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The UK Space & Planetary Robotics Network

ALEX ELLERY[1]*, DAVE BARNES[2], RODNEY BUCKLAND[3], CHRIS WELCH[1], JAMES GARRY[4], JOHN ZARNECKI[4], JONATHAN GEBBIE[5], ASHLEY GREEN[3], MARK SMITH[6], DAVID HALL[7], COLIN MCINNES[8], ALAN WINFIELD[9], ULRICH NEHMZOW[10] AND ANDREW BALL[4].

1. School of Engineering, Kingston University, Friars Avenue, Roehampton Vale, London, SW15 3DW, UK.
* Email: a.ellery@kingston.ac.uk
2. Department of Computer Science, Aberystwyth University of Wales, Aberystwyth, Dyfed, SY23 3BZ, UK.
3. Department of Design & Innovation, Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.
4. Planetary & Space Sciences Research Institute, Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.
5. Space & Defence Division, Logica, 75 Hampstead Road, London, NW1 2PL, UK.
6. Earth Observation, Navigation & Science Directorate, Astrium Ltd, Gunnels Wood Road, Stevenage, Hertfordshire, SG1 2AS, UK.
7. British National Space Centre, 151 Buckingham Palace Road, London, SW1W 9SS, UK.
8. Department of Aerospace Engineering, University of Glasgow, G12 8QQ, UK.
9. Intelligent Autonomous Systems Laboratory, University of West of Engand, Coldharbour Lane, Bristol, BS16 1QY, UK.
10. Department of Computer Science, University of Essex, Wivenhoe Park, Colchester, Essex, CO4 3SQ, UK.

A number of academic engineering research groups around the UK have become increasingly interested in the applications of robotics or robotics techniques to solving problems in space engineering. Although these groups have sprung up independently and have worked in essentially independent areas, they are seeking to form themselves into a network offering a diverse range of expertise within the UK with the capability of developing complete space robotic systems. Space robotics is an area in which the UK has dabbled in the past, but for the first time, the UK offers a solid base of expertise in mobile robotics and associated space engineering which would enable the UK to contribute to European space robotics projects funded by ESA and/or national agencies. To that end, following the inaugural meeting of the Space & Planetary Robotics Network, an extended group of interested parties will be putting forward an application to EPSRC for Network funding.

Keywords: Space robotics, planetary exploration, UK space policy

1. Introduction

The 17th May 2002 was a special day for space roboticists, a new breed of engineer cross-trained in spacecraft engineering and robotics in its various guises. This was the day of the Inaugural Meeting of the Space & Planetary Robotics Network (SPRN) hosted at the Open University (OU) jointly between the Planetary & Space Sciences Research Institute (PSSRI) and the Department of Design & Innovation. It was highly appropriate that this meeting be held at this venue, the home of the PSSRI which leads the UK's Beagle2 Mars lander mission to be carried to Mars by the European Space Agency's (ESA) Mars Express spacecraft towards the end of 2003. The Beagle2 lander mission is the brainchild of Professor Colin Pillinger FRS of PSSRI, Open University – see fig. 1.

One recent event of particular importance was the ESA Ministerial meeting in Edinburgh in November 2001 which initiated a new ESA programme called Aurora. The Aurora programme is a vision of the future of planetary exploration – its centrepiece is the robotic exploration of Mars (and other planets) culminating at some unspecified time in the future with a human mission to Mars. The recent discoveries on Mars by US missions and the recent work by the international astrobiology community have provided strong impetus to explore Mars in search of evidence of extraterrestrial life, be it extinct or extant. Unlike most ESA exploration missions however, Aurora is based around a technology focus rather than scientific priorities – the engineering community have, for the first time, the opportunity to propose planetary missions as a showcase for technology as well as for advancing science. This was the backdrop against which Ellery, Barnes and Buckland decided to test the level of interest in space robotic missions by the robotics and planetary science community in the UK.

Fig. 1 Beagle2 Mars lander (all rights reserved Beagle2) - visit www.beagle2.com for more information.

