Airborne Detection of Landmines and Unexploded Ordnances with Data Fusion Techniques Using Ground Penetrating Radar and Magnetometer Integrated Unmanned Aerial Systems

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Abstract

Figure 1: Onboard sensors: Integrated magnetometer and GPR.

Detecting and clearing legacy landmines, Improvised Explosive Devices (IED), and Unexploded Ordnances (UXO) using a force made up of humans or animals is extremely risky, labour- and time-intensive. The cost of clearance is estimated to be $300-1000 per mine using conventional techniques, and one person dies for every 5000 mines removed. More than 1,000 deminers have lost their lives or suffered injuries while performing demining operations between 1999 and 2012. All around the world, there are approximately 100 million buried landmines due to low-cost manufacturing and simplicity of deployment across wide regions. 61 states worldwide are severely impacted by the slow demining process. The average number of people killed or maimed annually is 26,000 and 80% of this figure is children. Ten mines are placed for every mine removed, despite recent efforts to reduce their use. Using conventional methods to remove millions of landmines/IDE/UXO would take more than a century with potential risks and high costs, which will have a long-term, significant impact on many nations in a variety of ways.

Landmines are composed of diverse materials, including plastic, glass, wood, and metal, and they come in a range of sizes. Multiple sensors with varying detection abilities can be employed simultaneously to fuse the acquired data instances at a time for better decision-making. Deploying uninhabited aerial vehicles (UAVs) equipped with multiple remote sensing modalities seems to expedite humanitarian clearance operations safely and efficiently. In this study, two integrated remote sensing modalities (i.e. ground penetrating radar (GPR) and magnetometer) are mounted on an advanced autonomous UAV (Fig.1) to increase the probability of detection and decrease the false alarm rate using an integrated bespoke android-based tablet application in analysing the fused data in real time.

The performance of the particular modalities was evaluated in field tests in Latvia, Croatia and Cambodia. The full system with the fusion of data obtained from the integrated system has been tested in a landmine field in the UK. The results in the outdoor minefields confirm the viability of the techniques and approaches for detecting legacy landmines efficiently with high accuracy rates. Sensor data fusion has been proven to decrease the number of false alarms for detection. The improved versions of the developed easy-to-use compact technology are aimed to be deployed by humanitarian demining teams to expedite their clearing operations safely and efficiently.

Index Terms— Landmines, unexploded ordnances, ground penetrating radars, magnetometer, airborne demining.

