Using Satellite Imagery to Create Topological Maps for Path Plan Through Non-Urban Environments

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I. Introduction

Satellites arguably represent the pinnacle of remote sensory data; almost all modern technology makes use of satellite information somewhere along the line. One of the main uses of Satellites is in the field of image capturing; this data is used in everything from weather pattern recognition and prediction, to the defence industry. The aim of this research is to investigate to what extent Environment Parsing and Image Processing can be combined with Heuristic Path Planning Algorithms to help find optimal routes through non-urban environments.

II. Background

A. Image Processing

Image Processing is the science of using a machine to interpret visual data [1], [2]. The result of this interpretation can be anything from classification [2], [3], [4], to control theory [5], [6]. The concept of having a computer interpret visual data in much the same way as humans do is very powerful, due to the fact that vision is our primary sense. However the means by which humans and computers work with image data is very different; Image Processing makes use of multiple different colour spectrums, such as RGB, Greyscale, HSV etc. The field of Image Processing can also be considered a subset of research into Signal Processing, due to the ways in which Image data is represented and manipulated. This means that a lot of Image Processing techniques (particularly de-noising and segmentation) make use of Filters [2], [7], [8].

The possible applications of Image Processing are very broad, human dependence on visual data means that working with image data can be a very intuitive processes for both the user and the system designer. For example, Image Processing in medical diagnosis is an up and coming field of research [9], [10]. There is also extensive research being done into using Satellite Imagery and Image Processing to help with Environment Parsing and Analysis [11], [12], [13], [14].

B. Path Planning

Path planning is a common behaviour in the field of mobile robotics, though in recent years some principles of this research has been translated to working in systems such as Satellite Navigation and the video games industry [15], [16]. One key concept in Path Planning is that the search space is divided into areas that are considered “traversable” (i.e pathways, unoccupied spaces etc.), and those that are not (i.e. walls and other obstacles). The purpose of Path Planning algorithms is to provide a route from one location to another, with some optimising this route with respect to another measure of quality (i.e. minimising the length of the route, visiting every node on the route only once, etc).

Two popular Heuristic Path Planning algorithms are A* and D* search [17], [18]. Both of these algorithms represent the search space, or C-Space (the environment through which a path must be found) as a tree structure, where the cost of traversing from one node to another is denoted along the adjoining vertex. The A* algorithm works by attempting to balance between the cost of each traversal, and the distance to the goal node [17], it is this aspect of the algorithm that defines it as a Heuristic approach. The D* algorithm is an expansion of A*, such that the same Dijkstra algorithm is used initially to find the shortest path to the goal, however D* is more dynamic in that the cost of traversing certain vertices is dynamic. As a result of this the path may be altered to provide a new, more optimal route [17], [18].

C. Topological Navigation/Contour Mapping

In the field of Robotics, a Topological Map is often a 2-Dimensional, Top-Down view of an environment where a series of vertices are created between pre-defined landmarks in the environment (as shown in Figure 1). Topological navigation can also be done in non-structured environments, where the robot does not have a pre-defined map with landmarks in it, but rather constructs both of these through the use of a mapping technology such as a Scattergram mapping algorithm [19], [20]. It is along these vertices that the robot may travel. These vertices are often straight lines of least distance, in order to simplify the map further [21].

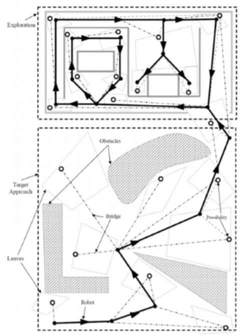

Fig. 1. A Topological Map, as used in Mobile Robotics, [22]

Topological Path Planning algorithms often follow the pattern of having the Robot (or Agent) follow a series of sequential instructions, based on traversing the vertices between nodes/landmarks that form the Topological Map [23], [24], [25], [21].

Contour mapping, on the other hand, is a way of representing different environments, and specifically changes within that environment [26], [27], [28]. Contour maps are most often used to give an impression of changes in altitude in rough terrain (as shown in Figure 2). Contour mapping is a very intuitive representation for viewing changes in an environment, but perhaps not the specific value at a given point. However a traditional contour map could easily be used to represent the symbolic "cost" of traversing from one location to another, as is often used by Path Planning Algorithms as previously discussed. Therefore a combination of a contour map designed to represent "cost of traversal" and a Topological Path Planning system could be used to represent a path planning algorithm in a way that is very powerful and intuitive for human interpretation.

