VCU College of Engineering

Project 25-344 Sensor Data Fusion and Algorithm Analysis

Project Proposal

Prepared for

James Perea/Nibir Dhar

U.S. Department of Defense

By

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Under the supervision of

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Date

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Executive Summary

This project, sponsored by the U.S. Department of Defense, focuses on the development of an algorithm for fusing the data from EMI and GPR sensors in order to effectively detect and pinpoint landmines in active war zones. Existing detection methods face challenges such as high false positive and false negative rates, inadequate sensor resolution, and general inaccuracy due to battlefield clutter and interference. A false negative can result in severe injury or loss of life, while a false positive can lead to unnecessary delays and resource expenditure. Therefore, a more reliable and accurate detection system is imperative.

The primary objectives of this project are to develop a robust sensor data fusion algorithm that effectively combines data from EMI and GPR sensors, processing them to be compatible for analysis and producing informed decisions based on the integrated readings; to reduce false positives and false negatives by enhancing detection accuracy and making the algorithm resistant to battlefield clutter, ensuring accurate identification of landmines and reducing misidentification; and to improve safety for troops and demining personnel by providing precise localization of landmines to prevent accidental encounters and facilitate efficient clearance operations. To achieve these objectives, certain design requirements must be met, which are outlined in the document alongside constraints the we will face, codes and standards that we will abide by to produce a secure and useable product, and the current work that we have produced, which at the moment consists only of research.

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Section A. Problem Statement

Landmine detection has been an important factor in maintaining as much safety as possible during military and humanitarian operations, as they pose huge threats both during combat and after. While we have sensors that are capable of piecing together an image of where these land mines are located, extracting the information from these sensors in a reliable and certain way has been presenting challenges to engineers for decades. Fusion algorithms are limited by false positives, false negatives, inadequate sensor data resolution, and general inaccuracy. Ware zones can be riddled with confounding objects, and defining land mine presence in the midst of lots of interference is no small challenge. A false negative could spell death or dismemberment, and a false positive could delay operations unnecessarily. It is clear why the U.S. Department of Defense would take interest in this issue and why they are choosing to sponsor us in our endeavor of creating a newer, better fusion algorithm with fewer flaws than those that already exist.

A large amount of the research on this topic is walled away behind classified defense contractor and defense department databases, never to be seen by the general public, however there are a good number of general academia papers that focus on it as well. Of particular interest is a line mine detection algorithm that relies on electromagnetic induction sensors and ground penetrating radar, the former of which are adept at detecting small metallic objects by inducing electric currents in them and measuring the created field, and the latter of which emits electromagnetic pulses into the ground to detect reflections caused by dielectric discontinuities. When leveraging their complementary strengths, landmines of many types can be detected – however, there are issues with false positives, and resolving discrepancies with the actual location of the sensors and their reported locations, which necessitates post-correction with techniques such as thin plate splines, or, simply, data interpolation and smoothing. Assessing which flags will be marked as positives and which will be ignored can be determined in a variety of different ways, and there seems to be no strong consensus on which is the best.

Our goal is to refine the techniques that already exist and create an algorithm that is capable of assessing a battlefield and identifying the precise locations of land mines with more certainty than any other publicly available algorithm, exploring the usage of not only the two sensors that seem to be commonly agreed upon as the best for land mine detection, but also others that may solidify the conclusion of whether a land mine is present. Our algorithm will be fast, secure, and will fuse data responsively and in a way that ensures a correct output.

Section B. Engineering Design Requirements

This section describes the goals and objectives of the project, as well as all **realistic constraints** to which the design is bound. It is meant to provide a structure that helps to formulate the problem. Design requirements are often derived from client or stakeholder needs. They may consider benchmarking against or improving on currently available solutions, providing novel techniques or design solutions, integration with existing components, systems, or equipment, required codes and standards, general observations of the problem space, etc. Describe how the requirements provided below were researched and decided upon. Common design requirements often include considerations of the design efficacy, cost, safety, reliability, usability, and risk, among others.

Note: The deign requirements should be revisited between major reports to ensure that the design objectives and constraints still accurately reflect the client needs and project goals and to make sure that the team is on track to meet all goals and objectives.

Note: The codes and standards section is not required for the Project Proposal, but is required for all subsequent reports. This section should be comprehensive and thorough, requiring a significant research effort.