REFERENCES

[1] N. Walsh and W. Walsh, "Rehabilitation of landmine victims—The ultimate challenge", Bull. World Health Org., vol. 81, pp. 665-670, Feb. 2003.
[2] S. Pati, B. K. Mishra, S. K. Bishnu, A. Mukhopadhyay and A. Chakraborty, "DroneMag: A novel approach using drone technology for detection of magnetic metal", Proc. 7th Int. Conf. Electron. Mater. Eng. Nano-Technol. (IEMENTech), pp. 1-4, Dec. 2023, [online] Available: https://api.semanticscholar.org/CorpusID:267576190.
[3] C. Yilmaz, H. T. Kahraman and S. Söyler, "Passive mine detection and classification method based on hybrid model", IEEE Access, vol. 6, pp. 47870-47888, 2018.
[4] K. Kuru, D. Ansell, B. J. Watkinson, D. Jones, A. Sujit, J. M. Pinder, et al., "Intelligent automated rapid and safe landmine and unexploded ordnance (UXO) detection using multiple sensor modalities mounted on autonomous drones", IEEE Trans. Instrum. Meas., 2024.
[5] M. Ihab, "Hyperspectral imaging for landmine detection", 2017.
[6] H. Aoyama, K. Ishikawa, J. Seki, M. Okamura, S. Ishimura and Y. Satsumi, "Development of mine detection robot system", Int. J. Adv. Robot. Syst., vol. 4, no. 2, pp. 25, 2007.
[7] K. Kuru, D. Ansell, W. Khan, and H. Yetgin, “Analysis and optimization of unmanned aerial vehicle swarms in logistics: An intelligent delivery platform,” IEEE Access, vol. 7, pp. 15 804–31, 2019.
[8] Landmine Monitor 2015, OT, Canada, 2015.
[9] I. Makki, R. Younes, C. Francis, T. Bianchi and M. Zucchetti, "A survey of landmine detection using hyperspectral imaging", ISPRS J. Photogramm. Remote Sens., vol. 124, pp. 40-53,
[10] X. Zhang, J. Bolton and P. Gader, "A new learning method for continuous hidden Markov models for subsurface landmine detection in ground penetrating radar", IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., vol. 7, no. 3, pp. 813-819, Mar. 2014.
[11] C. P. Gooneratne, S. C. Mukhopahyay and G. S. Gupta, "A review of sensing technologies for landmine detection: Unmanned vehicle based approach", *Proc. 2nd Int. Conf. Auton. Robots Agents*, pp. 401-407, Dec. 2004.
[12] P. Gao and L. M. Collins, "A two-dimensional generalized likelihood ratio test for land mine and small unexploded ordnance detection", Signal Process., vol. 80, no. 8, pp. 1669-1686, Aug. 2000,
[13] W. Rafique, D. Zheng, J. Barras, S. Joglekar and P. Kosmas, "Predictive analysis of landmine risk", *IEEE Access*, vol. 7, pp. 107259-107269, 2019.14] L. He, S. Ji, W. R. Scott and L. Carin, "Adaptive multimodality sensing of landmines", IEEE Trans. Geosci. Remote Sens., vol. 45, no. 6, pp. 1756-1774, Jun. 2007.
[14] S. B. I. Badia, U. Bernardet, A. Guanella, P. Pyk and P. F. Verschure, "A biologically based chemo-sensing UAV for humanitarian demining", Int. J. Adv. Robot. Syst., vol. 4, no. 2, pp. 21, 2007.
[15] ——, "Planning the Future of Smart Cities With Swarms of Fully Autonomous Unmanned Aerial Vehicles Using a Novel Framework," in *IEEE Access*, vol. 9, pp. 6571-6595, 2021, doi: 10.1109/ACCESS.2020.3049094.
[16] ——, “Management of geo-distributed intelligence: Deep insight as a service (DINSaaS) on forged cloud platforms (FCP),” Journal of Parallel and Distributed Computing, vol. 149, pp. 103–118, Mar. 2021.
[17] ——, “Technical report: Big data - concepts, infrastructure, analytics, challenges and solutions,” 2024.
[18] ——, “Technical report: Human-in-the-loop telemanipulation platform for automation-in-the-loop unmanned aerial systems.” 2024.
[19] ——, “Technical report: Towards state and situation awareness for driverless vehicles using deep neural networks,” 2024.
[20] ——, “6g in developing high-fidelity immersive digital twins,” In: 2nd International Conference on Communication, Information and Digital Technologies, 26-28 September 2025, Singapore.
[21] ——, “Joint cognition of remote autonomous robotics agent swarm in collaborative decision-making & remote human-robot teaming,” Proceedings of The Premium Global Conclave and Expo on Robotics & Automation (AUTOROBO, EXPO2024), 2024.
[22] ——, “Human-in-the-Loop Telemanipulation Schemes for Autonomous Unmanned Aerial Systems," *2024 4th Interdisciplinary Conference on Electrics and Computer (INTCEC)*, Chicago, IL, USA, 2024, pp. 1-6, doi: 10.1109/INTCEC61833.2024.10603071.
[23] ——, "Conceptualisation of Human-on-the-Loop Haptic Teleoperation With Fully Autonomous Self-Driving Vehicles in the Urban Environment," in *IEEE Open Journal of Intelligent Transportation Systems*, vol. 2, pp. 448-469, 2021, doi: 10.1109/OJITS.2021.3132725.
[24] ——, “Magnetic field mapping of a landmine field using a magnetometer-integrated drone and intelligent application,” 2024.