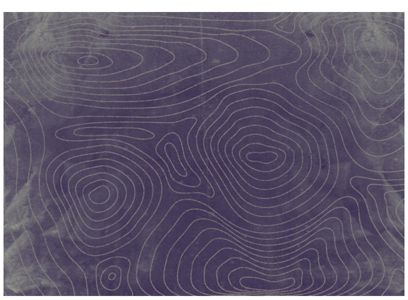

Fig. 2. A Contour Map, used to show altitude changes in rough terrain, [29]

III. Proposed Work

A. *Aims and Objectives*

The purpose of this research is to investigate how the combinations of Image Processing, Topological Mapping and Path Planning can be used to solve the problem of navigation through a non-urban environment. In order to help ensure that this research project is successful, this objective will be split down into a series of sub-tasks, namely:

- Investigate how Image Processing can be used to assess Satellite Imagery of non-urban environments, with a view to defining an environments degree of "traversability"
- Use this information to help form a Contour Map of the environment being assessed
- Use this Contour Map, and a relevant Heuristic Path Planning Algorithm (such as A* or D*) to help an agent navigate through this environment, following the most efficient path (with regard to either shortest route, or path of least resistance).

B. *Rationale*

In a world where nowhere is truly inaccessible any more, the ability to use remote sensing data (such as Satellite Imagery) to give us accurate and intuitive data about an environment is a very powerful tool. This is often a vital component of both government and privately funded expeditions to incredibly remote regions, such as the Arctic Circle [30]. Technologies such as GPS (Global Positioning System) are being used more and more in a vast array of settings; from the civilian SATNAV (Satellite Navigation) market, to Ship Guidance, and even the Mars Rover uses the same technology to help it navigate [31]. The addition of the proposed technology to this field of research would greatly boost humanity's ability to explore new environments safely, and even to traverse areas of Earth that are yet to be cultivated.

C. *Methodology*

Within the Literature review stage of this project, special care will be given to any research that is utilising Topological Navigation within the field of Mobile Robotics. This is because the concepts involved within this field can be seen as a fitting microcosm of what the end goal of this project hopes to achieve.

All decisions as to which Image Processing and Path Planning algorithms that are to be used will be made as a result of both the Literature Review, and any extra experiments that may be conducted into the surrounding areas related to these fields of study.

The proposed project contains areas of research that can be identified as both Quantitative, and Qualitative; the concept of using Image Processing to identify landmarks and features of a non-urban environment, and then assess these in terms of "traversibility" is largely a Qualitative task, and hence should be verified using the appropriate means. On the other hand Path Planning algorithms, and especially those that can be classified as Heuristic, form a largely Quantitative domain. Again this means that the methods by which any experimentation and further study is conducted will have to reflect this. For example, Quantitative experiments can be more empirically verified, through the use of Statistics and Data Analysis, whereas Qualitative experiments often tend to have more subjective results which are more difficult to verify under more rigid scientific methods.

With regard to project management, this proposal is designed around the Agile project management methodology, specifically a Scrum-style practice would be maintained, as well as possible considering that only one participant will be conducting the work. More expansive details of how Agile project management is conducted can be found in Appendix C. Also refer to Appendix B for a Burn-down chart detailing the expected time allocations of the proposed project.

D. Programme of Work - Work Packages

1) Literature Review - with special focus on any projects that have been conducted using the combination of Image Processing and environment analysis, Topological navigation and Contour Mapping
2) Initial Design of framework - any third party libraries to be used for Image Processing (i.e. Matlab etc.) The overall process flow for the proposed system.
3) Design of the Image Processing system - which specific method(s) are to be used, how the data will be represented / manipulated.
4) Design of the Contour Mapping system - how the data will be analysed, represented and shown, what kind of storage is to be used etc.
5) Design of Topological Navigation system - which algorithm is to be used to find the best route, how landmarks are selected, how the route is represented etc.
6) Implementation stage (this will be split into sub-goals, but will be represented by one deliverable at this, more abstract, level).
7) Design of experiments and tests for each system - Testing will be done individually and as a collective, to ensure no regression occurs in the system. Experiments will be designed at this stage also.
8) Finally the write up will be completed, including details of experiments and tests, so that they may be repeated and verified by other members of the scientific community.

