Research Plan for IPM: "A New Framework for the Design, Calibration, and Operation of a Modular Mobile Mapping System for a Small Robotic System"

By: Dr. Ehsan Khoramshahi

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1. Research Overview

The aim of this research is to investigate an experimental low-cost vision-based navigation system as a Mobile-Mapping System (MMS) using current, easily accessible sensorial technologies mixed with AI techniques. The project will explore efficient calibration schemes and the integration of sensors like multi-cameras, LiDAR, GNSS, and IMU. It will also investigate advanced machine learning methods for different aspects of data processing, aiming to replace expensive hardware with more cost-effective solutions for small robotic systems while ensuring precision and usability for many civil applications.

2. Research Objectives

The project is divided into three main objectives:

1. **Objective 1 (O1):** Build an experimental low-cost vision-based navigation system/MMS.
2. **Objective 2 (O2):** Develop a precise calibration scheme for the proposed system.
3. **Objective 3 (O3):** Ensure the functionality of the MMS through robust data collection, processing, and analysis.

3. Research Questions

Key research questions include:

- **RQ1:** Technological steps for the development of a low-cost robotic vision-based navigation system.
- **RQ2:** Effective methods for the automatic calibration of a multi-sensor MMS.
- **RQ3:** Utilization of state-of-the-art calibration methods in a low-cost MMS.
- **RQ4:** Optimizing the tie-point matching process between images and LiDAR point clouds.
- **RQ5:** Improving LiDAR point cloud quality using AI methods.
- **RQ6:** Feasibility of generating reliable terrestrial point clouds from high-resolution multi-camera systems.
- **RQ7:** Enhancement of point cloud generation using AI-based methods.

4. Expected Outcomes

The research aims to produce:

- A modular low-cost vision-based navigation system design with a reliable calibration scheme.
- Novel AI-based methods for enhancing point cloud generation.
- Open-source software and datasets for community use, reducing dependence on expensive commercial solutions.

5. Work Plan and Schedule

The research is structured into five work packages (WPs) spanning five years. Each WP addresses specific aspects of the research objectives.

Year 1: Foundation and Initial Development

- **WP1:** MMS Hardware Design
    - **Tasks:** Literature review; design of MMS frame; selection of low-cost sensors and synchronization systems.
    - **Outputs:** State-of-the-art review paper, initial MMS structural plan, initial hardware assembly.
    - **Milestones:** Submission of the first research article; hiring a PhD student to assist with WP1 tasks.
- **WP2:** MMS Calibration Setup
    - **Tasks:** Setup of a multi-camera calibration site; design of coded targets; initial calibration of sensors. Designing IMU and GNSS calibration test field, indoor navigation with IMU, etc.
    - **Outputs:** Calibration site setup, preliminary sensor calibration.
    - **Milestones:** Publication of results on robotic navigation methodologies.

Year 2: Prototype Development and Initial Testing

- **WP3:** Multi-camera Point Cloud Generation
    - **Tasks:** Integration of multi-camera configurations; initial software development for image processing and point cloud generation; investigate configurations that eliminate or reduce the need for LiDAR. Alternatively, the LiDAR could be used in an cost efficient configuration.
    - **Outputs:** Initial point cloud generation methods, first dataset collection campaign.
    - **Milestones:** Publication on point cloud generation methods; course on 3D Vision.

Year 3: Refinement and Advanced Data Collection

- **WP3 (Continued):** Optimization and Debugging
    - **Tasks:** Debugging and optimization of the initial MMS design; incorporation of additional sensors and advanced data processing methods; update heuristic methods.

    - **Outputs:** Improved MMS design, second dataset collection campaign in Finland and abroad.
    - **Milestones:** High-quality journal publications on optimized designs and data processing techniques.
- **WP4:** Data Collection Campaigns
    - **Tasks:** Plan and execute extensive data collection campaigns under different conditions; process and anonymize datasets; build large-scale datasets for training machine learning models.
    - **Outputs:** High-quality training and test datasets.
    - **Milestones:** Submission of datasets for open access; publication of research on multi-sensor data collection methodologies.

Year 4: AI Integration and Full System Testing

- **WP3 & WP4 (Continued):** Machine Learning Integration
    - **Tasks:** Development and integration of AI methods for enhancing calibration, point cloud generation, and tie-point matching; testing of AI-driven methods for data processing.
    - **Outputs:** AI models for point cloud generation, enhanced calibration methods.
    - **Milestones:** Publication on AI-enhanced MMS calibration and data processing; open-source code release.

Year 5: Finalization and Knowledge Transfer

- **WP5:** Managing Research and Dissemination
    - **Tasks:** Supervise and synchronize all WPs; finalize MMS design and calibration software; conduct demonstrations and workshops with civil partners.
    - **Outputs:** Final MMS prototype, comprehensive documentation and software; potential applications in real-world scenarios.
    - **Milestones:** Final reports, open-source software release, final workshop/conference presentations.

6. Research Environment and Collaboration

- The research will be conducted in collaboration with the Finnish Geospatial Research Institute (FGI) and other national and international partners.
- Collaboration will be sought for specialized equipment and cross-validation of data and methods.
- The research environment will leverage the computing resources at the University of Tampere, and data will be stored on secure servers with appropriate data protection measures.

7. Risk Assessment and Mitigation Strategies

Key risks include sensor synchronization issues, data protection challenges, and performance of the image-point cloud registration methods. Mitigation strategies:

- **Sensor Synchronization:** Use GNSS time stamps (PPS) for precise synchronization or model time shifts dynamically.
- **Data Protection:** Anonymize data using AI-based methods and follow strict data handling protocols.
- **Image-Point Cloud Registration:** Develop robust AI-based or heuristic methods and consider specialized targets if necessary.

8. Personnel and Key Roles

- **Dr. Ehsan Khoramshahi (PI):** Overseeing all aspects of the research, especially MMS design and calibration methodologies.
- **PhD Student:** Assisting with WP1 design, data collection, and AI integration tasks.
- **Collaborators:** Providing domain-specific expertise, equipment, and software validation.

9. Conclusion

The proposed research plan offers a structured approach to developing an affordable, modular vision-based navigation system for a small robot with efficient calibration and data processing capabilities. The combination of open-source tools, advanced machine learning methods, and collaborative efforts aims to produce a significant impact on both the scientific community and practical civil applications.