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**Geological Survey of Ireland Research Programme
- Short Call 2015, Final Report -**

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Organisation name	University College Dublin
Organisation type:	☒ HEI ☐ Public Sector (other) ☐ Private Sector
Department/section	School of Civil Engineering

Project Title	Coastal modelling through low-cost video-based photogrammetry
Contract No.	2015-sc-042



Project Report (max 1500 words, excluding figures and headings):

(i) Objectives and scientific/engineering targets beyond the state of the art

The goal of the project was to see if improved monitoring of Irish waterways could be achieved through the engagement of citizen science, specifically through the aggregation of video footage obtained from river-based low cost cameras. Specifically, the question became whether boating clubs and the general public could be encouraged to contribute video footage taken during boating activities along Irish rivers to make on-line three-dimensional reconstructions that would enable a faster, more frequent and arguable more accurate tracking of the condition of the waterways through Ireland.

(ii) Implementation (including reference to timelines, milestones, management)

We generally followed the plan and did a lot of preliminary work on the ground by investigating the best way to amalgamate and process the video footage. This resulted in two journal paper manuscripts to date. One is under re-review and the other is drafted but awaiting submission. The papers experimentally investigate the potentials and limitations of key point detectors under a variety of video capture conditions. A third is in preparation and will fully document the field study.

To best evaluate the output we added additional volunteer staffers along the riverways to document whatever they could with video based on river bank and river walk access. There was also a thorough documentation of the study area with an unmanned aerial vehicle (UAV). The flight and the work from the bank fully followed the several miles of river work (Fig. 1). While my research group has extensive access to such UAV equipment and experience using it, the university would not permit us to fly under their insurance. As such the work (nearly \$500) had to be sub-contracted. This dataset was essential as a counterpoint to what was collected along the banks and from the river itself. It also serves as the ground truth for validation and benchmarking, as well as the basis for the integration of the three-dimensional (3D) model.



Figure 1. Satellite imagery of the study area in its entirety showing dense vegetation on both river banks.

Extensive challenges were encountered in the field. While these were considered during the original experimental design the roughness of the water was greater than expected. These challenges related to the following main topics: (1) keeping the cameras dry (while the cameras were waterproof, keeping water off the lens was not simple); (2) keeping the cameras mounted in a consistent fashion; (see Figure 2 for mounting arrangement; not all boats were the same and each required a specialized solution); and (3) having the cameras mounted in a way to minimize water and sky capture and maximize river bank capture. This last item proved to be both the most difficult and the most important, as will be described below.



Figure 2. Sample camera mounting arrangement on kayak.

Specifically, all image matching algorithms work by finding unique points in two subsequent images. Those key points are then used to overlap the two images to stitch a scene together. Such points exist neither in the water nor in the sky (fig. 3). Thus more than 80% of what was being captured in each frame was unusable. Despite the absence of value of such data, all of that data had to be processed. The result was an unbelievably time consuming process with a relatively low quality output. Zooming in the image during capture (to minimize water and sky) was not possible as it required boating too close to the riverbank to be safe and to not get stuck in the shallows. We also tried a range of different paddling techniques in an attempt to improve data capture but unfortunately did none lead to any meaningful improvement in the quality of data collected. Furthermore Irish vegetation and river layout nearly wholly precluded river bank access, thereby (see Figure 4) precluding terrestrial-based approaches. The conclusion of the grant's research was that a much better approach could theoretically be devised through the

exclusive use of UAVs, but even UAVs face challenges because of the heavy vegetation obscuring the actual bank/water interface. After exhausting options for data collected from both the river and the shore, the imagery collected from the air was found to lack sufficient depth cues to enable a full reconstruction of the elevation profile of the river bank. The conclusion from all of this is that a relatively low-cost (9,000 euro), light-weight laser scanner (e.g. the velodyne puck) could be highly effective as the laser scanning can penetrate both the vegetation and the water.



Figure 3. Geometric matches (with close-up on right) of the aligned data set (left). The algorithms attempt to map each unique point (keypoint) across images and assign the keypoint a node in order to reconstruct the 3D image from one video frame to the next.