IV. Professional, Ethical and Legal Concerns

All Satellite Imagery used will be taken from reputable sources stating that this data is freely available without licensing agreements or copyright infringements. Additionally any third party software used in the design, development or testing of the proposed system will be used with valid licensing. No Images will be used in which any person, property or company will be identifiable, the images that are to be used are of remote areas, and as such are unlikely to contain any sensitive data or result in any breach of privacy.

V. Relevance to Benefactors

This research proposal represents development not only in the fields of Satellite Image Processing and Topological / Contour Mapping, but also in the combination of these fields. As mentioned previously, the field of Topological Navigation and Path Planning in Robotics is a very apt microcosm of one aspect of this research, therefore the fact that this field of study is very large and well established implies that there is significant benefit to expanding it into the field of global navigation and even possibly interstellar applications (as mentioned previously, the Mars Rover uses a type of GPS to help it navigate Mars).

Assuming a successful research project, the product that would be created would be of great use to a huge variety of industries, companies and even certain subsets of the population at large; for example the search for sources of Oil and other Fossil Fuels are causing companies to begin to search in more and more remote and inhospitable places [32], [33]. Extreme Sports are another viable application for the proposed system; with Extreme Sports going from a mere concept to a reported over 22 million participants in 15 years [34], the industry must continually supply fans with more and more outrageous exhibitions. Already this is starting to lead to more remote and uncharted territories being used to stage these events.

VI. Research Management Plan

This research project would make use of the Agile Project Management methodology, this has been decided for a few key reasons; firstly the candidate has experience working in an Agile environment, and has found this to be a very good way of conducting large pieces of work. Secondly the principles behind Agile Project Management are designed to help keep productivity high, and help improve good practices. Appendix C describes in detail some of the guiding principles of the Agile Project Management method. Naturally a fully Agile method will not be possible to implement during this research project, due to that fact that the team will consists of only one person (the research candidate). However the guiding principles of Agile can be taken on board in as many ways as possible.

VII. Justification of Resources

The primary resource that will be required is access to Satellite Imagery of rural areas. As mentioned previously, this will be sourced in an Ethical and Legal manner. However this still must be mentioned as without this data, the results of any research or systems designed cannot be tested. This data will be used both as Ground Truth data, and Testing Data. If any techniques are used that require Training Data (such as an Artificial Neural Network, or ANFIS - Adaptive Neuro-Fuzzy Inference System), a sample of images will be taken from the same source to use as Training Data.

Additionally, third party software will likely be used for the Image Processing, however this decision will be based purely on the results of the Literature Review, and which techniques it deems will provide the best results, and obviously what software packages can provide an implementation for these methods. For example Matlab has a very expansive Image Processing Toolbox [35], which provides implementations for a large amount of Pre-processing tools, Image Filtering, etc. An alternative to this however is the programming language Python, which includes packages for both OpenCV and other Image Processing libraries [36], [37].

VIII. Project Management

Appendices A, B and C provide details of how this research project will be managed.

References

[1] "What Is Image Processing? Image Processing Basics - http://www.coe.utah.edu/˜cs4640/slides/Lecture0.pdf."

[2] M. T. bin MohamadAzmi and N. M. Isa, "Orchid disease detection using image processing and fuzzy logic," in *2013 International Conference on Electrical, Electronics and System Engineering (ICEESE)*, pp. 37–42, IEEE, dec 2013.

[3] C. W. Chang, C. H. Shi, S. C. Liew, and L. K. Kwoh, "Land cover classification of very high spatial resolution satelite imagery," in *2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS*, pp. 2685–2687, IEEE, jul 2013.

[4] Zheru Chi and Jun Kong, "Image content classification using a block Kolmogorov complexity measure," in *ICSP '98. 1998 Fourth International Conference on Signal Processing (Cat. No.98TH8344)*, vol. 2, pp. 1185–1188, IEEE, 1998.

[5] J. A. Caley, N. R. J. Lawrance, and G. A. Hollinger, "Deep Learning of Structured Environments for Robot Search," pp. 3987–3992, 2016.

[6] L. K. Kong, J. Sheng, and A. Teredesai, "Basic Micro-Aerial Vehicles (MAVs) obstacles avoidance using monocular computer vision," *2014 13th International Conference on Control Automation Robotics and Vision, ICARCV 2014*, vol. 2014, no. December, pp. 1051–1056, 1997.

[7] G. Papari, N. Idowu, and T. Varslot, "Fast bilateral filtering for denoising large 3D images," *IEEE Transactions on Image Processing*, vol. 7149, no. August 2015, pp. 1–1, 2016.