B.1 Project Goals (i.e. Client Needs)

1. **Develop a Robust Sensor Data Fusion Algorithm:** The algorithm will effectively combine all sensor data types, processing them as necessary so that they become compatible for analysis, and come to an informed solution based on the readings.
2. **Reduce False Positives or False Negatives:** The algorithm will produce accurate results as often as possible, and will be resistant to battlefield clutter, detecting mines, or the lack thereof, accurately.
3. **Improve Safety for Troops and Demining Personnel:** The algorithm will be able to pinpoint a precise location for the mine, and will not be inaccurate in this regard, so that mines can effectively be avoided by troops on the ground.

B.2 Design Objectives

1. **Specific Target Detection**: The design will detect surface and buried landmines in both natural and urban environments.
2. **Multi-Sensor Fusion**: The design will integrate data from multiple sensors, such as electro-optic imagers and synthetic aperture radar, to enhance detection accuracy.

3. **Clutter and Obscurant Handling**: The design will effectively discriminate between threat targets and decoys, clutter, or obscurants to reduce false positives.
4. **Scalable Detection Algorithm**: The design will be adaptable to varying scales and environments, ensuring it performs consistently in different terrain types.
5. **Timely Processing**: The design will provide real-time or near real-time detection capability, delivering actionable intelligence within a defined time limit (e.g., under 1 minute).
6. **Measurable Accuracy**: The design will meet a specified detection accuracy rate, such as 90% target identification with less than 5% false positives.
7. **Energy Efficiency**: The design will operate efficiently within existing power constraints of field equipment.
8. **Interoperability**: The design will be compatible with existing U.S. Army systems and platforms, ensuring seamless integration.

B.3 Design Specifications and Constraints

1. **Detection Accuracy**: The algorithm must achieve at least 90% detection accuracy, with a false positive rate below 5%.
2. **Sensor Integration**: The system must fuse data from at least two sensors (e.g., electro-optic imager and synthetic aperture radar) and operate effectively across different weather conditions (functional constraint).
3. **Processing Speed**: The system must process and identify threats within 60 seconds or less (performance constraint).
4. **Data Storage**: The system must handle data volumes of up to 1 TB/day with secure encryption (data constraint).
5. **Compatibility**: The design must comply with U.S. Army data sharing protocols and integrate with existing communication networks (interoperability constraint).

B.4 Codes and Standards

DoD Instruction 8500.01 - Cybersecurity

Relevance: The design must incorporate security measures to protect sensor data from unauthorized access and cyber threats.

MIL-STD-882E - System Safety

Relevance: The design must identify potential hazards associated with sensor data fusion and implement risk management strategies.

MIL-STD-1553B - Data Bus Standard

Relevance: If the sensor fusion system interfaces with 1553 data buses, compliance is necessary for interoperability with military platforms.

NIST SP 800-53 - Security and Privacy Controls for Information Systems and Organizations

Relevance: The design must include controls that protect data integrity, confidentiality, and availability.

Standards

IEEE 802.15.4 - Low-Rate Wireless Personal Area Networks (LR-WPANs)

Relevance: If using wireless sensors for data fusion, adherence to this standard ensures reliable communication between sensors.

ISO/IEC 27001 - Information Security Management Systems

Relevance: The design must follow these guidelines to ensure that the sensor data is securely managed and protected.

ANSI/ISA 95 - Enterprise-Control System Integration

Relevance: It ensures that the sensor data fusion system can effectively interface with enterprise-level systems.

ASME Y14.5 - Dimensioning and Tolerancing

Relevance: The design documentation must adhere to this standard to ensure clarity and precision in the specifications of sensor components.

IEEE 1012 - Standard for Software Verification and Validation

Relevance: It ensures that the software components of the sensor data fusion system meet their requirements and perform as intended.

ISO 9001 - Quality Management Systems

Relevance: The design process must incorporate quality management practices to ensure reliable and consistent performance of the sensor fusion system.

Section C. Scope of Work

The project scope defines the boundaries of the project encompassing the key objectives, timeline, milestones and deliverables. It clearly defines the responsibility of the team and the process by which the proposed work will be verified and approved. A clear scope helps to facilitate understanding of the project, reduce ambiguities and risk, and manage expectations. In addition to stating the responsibilities of the team, it should also explicitly state those tasks which fall *outside* of the team's responsibilities. *Explicit bounds* on the project timeline, available funds, and promised deliverables should be clearly stated. These boundaries help to avoid *scope creep*, or changes to the scope of the project without any control. This section also defines the project approach, the development methodology used in developing the solution, such as waterfall or agile (shall be chosen in concert with the faculty advisor and/or project sponsor). Good communication with the project sponsor and faculty advisor is the most effective way to stay within scope and make sure all objectives and deliverables are met on time and on budget.

C.1 Deliverables

Software Code

- The complete source code for the sensor data fusion algorithms, including documentation for usability.

