PhD APRS Funding Proposal

Strategies for the trade-off of Scientific Goal Achievement vs. Robotic Survivability in Extreme and Hostile Environments

Michael F Clarke

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About the Candidate

Michael Clarke is currently a first year PhD candidate and member of the Intelligent Robotics Group within the Department of Computer Science. In 2010 he graduated with a first class MEng Software Engineering degree and his final year dissertation (Clarke 2010) focused on the development of a control system for a six-wheeled amphibious skid-steer robotic platform. He presented his work at the Towards Autonomous Robotic Systems (TAROS) conference in Plymouth in September 2010 (Clarke & Blanchard 2010). In addition, Michael makes a significant contribution to the department at public engagement events, visiting days, and through demonstrating and advisory work. Michael is looking for funding for the final two years of his PhD.

Background

In 2006 it was confirmed that, since 2004, the Greenland ice sheet has been receding at an accelerated rate, possibly due to the effects of global warming, of -239 $\pm$ 23 km^3/year compared with an average of -80 $\pm$ 12 km^3/year between 1997 and 2003 (Chen, Wilson & Tapley 2006). Such acceleration of the Greenland ice sheet alone is resulting in significant increases in run-off meltwater which in turn is estimated to be contributing to sea level rise by approximately 0.57 $\pm$ 0.1mm/year (Rignot & Kanagaratnam 2006). Glaciologists and Environmental Scientists, including those at Aberystwyth University, have a significant interest in determining the mechanics of such ice sheets and the extent to which global warming is affecting their rate of recession. In order to successfully model the movements of glaciers and ice sheets, data is needed regarding the physical structure of the ice and the meltwater channels under the surface. Currently, such data is gathered manually by teams of scientists during the early melt-season on the Greenland ice sheet, mainly using ground penetrating radar, and during the summer months at the calving-fronts of glaciers using swath bathymetry and terrestrial laser scanners.

Apart from the obvious financial costs of sending teams of scientists to such remote, Arctic areas there are significant dangers and hazards for any human expedition, both at the calving-fronts of glaciers and on the ice sheet, such as the extreme temperatures, meltwater moulins, crevasses, rising and falling ice, etc. In an effort to reduce the risks to scientists, and improve the quantity, consistency and quality of data acquired on such missions, the Computer Science department has already been working closely with Glaciologists at Aberystwyth to develop robotic systems capable of performing many of the more hazardous survey operations. To this end Minty, a remote-controlled boat designed for scanning at the glacier fronts using swath bathymetry and terrestrial laser scanning equipment, has already been deployed successfully. Returning data of comparable quality to that acquired during human expeditions (Neal, Blanchard, Hubbard, Bates & Woodward 2010), Minty has shown that robotic systems have the potential to gather science data in such harsh environments, with significantly less risk than human expeditions, without compromising the quality of the data. However, the potential application areas for Minty were severely limited due to the lack of autonomy.

Other ground based robotic systems have been developed for use in Arctic environments, including the Cool Robot (Ray, Lever, Streeter & Price 2007) and Nomad (Apostolopoulos, Wagner, Shamah, Pederson, Shillcutt & Whittaker 2000). These robots have addressed some of the issues relating to autonomous operation in Arctic environments including simple GPS (Global Positioning System) way-point navigation and the power requirements of robotic systems, identification of scientifically interesting objects such as meteorites and obstacle avoidance techniques, though they have paid little attention to the problems of robotic survivability. With many of the most interesting science targets located in hazardous areas such as at the edges of meltwater lakes and moulins more recent work in the field has been towards the development of visual terrain and pose estimation techniques (Williams & Howard 2008, Williams & Howard 2010*a*, Williams & Howard 2010*b*) which are vital for the safe navigation of robotic systems from, to and around these hazardous, scientifically interesting areas. Whilst such techniques can help with path planning, localisation and ensuring robotic systems are stable and do not fall over, they do not provide the high-level decision making capabilities that robotic systems need in order to "decide" if a given mission (including many factors such as the navigation required to reach the site, any scientific instruments that need deployment, sample acquisition tasks, power availability, weather conditions, etc.) truly is safe, or if not entirely safe, is of acceptable risk.

Any truly autonomous robotic platform must be able to make decisions regarding its own survival and the need for the scientific data. A robotic system which has the capability to "decide" to forgo scanning at the edge of a crevasse would be able to gather more data at other scientifically interesting areas, yet the data available at the edge of the crevasse may be of significantly more value, thus justifying the risks involved. Robotic systems must have the ability to make decisions regarding the importance of the available scientific data over their own survival.