[8] "Linear Filters and Image Processing - https://web.eecs.umich.edu/˜jjcorso/t/598F14/files/lecture_0924_filtering.pdf."

[9] P. Suapang, K. Dejhan, and S. Yimmun, "Medical image processing and analysis for nuclear medicine diagnosis," *Control Automation and Systems (ICCAS), 2010 International Conference on*, pp. 2448–2451, 2010.

[10] A. Chohra, N. Kanaoui, V. Amarger, and K. Madani, "Fuzzy Hybridization of "Artificial Neural Networks" (ANN) Based Signal and Image Processing Techniques: Application to Intelligent "Computer Aided Medical Diagnosis" (CAMD)," in *2005 IEEE Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications*, pp. 78–83, IEEE, sep 2005.

[11] L. Fang, T. Jiang, C. Shan, and H. Li, "A Per-Pixel Stratified Classification Methodology for Land Cover Mapping Based on Medium-Resolution Satellite Imagery," in *2009 2nd International Congress on Image and Signal Processing*, pp. 1–5, IEEE, oct 2009.

[12] S. Khandare and U. Shrawankar, "Classification of high resolution pixels into non-heterogeneous groups using rule based fuzzy approach," in *2014 IEEE International Conference on Computational Intelligence and Computing Research*, pp. 1–6, IEEE, dec 2014.

[13] T. Blaschke, S. Lang, E. Lorup, J. Strobl, and P. Zeil, "Object-Oriented Image Processing in an Integrated GIS / Remote Sensing Environment and Perspectives for Environmental Applications," *Umweltinformation für Planung, Politik und Öffentlichkeit / Environmental Information for Planning, Politics and the Public*, no. 1995, pp. 555–570, 2000.

[14] M. Bhowmik, A. Sarkar, and R. Das, "Shannon entropy based fuzzy distance norm for pixel classification in remote sensing imagery," in *Proceedings of the 2015 Third International Conference on Computer, Communication, Control and Information Technology (C3IT)*, pp. 1–6, IEEE, feb 2015.

[15] D. Ferguson, M. Likhachev, and A. Stentz, "A guide to heuristic-based path planning," *Proceedings of the International Workshop on Planning under Uncertainty for Autonomous Systems, International Conference on Automated Planning and Scheduling (ICAPS)*, pp. 1 – 10, 2005.

[16] N. Museum and H. Example, "Navigation and Metric Path Planning," *October*, 2008.

[17] H. Choset, "Robotic Motion Planning using A* and D* Search,"

[18] D. Ferguson and A. Stentz, "The Field D* Algorithm for Improved Path Planning and Replanning in Uniform and Non-Uniform Cost Environments,"

[19] "An Introduction to Mapping and Localization - Tutorials."

[20] J. Borenstein and Y. Koren, "HISTOGRAMIC IN-MOTION MAPPING FOR MOBILE ROBOT OBSTACLE AVOIDANCE," *IEEE Journal of Robotics and Automation*, vol. 7, no. 4, pp. 535–539, 1991.

[21] B. Passow and P. Hardaker, "Lec12-Path Planning."

[22] A. Thomas Abraham, S. S. Ge, and P. Y. Tao, "A topological approach of path planning for autonomous robot navigation in dynamic environments," in *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 4907–4912, IEEE, oct 2009.

[23] A. Pipe, B. Carse, and A. Winfield, "A topological map based navigation system for mobile robotics," in *1997 IEEE International Conference on Systems, Man, and Cybernetics. Computational Cybernetics and Simulation*, vol. 5, pp. 4394–4399, IEEE.

[24] Lixiao Guo, Q. Yang, and W. Yan, "Intelligent path planning for automated guided vehicles system based on topological map," in *2012 IEEE Conference on Control, Systems & Industrial Informatics*, pp. 69–74, IEEE, sep 2012.

[25] D. Marinakis and G. Dudek, "Pure Topological Mapping in Mobile Robotics," *IEEE Transactions on Robotics*, vol. 26, pp. 1051–1064, dec 2010.

[26] P. Denbigh, "Stereoscopic visualization and contour mapping of the sea bed using a bathymetric sidescan sonar (BASS)," *Radio and Electronic Engineer*, vol. 53, no. 7-8, p. 301, 1983.