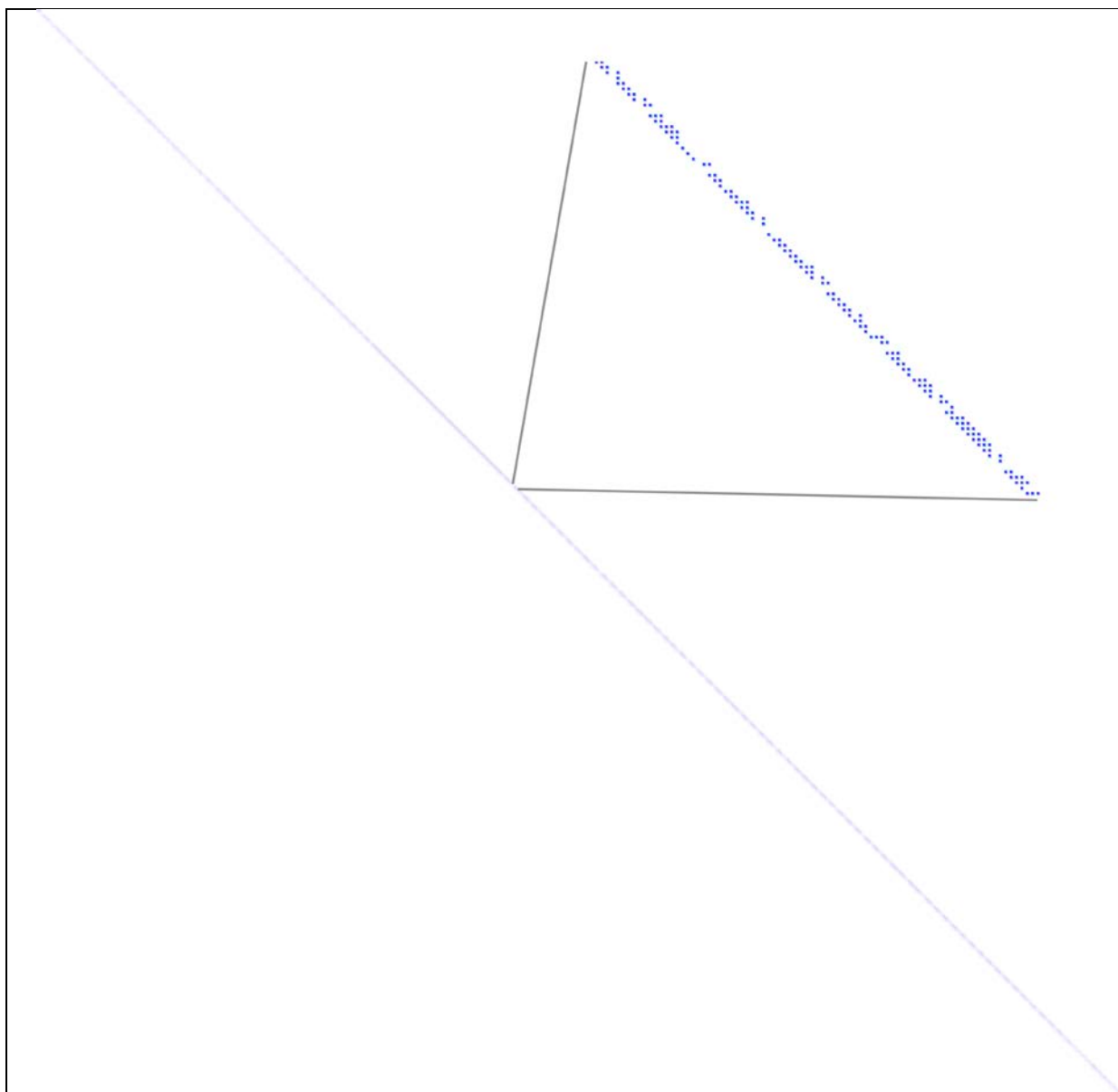


Figure 4. Geometric matrix (with close-up). Each blue dot represents a 2D projection of a keypoint.

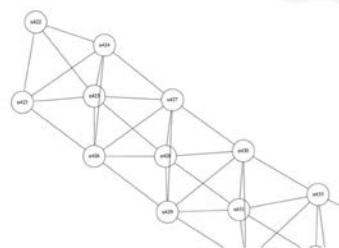


Figure 5. Putative matches (with close-up). Each node represents a keypoint and its mapping across frames of the video imagery.