In addition to the environmental factors already discussed (such as weather, visibility and obstacles) there are a number of additional factors internal to the robotic system which affect what is considered safe. Examples of such include the remaining power available to the vehicle, the operational efficiency of the sensors, other scientific missions that the robot must still perform, etc. In addition to the current state, the conditions in the near or long-term future also need consideration; it may be, for example, pointless to perform a survey if it would mean that the robotic system would be unable to return to its base before a storm which has the potential to affect its navigation capabilities. Conversely, it may be vital that the survey be performed immediately, before the storm arrives and adversely affects the scan site. All these factors need to be evaluated, both in terms of their short and long term effects, by the robotic system in order for sensible operational decisions to be made.

For many millions of years biological systems have proved to be more than adequate at instinctively making such life-or-death decisions, and this has paved the way for biologically inspired robotics. Such robotic systems use techniques found in nature such as the neuro-endocrine system which adapts to short-term changes in the environment, with effects lasting up to a few minutes, and the immune system which can have effects on the body for months or even years. Some work has already taken place, particularly at Aberystwyth, to use neuro-endocrine and artificial neural network control techniques for the long-term survivability of sailing robots (Sauze & Neal 2010, Sauze & Neal 2008), with significant emphasis on adapting the behaviour based on the proprioceptive state of the robotic system, in particuar the power required over that which is available.

Other Artificial Intelligence techniques such as fuzzy logic systems also have the potential to help with such short and long term decision making (El-Nasr & Skubic 1998). Fuzzy logic systems have seen considerable use in robotic simulations and platforms where there are various differing (and often conflicting) concurrent tasks providing methods for the smooth transitions between such tasks. Examples have included the navigation of robotic systems and the avoidance of obstacles en route (Parasuraman, Ganapathy & Shirinzadeh 2005, Fatmi, Yahmadi, Khriji & Masmoudi 2006). It is thus clear that fuzzy logic systems have the potential to aid autonomous decision making regarding scientific objective achievement and robotic survivability when there is incomplete, inaccurate or vague sensor data; something that is often true of robotic systems in real-world, harsh, dynamic environments.

The PhD, which is already underway, is primarily focused on the exploration and development of biologically inspired and fuzzy logic techniques for the survival of robotic systems in hostile environments which will be demonstrated through a robust robotic survey platform capable of prolonged, unattended, autonomous operations in Greenland. The resulting platform, in addition to demonstrating new robotic survivability and planning techniques vital to robotics research, which relate closely to existing research within the department, will have the added benefit of significantly improving the quantity (and potentially quality) of data gathered by the Glaciologists during survey operations in Greenland.

Key Research Question

The key research question being studied during the PhD is *"How useful are biological inspired control methods, such as neuro-endocrine control, artificial neural networks and the immune system, compared to fuzzy logic control techniques, at adapting the behaviour of robotic systems in order to ensure robotic survivability and the maximum possible science data return in harsh and extreme environments?"*

Aims and Objectives

Whilst limited work has already been undertaken towards autonomous operation in the Arctic the focus has never been towards the long term survivability of the robotic platforms. This PhD aims to build on the recent work of Sauze, Neal and Timmis (Sauze & Neal 2010, Sauze & Neal 2008, Neal & Timmis 2003) through the investigation of biologically inspired control techniques, such as neuro-endocrine control and the immune system, for the provision of robotic systems with the ability to make high-level decisions regarding their own survival in extreme and hostile environments. The PhD will make further contributions and developments to the use of fuzzy logic control techniques, with particular emphasis on attempting the similar trade-off of robotic survivability vs. scientific goal achievement.

The PhD will provide significant contributions within the existing work by the Intelligent Robotics Group of the Computer Science department, and that of the Glaciology group in the Institute of Geography and Earth Science, towards the autonomous surveying and scanning of glaciers and ice sheets.

Objectives Summary

1. To test the hypothesis that biologically inspired control techniques are more appropriate for ensuring the maximum possible scientific data return and robotic survival rates when than fuzzy logic control methods.

2. To develop a framework for defining what is appropriate in terms of the risk to robotic systems when performing scientific survey operations in various environments.

3. To make significant contributions to the existing work in biologically inspired control techniques, in particular developing new methods for ensuring robotic survivability in hostile environments.

4. To make contributions to the existing work in fuzzy logic based control methods, with emphasis on building new methods for ensuring the survival of robotic systems in hostile environments.

5. To make a considerable contribution towards the efforts of the Glaciology Group at Aberystwyth in their efforts to understand the Greenland ice sheet through the development of a fully autonomous survey platform.

6. To make use of the existing robotic platforms available within the Computer Science department to act as long term test platforms, which are able to operate fully autonomously in Greenland (or other similar environments), for automated surveying tasks.

