PRIFYSGOL ABERYSTWYTH UNIVERSITY

Estimation of Terrain Shape Using a Monocular Vision-based System

OUTLINE PROJECT SPECIFICATION

CS39440 - MAJOR PROJECT

G601 (MENG SOFTWARE ENGINEERING)

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1 Project description

1.1 Background

Accurate navigation allows for robot requiring autonomous motion capabilities to make safe, yet objective decisions on how best to traverse from a starting location to a target location over typically uneven and/or poorly modelled terrain.

The identification and subsequent avoidance of obstacles is naturally a crucial ability for an autonomous mobile robot to possess in order to help to maximise its own chances of survival. As a result, it is a keen and well-explored area of robotics research, with a variety of approaches now available adopting many types of sensor including sonar and laser scanning. An alternative approach that has enjoyed increasingly greater research focus over the past decade is that of vision-based obstacle avoidance, involving the analysis of images captured from one or more digital cameras in order to identify possible dangers currently situated within the robot's field of view.

Cameras are becoming an increasingly favourable sensor for use on robotic systems, due primarily to the impressive variety and quantity of potential data that can be captured *simultaneously* from a single device. They are also one of few sensors that have experienced a consistent reduction in price over the past decade, making them viable for many types of project application and budget.

Many solutions to vision-based obstacle avoidance have been suggested and published, with the majority proposing novel approaches of combining "standard" computer-vision algorithms (e.g. optical flow, feature tracking or patch tracking) with a variety of hardware configurations (e.g. monocular systems, stereo cameras, vision and 3D hybrid). Typically these improve on previously published performance results, or to focus on specific types of obstacle avoidance (e.g. precipice or animal detection).

1.2 Project Overview

Combining recent advances in camera technology with appropriate computer vision algorithms and technique, the proposed project aims to design and implement a vision-based software application capable of estimating the general "shape" of the terrain currently in front of a moving robot as it follows a route through its environment. Through this system, it should be possible to identify the presence of both positive, and negative obstacles (e.g. rocks and pits respectively), providing a reasonable indication of their general size and location.

In addition, it is predicted that such a system will also be able to provide an estimation of the speed and change in rotation/orientation of the robot as it traverses along a path. These will be calculated as by-products of the terrain inference mechanism, and could form part of a larger visual odometry system.

While the primary aims of the proposed project are research-focussed, the ultimate goal of the project will be to implement the system onto a working mobile robot, such as the 'IDRIS' all-terrain wheeled robot currently in use by the Aberystwyth University Computer Science department.

Although at the time of writing there is still much discussion to be had as to the exact implementation details, it is generally expected that the system will adopt image patch-based tracking and correspondence to allow for the establishment of the general motion trend (i.e. optical flow) of the ground (or the egomotion of the robot).

2 Proposed Tasks

1. **Research & Analysis of Existing Computer Vision Approaches** - A thorough analysis of previously published work will be conducted to identify the key strengths and weaknesses of these various approaches. This will allow for an informed decision to be made as to the most appropriate computer-vision methods for use in the project. Particular attention will be focussed on the comparison between appearance-based, and feature-based tracking as a mechanism for determining the distance travelled between subsequent images.

2. **Project & System Planning** - Information gathered from analysis of existing approaches will be fed into discussions with the project supervisor to plan and confirm the exact details of what the proposed system will do, and the approach to be taken in its implementation.
3. **Investigation of Software Technologies** - An investigation into suitable programming languages and (if appropriate) third-party libraries will be conducted prior to beginning design work. Factors including recommendations from published work and robot hardware requirements will need to be taken into consideration.
4. **Investigation of Hardware Technologies** - Decisions around the selection of hardware will need to be made, focussing mainly on the type and number of cameras. These will be influenced primarily by the choice of computer-vision methods and the existing hardware available.
5. **System Design** - Architectural and component-level designs will be produced, detailing the structure of the software and hardware aspects individually, along with the interactions between the two.
6. **Testing Design** - Given the research-based nature of the project, appropriate testing strategies will require careful planning and design. This is to ensure robust evaluation of the "successes" of the system processes and methods in addressing the project aims (e.g qualitative vs quantitative evaluation).
7. **System Implementation** - All code will be version controlled and checked-in against relevant work items (project is expected to follow a SCRUM agile-methodology approach to development).
8. **System Testing & Evaluation** - A significant level of attention is expected to focus on testing of the computer-vision approach/algorithms using "ground truth" testing data as a primary measure. However, extensive software testing will also be conducted incorporating unit testing, testing tables, and possibly continuous integration testing (if appropriate).
9. **Production of Final Report** - A 20,000-word report will be written describing and justifying all aspects of the major project including the planning, design, implementation, testing and evaluation.
10. **Logging of Work** - Throughout the entirety of the project, any key thoughts or notes will be published to a live web-blog available at: `http://mmpblog.connorlukegoddard.com`. This blog will act as a memory aid when writing the final report.