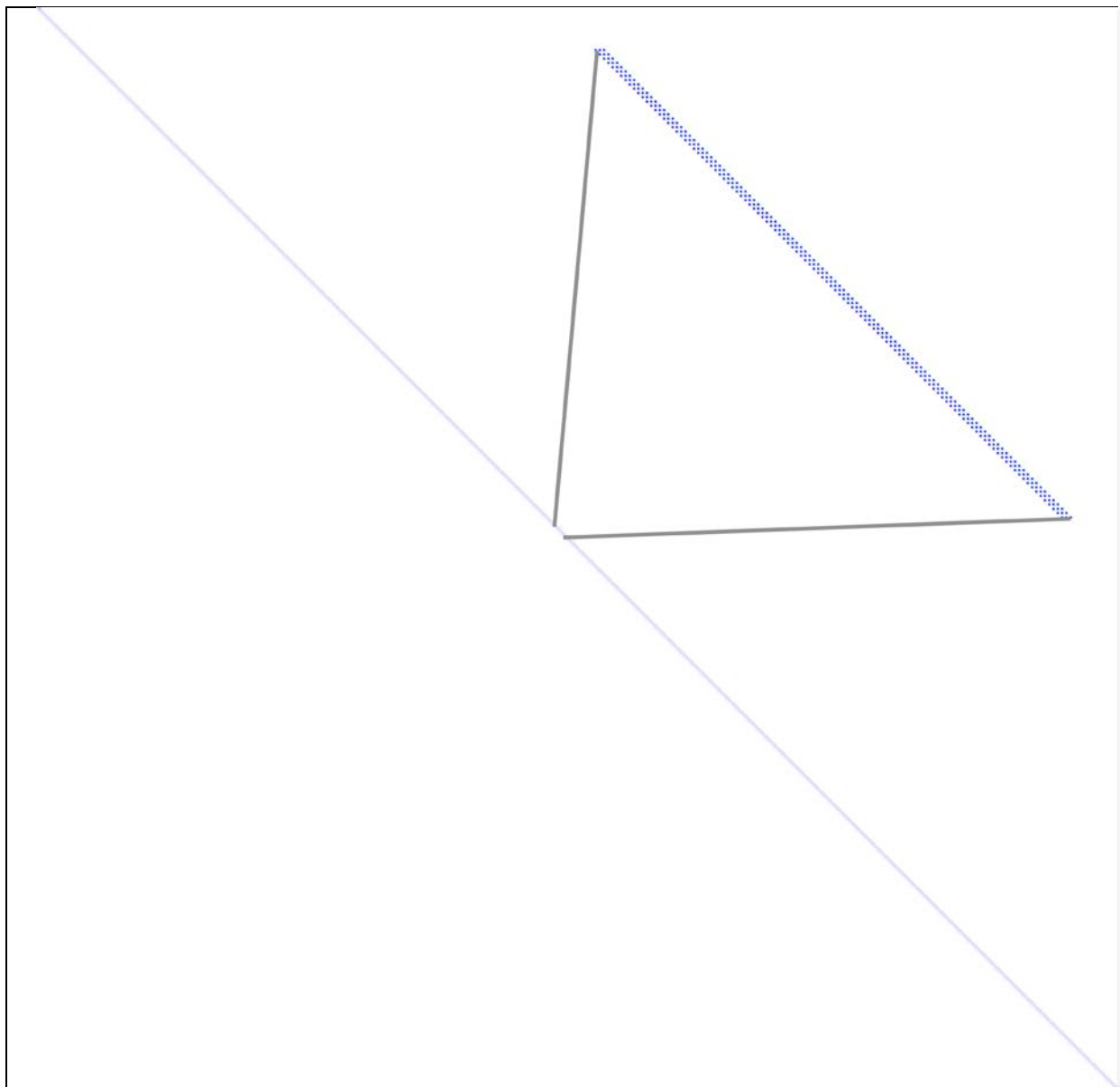


Figure 6. Putative matches (with close-up). Each blue dot represents a 2D projection of a keypoint.

