

## Research Proposal

### Improving Incremental Structure-from-Motion Efficiency and Performance with Physical Sensor Data

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#### Introduction

This research proposal suggests a novel method for improving the performance of incremental structure from motion algorithms. Structure from motion (SfM) is a key part of extracting 3D information from images, which has applications in medicine, architecture, autonomous vehicles, structural analysis and disaster relief. For example, it has been used to delimit flood risk areas (2008, I. Ion et al), medical imaging (2005, B. Starly et al.), deformation detection and structural health monitoring and to assist first responders and investigators in natural disaster and humanitarian crises (2021, R. P. Murphy).

However, existing SfM algorithms suffer from poor performance, which makes them unfeasible for real time applications. This is especially the case when processing power is limited or when the results are required almost immediately. For example, drones and autonomous cars that are navigating in an unknown environment will need to make decisions in fractions of a second based on what they can see. This was one of the biggest challenges faced by engineers in the aftermath of the 2011 Fukushima nuclear disaster (2018, V. Beiser), where experts from the private sector developed robots to survey the power plant. Many got stuck, were hit by falling debris or simply failed to withstand the harsh environment.

The method outlined in this proposal is an effort to improve the performance of an incremental SfM algorithm using position and orientation sensor data, to make it more viable for real-time applications. Incremental SfM involves estimating the camera's position in space when it captured each image in the image set. It does this by extracting features from each image and comparing them. The poor performance results from the fact that many iterations are needed for the error to be acceptably small, and because the volume of feature data is very large.

However, the absolute position and orientation of a device can be determined within a couple of centimetres and degrees using Inertial Measurement Units (IMU) and Real-Time-Kinematics (RTK) capable GPS. With these sensors, it will be possible to greatly reduce the number of iterations required for SfM, as well as the volume of features and subsequent comparisons required. The question that this research poses is extent to which the inclusion of this data will improve the performance of incremental SfM.

#### Methodology

Our proposed approach is to develop the software portion of the project using a test dataset, before implementing the augmented algorithm on hardware. This means that valid results may still be obtained should there be any issues with hardware.

The test dataset models the type and quality of data that the proposed hardware is expected to produce. It consists of images of a virtual 3D scene, where the camera position can be controlled exactly. A small degree of error, corresponding to the expected error of the sensors, is added to the camera position and orientation.

The sensor data is incorporated into the existing COLMAP reconstruction pipeline (2016, J L. Schönberger):

- The naïve feature matcher is replaced with one that uses the estimated camera position and orientation.
- The outlier filter is modified to discard features that the sensor data determines cannot match.

The test data is then used to determine the correctness of the modified SfM algorithm, by comparing the camera positions and orientations from the test data to the ones predicted by the algorithm.

Finally, the effectiveness of the proposed approach is determined by measuring the performance (i.e. processing time) with and without the sensor data. It can then be implemented on the hardware platform:

- An RTK-capable GPS unit connected to a Raspberry Pi and attached a smartphone with an internal camera and an IMU. The smartphone captures images and takes orientation measurements, while the Raspberry Pi executes the SfM algorithm.
- An RTK-capable GPS base station. The base station is required to achieve 1cm accuracy for the position measurements. It communicates wirelessly with the GPS unit.

Once the hardware platform is complete, the algorithm will be evolved to run in as close as possible to real time. It can then be deployed on a drone and tested in a real-world use case scenario, such as autonomous landing on unknown terrain.

### Estimated Timeline

	Week	1	2	3	4	5	6
Generating test data		■					
Writing an SfM implementation that uses sensor data		■	■	■	■		
Putting together hardware platform			■	■	■	■	
Further improvement of algorithm for real-time applications						■	■

### International focus

This area of research is of interest to many fields and industries, such as in humanitarian missions and disaster response. Once completed, the code and schematics will be published opensource, and I will endeavour to work with organisations who make use of drones to provide tactical and first response as part of my LiA experience.

### Research Supervisor

Dr. Ciaran Mc Goldrick is an associate professor of computer science at Trinity. He was one of "Ireland's Champions of EU Research" for exhibiting outstanding leadership through MSCA ICONN in 2020. He is a senior member of the Association for Computing Machinery, and the Institute of Electrical and Electronics Engineers.

## **Collaboration**

This research would be a collaboration between myself, an electronic engineering student, and my supervisor, a professor from the department of computer science.

## **Outcomes**

The primary outcome of this research will be a more accurate, faster and efficient approach, with validation and verification of methods and results. Conclusions will be presented in the context of its use in real-time applications.

**Pre-clearance Requirements:** None

## **References**

1. 2005, B. Starly et al. Three-Dimensional Reconstruction for Medical-CAD Modelling, Computer-Aided Design & Applications, Vol. 2, Nos. 1-4, 2005, pp 431-438
2. 2008, I. Ion et al. Digital Photogrammetric Products from Aerial Images, used for Identifying and Delimiting Flood Risk Areas, IPRS, V. XXXVII P. B7
3. 2016, J. L. Schönberger, Structure-from-Motion Revisited, CVPR 2016, 10.1109/CVPR.2016.445
4. 2018, V. Beiser, The Robot Assault on Fukushima, WIRED magazine, available at <https://www.wired.com/story/fukushima-robot-cleanup/>
5. 2021, R. P. Murphy, How Robots Helped Out After the Surfside Condo Collapse, IEEE Spectrum, Robotics, available at <https://spectrum.ieee.org/building-collapse-surfside-robots>