[27] W. P. Jameson and R. M. Eisenberg, "A Land-Mass Radar Simulator Incorporating Ground and Contour Mapping and Terrain Avoidance Modes," *IRE Transactions on Military Electronics*, vol. MIL-3, pp. 105–114, jul 1959.

[28] J. Han and Y. Chen, "Cooperative source seeking and contour mapping of a diffusive signal field by formations of multiple UAVs," in *2013 International Conference on Unmanned Aircraft Systems (ICUAS)*, pp. 35–40, IEEE, may 2013.

[29] "How To Create a Contour Map Effect in Illustrator - http://blog.spoongraphics.co.uk/tutorials/create-contour-map-effect-illustrator."

[30] "30 Types of Navigation Equipment and Resources Use Onboard Modern Ships - http://www.marineinsight.com/marine-navigation/30-types-of-navigational-equipment-and-resources-used-onboard-modern-ships/."

[31] "Mars Exploration Rover Mission: Technology - http://mars.nasa.gov/mer/technology/is_autonomous_mobility.html."

[32] "FRONTIER EXPLORATION Remote and deepwater frontier areas seeing more exploration - Offshore - http://www.offshore-mag.com/articles/print/volume-56/issue-4/news/exploration/frontier-exploration-remote-and-deepwater-frontier-areas-seeing-more-exploration.ht."

[33] "Login to access the Oil & Gas Journal Subscriber Premium features. - http://www.ogj.com/articles/print/volume-106/issue-14/exploration-development/special-report-exploration-companies-drawn-to-more-of-worldrsquos-remote-areas.html."

[34] "Action Sports The Action Sports Market," 1997.

[35] "Image Processing Toolbox - MATLAB - MATLAB & Simulink - https://uk.mathworks.com/products/image.html."

[36] "Image Processing in OpenCV OpenCV-Python Tutorials 1 documentation - http://opencv-python-tutroals.readthedocs.io/en/latest/py_tutorials/py_imgproc/py_table_of_contents_imgproc

[37] "Image Manipulation The Hitchhiker's Guide to Python - http://docs.python-guide.org/en/latest/scenarios/imaging/."

[38] "Products — Atlassian - https://www.atlassian.com/software."

[39] "Manifesto for Agile Software Development - http://agilemanifesto.org/."

[40] "12 Principles Behind the Agile Manifesto — Agile Alliance - https://www.agilealliance.org/agile101/12-principles-behind-the-agile-manifesto/."

Appendix A
Project Management and Time keeping

Atlassian provide a wide range of Agile Toolkits to aid in the maintenance of an Agile Software methodology [38]; for example the Tool JIRA provides a virtual Scrum Board tool, allowing for tasks to be tracked, time logged against tasks, along with the creation and maintenance of virtual Sprint cycles. Atlassian also provide tools like SourceTree, Fisheye and Crucible; which all add extra features to aid with an Agile Scrum development cycle, such as the ability to conduct Code Reviews easily and monitor Source Control systems, such as Mercurial or Git. While the license for Atlassian is prohibitively expensive, there are alternatives to this toolchain that are comparatively affordable, and would represent a worthwhile investment considering the benefit they would give to this research project.

As previously mentioned in this proposal, the Agile method uses Burn-Down charts for time keeping over the course of a Project or Sprint. As this research project will be conducted using Agile methodologies, a Burn-Down chart has been provided, in place of a Gantt chart, as an estimate of how the life cycle of the project is expected to play out. See Appendix B for details.