Current Progress

To date significant work has been undertaken developing a robotic platform, built from an Argo six wheeled skid-steer amphibious vehicle, equipped with a SICK laser scanner, terrestrial laser scanner (Leica HDS6200), panoramic camera, GPS, tilt-compensated magnetic compass, 3-axis accelerometer, 9-DOF (Degrees of Freedom) IMU (Inertial Measurement Unit), penetrometer and wheel odometry sensors. This work is almost complete, and the platform will be shipped to Greenland in March 2011 for its first deployment in April 2011. Having such a real-world robotic platform ready for immediate use is vital for the future testing and development of the proposed biologically and fuzzy logic inspired survivability strategies.

Further, it also allows for early scientific data return. Software has now been developed for both the control of the platform and for initial sensor data gathering, with the initial trip to Greenland focused on gathering as much data as possible, from as many sensors as possible, in as many different conditions as possible, in order to better understand the requirements of the Glaciologists and to identify better the conditions the robotic platform will be exposed to and where the problems lie with the existing control techniques. Even on its first mission, whilst work is underway testing existing control techniques, the Argo will make significant contributions towards existing research within the Computer Science and IGES departments, such as additions to existing visual navigation techniques (Labrosse 2006, Labrosse 2007) and the provision of vital ground penetrating radar, terrestrial laser scanner and penetrometer data.

Further trips to Greenland are planned for April 2012 and April 2013, where the primary in-situ testing and experimentation relating to survivability, scientific goal achievement and autonomous surveying techniques will take place.

Additionally, the candidate has been progressing with a comprehensive literature review of a number of related areas such as neuro-endocrine robotic control, fuzzy logic and robotic systems in Arctic environments.

Relation to Departmental Research

The proposed research has significant relation to existing efforts within the Computer Science department. *Some* examples of recent, related work within the department are provided:

- The use of sea-based robotics for the scanning of glaciers in Greenland, including a recent survey of the Lille Gletscher glacier in 2010 by 'Minty' (Neal et al. 2010).
- The use of biologically inspired control techniques for power-management of robotic sailing boats (Sauze & Neal 2010), including the recent Microtransat Challenge to sail the Atlantic ocean by 'Pinta'.
- The development of autonomous scientific target identification (Barnes, Pugh & Tyler 2009) techniques by the space robotic team in an attempt to maximize the science return of rovers sent to Mars. Much of the Martian environment, and therefore challenges involved, draws parallels with Greenland.

Current Publications

Clarke, M. and Blanchard, T. "*Development of a Control System for a Skid-Steer Amphibious Vehicle*", in proceedings of TAROS 2010, Plymouth, UK, Pages 41 - 46, Sept 2nd 2010.

Short-term Publication Aims

Upon return from Greenland it is planned that a paper will be submitted to the Journal of Field Robotics detailing the robotic platform, testing and scan results obtained and the limitations identified, along with an outline of the proposed further research. It is also anticipated that a joint

Computer Science/Glaciology publication will also be submitted on return from Greenland to the Journal of Glaciology.

Further publications are planned as the PhD progresses at conferences such as Towards Autonomous Robotic Systems (TAROS), Systems, Man & Cybernetics and Control, Automation and Robotics (CAR), as well as various journal papers both in Geography and Computer Science based journals such as the Journal of Geophysical Research and the journal Robotics and Autonomous Systems.

Work Plan

Note that all time periods assume a funding start date of 1st September 2011, continuing to 31 August 2013 (2 years funding). Current (one year) funding expires on the 31 August 2011.

WP1: Literature Review (Months 1 - 3)

Complete existing literature review covering biological background, fuzzy logic background, overview of robotic systems previously deployed in environments such as Greenland and Antarctica.

WP2: Neuro-Endocrine and Fuzzy Logic Controller Implementation and Experiment Design (Months 4 - 9)

Design and implement neuro-endocrine and fuzzy logic control architectures. Devise experiments to test and compare the use of both control architectures for autonomous decision making, emphasising scientific goal achievement and robotic survivability.

WP3: Experimentation and Analysis (Months 10 - 20)

Perform the experiments devised in WP2 over long periods, both locally at Aberystwyth and in real-world situations such as during scheduled excursions to Greenland showing the success or failure, functionality and adaptability of the differing control architectures. Produce comparisons between the neuro-endocrine controller and the fuzzy logic techniques and draw conclusions regarding their appropriateness for the given task.

WP4: Writeup and Dissemination (Months 15 - 24)

Progressively writeup thesis. Presentation of experimental trials and results, as well as final research conclusions, in the form of papers at appropriate conferences and journals (as detailed in planned publications).

WP5: Public Engagement (Months 1 - 24)

Robotic systems present significant opportunities for public engagement. Where possible public demonstrations of the robots used in the PhD, along with appropriately detailed talks, will be given at university open and visiting days, conferences, etc.

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