With respect to the originally anticipated scope of work, which was undertaken, due to the nature of the data having large, unusable regions of sky and water in each image, the processing time was found to overwhelm any conventional research and/or commercial solution currently available. As such, the processing of seven concurrent datasets with two hours of filming required multiple months of processing time on a fairly robust computer system. Thus, even when consistent results were obtained (as illustrated in Figures 4-7), they required computing resources that were both far beyond that which could be provided in an online system and disproportionate with any possible benefit they might generate as they idea was to have a rapid data capture and analysis system. As a result, unfortunately the originally proposed online graphical user interface was found to be untenable at this time and with existing computational resources. Numerous efforts were undertaken to find better processing solutions (see papers 1 and 2 in the Annex), but none were found. As the time and funding for this grant were both modest in nature a workaround was not possible.

(iii) Outputs (please use bullet points)

- WP1: Literature review for georeferencing and computer vision
 - See Attachments 1.1 and 1.2
- WP1: Image analysis for detecting blurred and improper lighting conditions
 - See Attachments 1.1 and 1.2
- WP1: Image location calculation using GPS data
 - Completed as part of project workflow
- WP1: Image placement within aerial reconstruction dataset and submission for 3D model reconstruction
 - See Figure 3
- WP2: Literature review and learn visual SFM
 - See Attachments 1.1 and 1.2
- WP2: Gathering sample data and complete 3D point cloud reconstruction of a section of coast
 - Real world data set that will be released in early 2017 as part of a larger open data release from Prof. Laefer's Urban Modelling Group
 - See Attachments 1.1 and 1.2 for use in journal articles
 - See Figures 3-6 for examples of reconstructions
- WP2: Incorporating GPS data into model reconstruction
 - See Figure 3
- WP2: Combining multiple point cloud sources
 - To appear in forthcoming publication
- WP2: Model validation and new image integration
 - To appear in forthcoming publication
 - See Figures 3-6 for examples of model reconstructions
- WP3: Gather aerial data
 - Real world data set that will be released in early 2017 as part of a larger open data release from Prof. Laefer's Urban Modelling Group
- WP3: Generate 3D model for system framework
 - Proposed system proved to be non-viable
 - See section (ii) for further details
- Output: Internet-based Graphical User Interface
 - Proposed system proved to be non-viable
 - See section (ii) for further details
- Output: Journal Article
 - 3 journal papers (1 in final review; 1 ready for submission, and 1 in draft form)
- Output: User Guidelines
 - Proposed system proved to be non-viable
 - See section (ii) for further details
- Output: Final Report
 - Submitted
- Output: Half-day workshop
 - Proposed system proved to be non-viable
 - See section (ii) for further details

Impact/value of the project (Max 500 words):

The project shows a definitive and quantifiable set of outputs to guide waterway monitoring in Ireland. It has demonstrated that while a citizen science approach to low cost data collection through video is unlikely to be sufficiently robust and scalable that use of a low-cost UAV holds strong potential though it also has significant limitations. As Irish Aviation Authority regulations evolve there should be sufficient latitude in which to develop a regular monitoring programme (e.g. on a monthly basis) as well as for ad hoc (e.g. storm) events.

Appendix 1 – Publications & Presentations:

[Journal paper] A comparative study of current state of the art feature detectors with simulated image affine invariance. *Transactions on Geoscience and Remote Sensing, IEEE*. TIP-15937-2016. (Attachment 1.1)

[Journal paper] Maximising Feature Detection in Aerial UAV Datasets. *Journal of Imaging*, To be submitted (Attachment 1.2)

One additional journal paper under preparation.

Imagery-based Limitations for Regular Waterway Documentation. *Journal of Surveying Engineering*

Appendix 2 – Any additional information not included above:

The PI has moved to NYU, and we are actively working with the library system to make this data publicly available through NYU's Faculty Digital Archive (<https://archive.nyu.edu/>) and Spatial Data Repository (<https://geo.nyu.edu/>) within the next 8 weeks.

Storing the data in these repositories will not only ensure both the preservation and accessibility of into the future but will also allow the data to be discovered through a common portal shared by Stanford, Harvard, NYU, CUNY, and other major US universities. In this interface users can conduct searches by highlighting an area of interest on a map to display all datasets relevant to that geographical region. Using this mechanism the data collected under the support of the GSI will be available alongside co-located datasets from the participating institutions including Bacon's 1900 plan of Dublin and a 1797 map of Dublin from NYU, as well as historical maps of Dublin from the 1700s provided by Harvard University.

Once the data are installed in this repository, they will become a permanent record of the GSI's funding and contribution to the important area of mapping Ireland's waterways.