Appendix B
Burn-down Charts

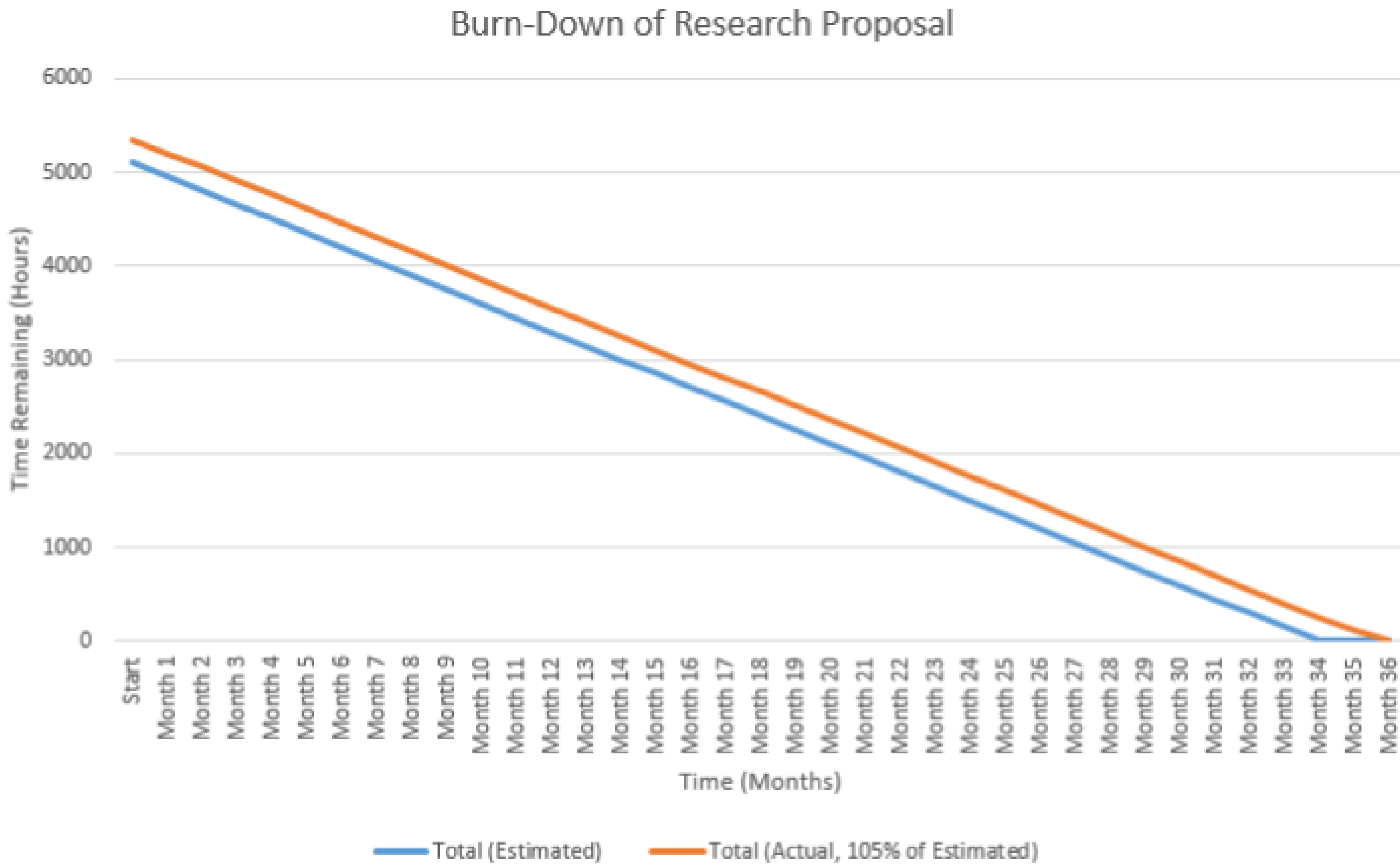

Fig. 3. Project Overview Burn-Down

Fig. 4. Task Specific Burn-Down

Appendix C
Agile Project Management

The traditional software development methodology is the Waterfall method; whereby a series of sequential tasks are completed one after another until the project is completed. This is easier to maintain, but ultimately far less effective compared to more complex project management solutions, such as the Agile Method.

Agile project management is based around a few key concepts, most notably the concept of maintaining short, constantly improving development sprints [39], [40]. A sprint can be defined as a period of time (usually two or three weeks) where a series of pre-defined development tasks have to take place. These tasks are usually allocated to a specific sprint because they involve the next logical step in the development cycle, or they can be arranged such that the estimated time to complete these tasks coincides with the length of the sprint.

The concept of continual improvement means that, under the Agile Scrum Method, the development team will have a Retrospective meeting at the conclusion of every sprint [39], [40]. The purpose of this meeting is to help improve any team processes that may be carried out, in the hopes of improving the quality or turn around time of the team's work. Any inter-personal issues or other points of contention within the team may also be raised during this meeting in the hopes of finding a solution.

Another defining principle of Agile work methodologies is the understanding that development work cannot always be accurately defined ahead of time [39], [40]; and therefore time planning tools such as Gantt charts which span an entire project lifecycle are not only inaccurate, but may cause actual harm to the project itself. Agile Methods instead utilise tools such as Burn-Down charts, to illustrate how the team's rate of work (taken from previous sprints), combined with the estimated amount of time that will be needed to fulfil a project brief, will cause the next sprint to play out.