3 Project Deliverables

1. **Existing Approach Analysis Report** - Results of analysis conducted to identify suitable computer vision algorithms/approaches adopted in previously published work, including a statement of the investigation outcomes and justification.
2. **Design Documentation** - While focussing primarily on algorithm design documentation (e.g. experiment/test design), documentation will also contain software-level designs (including UML sequence, class and use case diagrams) with accompanying descriptions and justifications for choices made.
3. **Testing Plan** - Details of testing strategies (with criteria) for the final system, including a specific breakdown and analysis of tests for both the high-level computer vision algorithm(s) and implemented software.
4. **Proposed Algorithm(s)** - Description, discussion and justification of proposed algorithm(s) developed for the project, including details of the approach to testing and expected evaluation criteria.
5. **Final Implemented System** - The complete system in a working, demonstrable state, that achieves the complete set of finalised tasks. The full source code, in addition to a system demonstration will also be provided.
6. **Progress Report** - Details of the current state of the project to date, including any changes made to the expected aims, tasks or deliverables (and the reasons for these) and any significant issues encountered with (if possible) descriptions of the solution.
7. **Final Report** - Final project report providing a detailed description, discussion and justification of aspects including the design, implementation, deployment and documentation of the final system. Particular focus given to the evaluation of the computer-vision algorithm(s) developed and any future expansions that could be pursued.

Annotated Bibliography

[1] J. Campbell, R. Sukthankar, and I. Nourbakhsh, "Techniques for evaluating optical flow for visual odometry in extreme terrain," in *Intelligent Robots and Systems, 2004.(IROS 2004). Proceedings. 2004 IEEE/RSJ International Conference on*, vol. 4. IEEE, 2004, pp. 3704–3711.

Provides clear information on practical approaches for evaluating the success of vision-based systems. While the paper focusses on the evaluation of optical-flow, many of the points discussed could be applied in the general case (e.g. open loop vs. closed loop testing).

[2] J. Campbell, R. Sukthankar, I. Nourbakhsh, and A. Pahwa, "A robust visual odometry and precipice detection system using consumer-grade monocular vision," in *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*. IEEE, 2005, pp. 3421–3427.

Highly informative paper describing an approach for inferring the presence of positive and negative obstacles in a scene, utilising the effects that motion parallex can cause to optical flow vectors of tracked features.

[3] R. Cipolla, Y. Okamoto, and Y. Kuno, "Robust structure from motion using motion parallax," in *Computer Vision, 1993. Proceedings., Fourth International Conference on*, May 1993, pp. 374–382. [Online]. Available: http://dx.doi.org/10.1109/ICCV.1993.378190

Provides a clear insight into the general use of parallax observed within an image scene in the inference of the ego motion of a robot through an environment.

[4] S. Fazli, H. M. Dehnavi, and P. Moallem, "A robust negative obstacle detection method using seed-growing and dynamic programming for visually-impaired/blind persons," *Optical Review*, vol. 18, no. 6, pp. 415–422, 2011.

Describes a novel approach to improving the accuracy and speed of traditional vision-based negative obstacle avoidance algorithms using of problem-solving models (dynamic programming) with a seed-growing algorithm.

[5] M. S. Guzel and R. Bicker, *Vision based obstacle avoidance techniques*, A. Topalov, Ed. INTECH Open Access Publisher, 2011, 978-953-307-909-7.

Clear analysis and comparison of various approaches to obstacle avoidance using vision-based techniques. Includes an insightful discussion on the key strengths and weaknesses of feature-based and appearance-based algorithms for obstacle tracking.

[6] R. D. Morton and E. Olson, "Positive and negative obstacle detection using the HLD classifier," in *Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on*, Sept. 2011, pp. 1579–1584. [Online]. Available: http://dx.doi.org/10.1109/IROS.2011.6095142

Proposes an approach to inferring precise details of an approaching positive or negative obstacle through the interrogation of 3D point-cloud data (gathered using a LiDAR scanner) using a Height, Length and Depth (HLD) classifier.

[7] D. Nister, O. Naroditsky, and J. Bergen, "Visual odometry," in *Computer Vision and Pattern Recognition, 2004. CVPR 2004. Proceedings of the 2004 IEEE Computer Society Conference on*, vol. 1, June 2004. [Online]. Available: http://dx.doi.org/10.1109/CVPR.2004.1315094

Describes an alternative approach to vision-based obstacle avoidance utilising two cameras over a monocular vision system to provide depth information of the environment (i.e. stereo vision) that is later used to determine the position of obstacles.

[8] I. Ulrich and I. Nourbakhsh, "Appearance-based obstacle detection with monocular color vision," in *AAAI/IAAI*, 2000, pp. 866–871.

Describes an appearance-based obstacle detection approach that focusses on the use of pixel colour within a sub-region of an image to distinguish between the ground, and obstacles.