[Online]. Available: https://dx.doi.org/10.21227/ebny-b828
[25] ——, “Sensors and sensor fusion for decision making in autonomous driving and vehicles,” 2023
[26] ——, “Trustfsdv: Framework for building and maintaining trust in self-driving vehicles,” IEEE Access, vol. 10, pp. 82 814–82 833, 2022.
[27] ——, “Definition of multi-objective deep reinforcement learning reward functions for self-driving vehicles in the urban environment,” IEEE Trans. Veh. Technol., vol. 11, pp. 1–12, Mar. 2024
[28] ——, “Use of autonomous uninhabited aerial vehicles safely within mixed air traffic,” in Proceedings of Global Conference on Electronics, Communications and Networks (GCECN2024), 2023.
[29] ——, “A Novel Hybrid Clustering Approach for Unsupervised Grouping of Similar Objects,” Lecture Notes in Computer Science (pp. 642–653), 2014.
[30] ——, “Human-in-the-Loop Teleoperation Modes for Autonomous Unmanned Aerial Vehicles,” 4. Interdisciplinary Conference on
Electrics and Computer (INTCEC 2024), 11-13 June 2024, Chicago-USA.
[31] ——, "Technical report: Analysis of intervention modes in human-in-the-loop (hitl) teleoperation with autonomous ground vehicle systems.", 2022.
[32] ——, "Platform To Test and Evaluate Human-Automation Interaction (HAI) For Autonomous Unmanned Aerial Systems.", 2024
[33] K. Kuru, O. Erogul, and C. Xavier, “Autonomous low power monitoring sensors,” Sensors, vol. 21, 2021.
[34] Kuru, Kaya. "Technical Report: Analysis of Intervention Modes in Human-In-The-Loop (HITL) Teleoperation With Autonomous Unmanned Aerial Systems.", 2024
[35] K. Kuru, D. Ansell, D. Jones, B. Watkinson, J. M. Pinder, J. A. Hill, E. Muzzall, C. Tinker-Mill, K. Stevens, and A. Gardner, “Intelligent airborne monitoring of livestock using autonomous uninhabited aerial vehicles,” in The 11th European Conference on Precision Livestock Farming, 2024.
[36] K. Kuru, J. M. Pinder, B. J. Watkinson, D. Ansell, K. Vinning, L. Moore, C. Gilbert, A. Sujit, and D. Jones, “Toward mid-air collision-free trajectory for autonomous and pilot-controlled unmanned aerial vehicles,” IEEE Access, vol. 11, pp. 100 323–100 342, 2023.
[37] K. Kuru, S. Worthington, D. Ansell, J. M. Pinder, A. Sujit, B. Jon Watkinson, K. Vinning, L. Moore, C. Gilbert, D. Jones et al., “Aitl-wing-hitl: Telemanipulation of autonomous drones using digital twins of aerial traffic interfaced with wing,” Robotics and Autonomous Systems, vol. 5, 2024.
[38] K. Kuru, S. Clough, D. Ansell, J. McCarthy, and S. McGovern, “WILDetect: An intelligent platform to perform airborne wildlife census automatically in the marine ecosystem using an ensemble of learning techniques and computer vision,” Expert Systems with Applications, vol. 231. Elsevier BV, p. 120574, Nov-2023.
[39] K. Kuru, S. Clough, D. Ansell, J. McCarthy, and S. McGovern, “Intelligent airborne monitoring of irregularly shaped man-made marine objects using statistical Machine Learning techniques,” Ecological Informatics, vol. 78. Elsevier BV, p. 102285, Dec-2023.
[40] K. Kuru and W. Khan, “Novel hybrid object-based non-parametric clustering approach for grouping similar objects in specific visual domains,” Applied Soft Computing, vol. 62. Elsevier BV, pp. 667–701, Jan-2018.
[41] K. Kuru *et al.*, "Platform to Test and Evaluate Human-in-the-Loop Telemanipulation Schemes for Autonomous Unmanned Aerial Systems," *2024 20th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, Genova, Italy, 2024, pp. 1-8, doi: 10.1109/MESA61532.2024.10704856.
[42] K. Kuru and W. Khan, "A Framework for the Synergistic Integration of Fully Autonomous Ground Vehicles With Smart City," in *IEEE Access*, vol. 9, pp. 923-948, 2021, doi: 10.1109/ACCESS.2020.3046999.
[43] [K. Kuru, A. Sujit, D. Ansell, J. M. Pinder, D. Jones, B. Jon Watkinson, R. Hamila and C. L. Tinker-Mill, “Intelligent, Automated, Rapid, and Safe Landmine, Improvised Explosive Device and Unexploded Ordnance Detection Using Maggy,” IEEE Access, 2024.
[44] Kuru, K. and Ansell, D., 2023. Vision-based remote sensing imagery datasets from Benkovac landmine test site using an autonomous drone for detecting landmine locations. IEEE Data Port, pp.1-10.
[45] K. Kuru and H. Yetgin, “Transformation to advanced mechatronics systems within new industrial revolution: A novel framework in automation of everything (aoe),” IEEE Access, vol. 7, pp. 41 395–41 415, 2019.
[46] K. Kuru et al., Non-Invasive Detection of Landmines, Improvised Explosive Devices and Unexploded Ordnances Using Bespoke Unmanned Aerial Systems. In: IEEE International Conference on Electrical and Computer Engineering Researches (ICECER'24), 04-06 December 2024, Gaborone, Botswana, 2024.