Flow Charts/ Diagrams

- Flowcharts outlining the processes for data collection, fusion, and output. Diagrams illustrating system architecture, data flow, and integration points with other systems.

User Manuals

- Documentation for end-users detailing how to operate and troubleshoot the system.

Desktop Models

- 3D digital models of the system for visualization and analysis.

Functional Prototype

- A working prototype demonstrating the core functionalities of the sensor data fusion system.

Project Proposal

- A formal document outlining the project objectives, scope, and methodology.

Preliminary Design Report

- A report detailing the initial design concepts and decisions made.

Final Design Report

- A comprehensive report summarizing the design process, analysis, results, and conclusions.

Capstone EXPO Poster and Presentation

- A visual and oral presentation of the project findings, designed for an academic audience.

Fall Poster and Presentation

- An interim presentation showcasing progress to date, tailored for faculty and peers.

Team Contract

- A document outlining roles, responsibilities, and commitments of each team member.

Campus Access Requirements

Deliverables:

- Prototyping work and testing may require lab access or specialized equipment.

Availability:

- Assess how many team members are available on campus regularly for hands-on work and testing.

Remote Work Limitations

Deliverables:

- Software development, documentation, and design analysis can be done remotely.

Resources Needed:

- Ensure access to required software licenses, collaboration tools (e.g., Zoom, Slack), and shared drives (e.g., Google Drive, Dropbox) for effective remote collaboration.

Third-Party Vendor Dependencies:

- Components for the prototype may need to be ordered from external suppliers.

Lead Times:

- Identify any components with long lead times, such as specialized sensors or processors, and consider alternatives or contingencies.

Mitigation Strategies:

- Build a buffer into the project timeline to accommodate potential delays.
- Plan for early ordering of critical components and have backup components identified.

Coordination with DoD Regulations

Requirements:

- Ensure compliance with DoD cybersecurity and safety standards, which may necessitate additional documentation or testing.

Impact:

- Delays in approval processes or additional requirements could affect project timelines.

Collaboration Needs:

- If the project requires expertise outside the team's capabilities (e.g., cybersecurity, advanced algorithms), identify potential collaborators early.

Communication:

- Establish clear communication channels with advisors and stakeholders to ensure alignment on expectations and deliverables.

C.2 Milestones

Sensor Data Fusion Project Milestones

1. Project Initiation and Planning (2 weeks): Develop project charter, define scope, and create initial project plan.

2. Contact Military Sponsor (1 week): Establish communication with the DoD sponsor to clarify project scope and sensor specifications.

3. Research and Literature Review (1 week): Conduct comprehensive research on sensor data fusion algorithms and applications.

4. Requirements Gathering (1 week): Document detailed project requirements based on sponsor input and research findings.

6. Algorithm Selection and Design (1 week): Choose and design appropriate sensor data fusion algorithms.

9. Data Collection Module Development (2 weeks): Develop a software module for sensor data collection.

10. Data Fusion Algorithm Implementation (2 weeks): Implement core data fusion algorithms with sample data.

Note that the timeframe and order of these milestones are tentative, and are subject to change and be moved around based on project needs/demands and the flow of it.

C.3 Resources

Sensors:

- Ground Penetrating Radar (GPR)
- Electromagnetic Induction (EMI) sensors

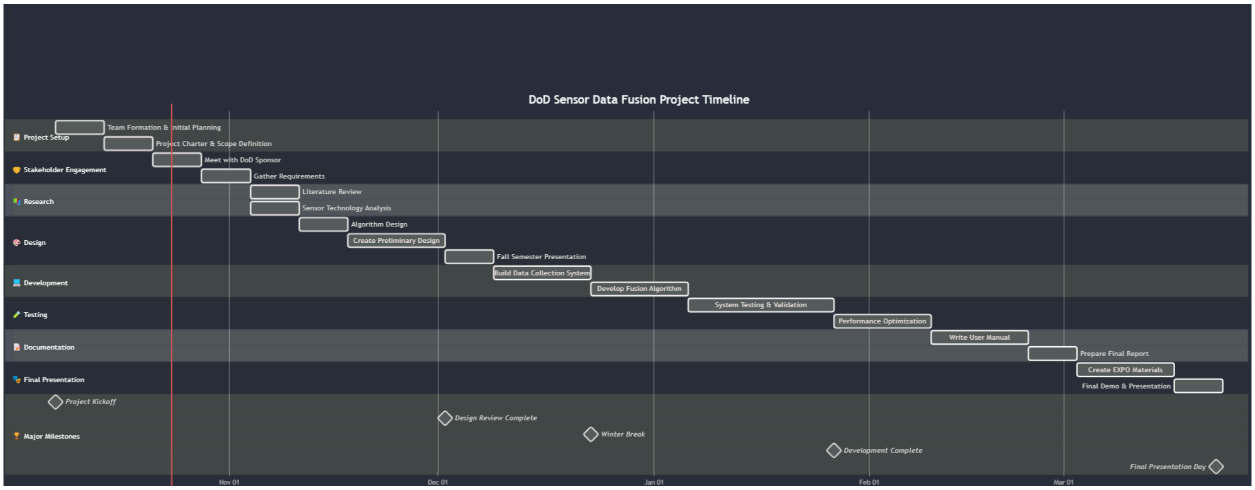
Software:

- MATLAB or Python for algorithm development and data analysis
- Specialized GPR and EMI data processing software (e.g., GPR-SLICE, GPRMAX)
- Machine learning libraries (e.g., TensorFlow, PyTorch, scikit-learn)
- Data visualization tools (e.g., Tableau, Power BI)
- Version control system (e.g., Git)
- Integrated Development Environment (IDE) like PyCharm or Visual Studio Code

Simulation Tools:

- Electromagnetic simulation software (e.g., COMSOL Multiphysics, ANSYS HFSS)
- Sensor modeling software for virtual prototyping

Appendix 1: Project Timeline



Appendix 2: Team Contract (i.e. Team Organization)

VCU College of Engineering

25-344 Sensor Data Fusion and Algorithm Development

Team Contract

Prepared for

Nibir Dhar

DoD Aspire

By

David Anthony

Grace Gillam

Jeffrey Weaver

Paul Reid

Sep 5, 2024

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Step 1: Get to Know One Another. Gather Basic Information.

Task: This initial time together is important to form a strong team dynamic and get to know each other more as people outside of class time. Consider ways to develop positive working relationships with others, while remaining open and personal. Learn each other's strengths and discuss good/bad team experiences. This is also a good opportunity to start to better understand each other's communication and working styles.

Team Member Name	***Strengths each member bring to the group***	***Other Info***	***Contact Info***
David Anthony	C, C++,C# , Java, LUA	Worked in tech support for 7 years.	anthonyde@vcu.edu
Paul Reid	ReactJS, NodeJS, Tensorflow, Kali Linux, Python, C#	GAN AI image modeling, ReactJS website	reidp@vcu.edu
Grace Gillam	React, Angular, Matlab maybe…., Node, SpringBoot, Java, JS, HTML, Python maybe….	Full-stack development internship, web app, taking cryptography	gillamga@vcu.edu
Jeffrey Weaver	Java, C/C++, Python,	Swift IOS dev	weaverjs@vcu.edu

Other Stakeholders	***Notes***	***Contact Info***
Luo Changqing	Met with and got told to research! He's done this a billion times already!	cluo@vcu.edu
Nibir Dhar	N/A	dharnk@vcu.edu

Step 2: Team Culture. Clarify the Group's Purpose and Culture Goals.

Task: Discuss how each team member wants to be treated to encourage them to make valuable contributions to the group and how each team member would like to feel recognized for their efforts. Discuss how the team will foster an environment where each team member feels they are accountable for their actions and the way they contribute to the project. These are your Culture Goals (left column). How do the students demonstrate these culture goals? These are your Actions (middle column). Finally, how do students deviate from the team's culture goals? What are ways that other team members can notice when that culture goal is no longer being honored in team dynamics? These are your Warning Signs (right column).

Resources: More information and an example Team Culture can be found in the Biodesign Student Guide "Intentional Teamwork" page (webpage | PDF)

Culture Goals	***Actions***	***Warning Signs***
Have a consistent weekly meeting time.	- Meeting at 3:30 every Thursday	- Student misses first meeting - Student misses meetings afterwards
Adhering to sprint timelines	- Holding each other accountable for work at deadlines - Checking trello every thursday Trello	- Student shows up for weekly meeting with no considerable work done - Student does not talk with members of group and does not meet deadlines
Have a highly efficient code runtime and comments	- Code review weekly and everyone will assess what has been pushed - Read Algorithms textbook	- Multiple poor reviews - Is not writing a lot of code that is getting committed
Push to the GitHub on your own branch when you do something and then merge carefully	- Don't resolve merge conflicts in VSCode - just use GitHub desktop or actual GitHub	-Breaking main and not saying anything about it -Student pushes without confirming integrity

Step 3: Time Commitments, Meeting Structure, and Communication

Task: Discuss the anticipated time commitments for the group project. Consider the following questions (don't answer these questions in the box below):

- What are reasonable time commitments for everyone to invest in this project?
- What other activities and commitments do group members have in their lives?
- How will we communicate with each other?
- When will we meet as a team? Where will we meet? How Often?
- Who will run the meetings? Will there be an assigned team leader or scribe? Does that position rotate or will same person take on that role for the duration of the project?

