.

[34] Coluccia, A.; Parisi, G.; Fascista, A. Detection and Classification of Multirotor Drones in Radar Sensor Networks: A Review. *Sensors* 2020, *20*, 4172. https://doi.org/10.3390/s20154172.

[35] Lu, F.; Tan, Q.; Ji, Y.; Guo, Q.; Guo, Y.; Xiong, J. A Novel Metamaterial Inspired High-Temperature Microwave Sensor in Harsh Environments. *Sensors* 2018, *18*, 2879. https://doi.org/10.3390/s18092879.

[36] Liou Sy-Hwang. (2008). Magnetic Sensors with Picotesla Magnetic Field Sensitivity at Room Temperature. 17.

[37] Hu, X.; Duan, X.; Zhang, W.; Fu, Y.; Li, Y.; Zhao, P.; Deng, X.; Yu, C.; Wang, J. Design and Optimization of Multi-Stage TMR Sensors for Power Equipment AC/DC Leakage Current Detection. *Sensors* 2023, *23*, 4749. https://doi.org/10.3390/s23104749.

[38] Lenz, James & Edelstein, Alan. (2006). Magnetic Sensors and Their Applications. Sensors Journal, IEEE. 6. 631 - 649. 10.1109/JSEN.2006.874493.

[39] Hsieh, C.-H.; Dai, C.-L.; Yang, M.-Z. Fabrication and Characterization of CMOS-MEMS Magnetic Microsensors. *Sensors* 2013, *13*, 14728-14739. https://doi.org/10.3390/s131114728.