Required: How often you will meet with your faculty advisor advisor, where you will meet, and how the meetings will be conducted. Who arranges these meetings?
See examples below.

Meeting Participants	***Frequency Dates and Times / Locations***	***Meeting Goals Responsible Party***
Students Only	When questions arise, On Discord Voice Channel/ put question on trello board	Update trello as needed and maybe a discord message if something big happened! Actively monitor discord (Jefferson will record these for the weekly progress reports and meetings with advisor)
Students Only	Every Thursday at 3:30	Review commits and pushes to github and go over any questions. Prototyping pngs will go in github Trello tasks can be added by everyone - push status reports into GitHub
Students + Faculty advisor	*TBD - Advisor is currently unsure, will circle back*	Update faculty advisor and get answers to our questions (Jeff will scribe; Grace will create meeting agenda and lead meeting)
Project Sponsor	*TBD - No response so far*	Update project sponsor and make sure we are on the right track (Responsibilities can be rotated)

Step 4: Determine Individual Roles and Responsibilities

Task: As part of the Capstone Team experience, each member will take on a leadership role, ***in addition to*** contributing to the overall weekly action items for the project. Some common leadership roles for Capstone projects are listed below. Other roles may be assigned with approval of your faculty advisor as deemed fit for the project. For the entirety of the project, you should communicate progress to your advisor specifically with regard to your role.

- **Before meeting with your team**, take some time to ask yourself: what is my "natural" role in this group (strengths)? How can I use this experience to help me grow and develop more?
- **As a group,** discuss the various tasks needed for the project and role preferences. Then assign roles in the table on the next page. Try to create a team dynamic that is fair and equitable, while promoting the strengths of each member.

Communication Leaders

Suggested: Assign a team member to be the primary contact for the client/sponsor. This person will schedule meetings, send updates, and ensure deliverables are met.

Suggested: Assign a team member to be the primary contact for faculty advisor. This person will schedule meetings, send updates, and ensure deliverables are met.

Common Leadership Roles for Capstone

1. **Project Manager:** Manages all tasks; develops overall schedule for project; writes agendas and runs meetings; reviews and monitors individual action items; creates an environment where team members are respected, take risks and feel safe expressing their ideas.
   Required: On Edusourced, under the Team tab, make sure that this student is assigned the Project Manager role. This is required so that Capstone program staff can easily identify a single contact person, especially for items like Purchasing and Receiving project supplies.
2. **Logistics Manager:** coordinates all internal and external interactions; lead in establishing contact within and outside of organization, following up on communication of commitments, obtaining information for the team; documents meeting minutes; manages facility and resource usage.
3. **Financial Manager:** researches/benchmarks technical purchases and acquisitions; conducts pricing analysis and budget justifications on proposed purchases; carries out team purchase requests; monitors team budget.
4. **Systems Engineer:** analyzes Client initial design specification and leads establishment of product specifications; monitors, coordinates and manages integration of sub-systems in the prototype; develops and recommends system architecture and manages product interfaces.
5. **Test Engineer:** oversees experimental design, test plan, procedures and data analysis; acquires data acquisition equipment and any necessary software; establishes test protocols and schedules; oversees statistical analysis of results; leads presentation of experimental finding and resulting recommendations.

6. **Manufacturing Engineer:** coordinates all fabrication required to meet final prototype requirements; oversees that all engineering drawings meet the requirements of machine shop or vendor; reviews designs to ensure design for manufacturing; determines realistic timing for fabrication and quality; develops schedule for all manufacturing.

Team Member	***Role(s)***	***Responsibilities***
David Anthony	Systems Engineer	Creating high-level design and architecture that define the system's components, their relationships, and how they interact.
Jeffrey Weaver	Logistics	following up on communication of commitments, obtaining information for the team; documenting meeting minutes;
Paul Reid	Test Engineering	Review github commits weekly, verify that all of the code works in sync with each other.
Grace Gillam	Project Manager	Make sure everyone has tasks and also manage the project. Manage GitHub and make sure no one breaks main, also code a lot, book library rooms weekly for meetings.

Step 5: Agree to the above team contract

Team Member: *Signature: **Paul Reid***

Team Member: Grace Gillam *Signature:* Grace Gillam

Team Member: *Signature:* Jeffrey Weaver !!

Team Member:David Anthony *Signature:* David Anthony