2. The SPRN Meeting

The meeting was attended by almost 130 scientists and engineers from 27 different universities and a number of companies. It came to fruition after discussions between Ellery, Barnes and McInnes who had built, over a number of years, independent research groups focussing on different aspects of space robotics. Ellery's group at Kingston were focussed on planetary rover locomotion and robotic in-orbit servicing, particularly control systems – see fig. 2. Barnes' group at Aberystwyth were focussed on the development of planetary aerobots and are part of the Beagle2 Mars mission team involved in kinematics analysis of the robotic arm. McInnes' group at Glasgow were strongly focussed on robotic path planning and obstacle avoidance. Each group was convinced that space robotics is a rich area of development and that it would be beneficial to cooperate in and consolidate our work which we thought might be of interest to other groups. Discussions soon brought Rodney Buckland on board who almost single-handedly put together and organised a remarkable programme to introduce the Space & Planetary Robotics Network through an inaugural meeting. The delegates came from terrestrial robotics groups, space engineering groups, planetary science groups and others with more than a peripheral interest in space robotics (representatives from both EPSRC and PPARC were present).

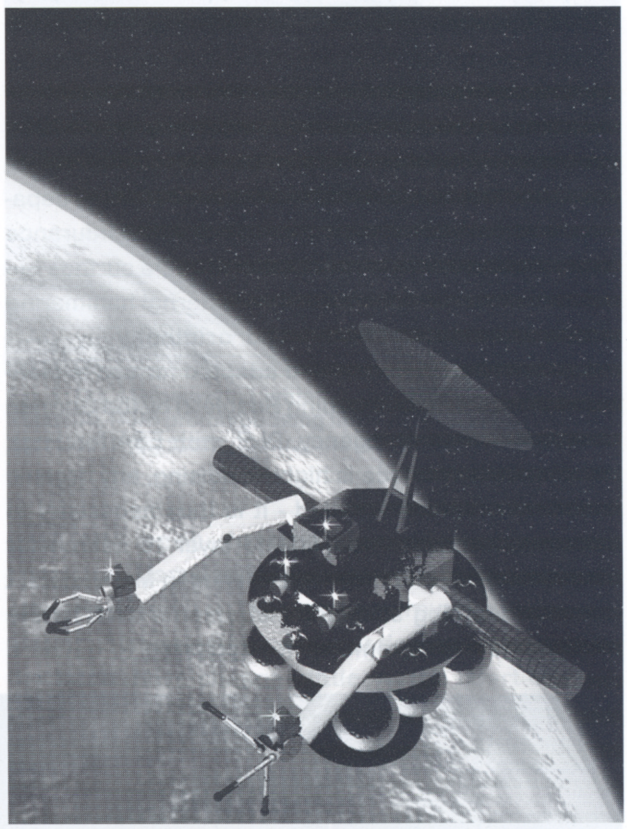

Fig. 2 The ATLAS (Advanced TeLerobotic Actuation System) servicer proposed for robotic in-orbit servicing missions. (courtesy Praxis Publishers)

3. The View from Kingston University

The meeting opened with a welcoming address from Professor Brenda Gourley, the Vice Chancellor of the Open University who expressed her delight that so many delegates from so many institutions and disciplines had converged on the Open University which is home to Professor Colin Pillinger FRS's Beagle2 Mars lander team. Rodney Buckland as chairman introduced the first main speaker, Dr Alex Ellery of Kingston University who began with outlining the need for the UK to carry on the momentum of Beagle2 by showing leadership in proposing new subsequent robotic Mars missions. He outlined the engineering requirements for a Mars micro-rover and showed how the different robotics research groups in the UK – namely, Kingston University, Aberystwyth University, University of West of England, University of Essex and University of Glasgow – possessed complementary areas of expertise which together could develop a micro-rover testbed. He then introduced a new Mars mission proposal called Vanguard – see fig. 3. Mars has recently become a focus of interest for the new multi-disciplinary field of astrobiology in which the UK is a major player. Vanguard represented the fruits of discussions between Ellery and the late astrobiologist Dr David Wynn-Williams – a rare and close collaboration between a scientist and an engineer involved in the mission design at the outset to anticipate problems and difficulties early in the design process. The Vanguard Mars lander would be delivered from a Mars Express-class spacecraft bus by an Entry, Descent and Landing System (EDLS) similar to that employed by Beagle2. The Mars entry profile comprises an ablative heat shield, parachute deployment and airbag impact onto the surface. The surface element comprises the Vanguard lander, the Endurance micro-rover (somewhat similar to the Sojourner micro-rover on the US Mars Pathfinder mission of 1997), and three ground-penetrating "moles" mounted onto the rover. The moles would be delivered to three separate sites on the Martian surface by the Endurance rover. Each mole would penetrate into the surface using a motor-driven, spring-loaded internal hammering mechanism (being developed originally by OAO VNIITransMash in Russia and adapted for use in planetary missions (now including Beagle 2) by the German aerospace research agency, DLR, with ESA funding). As the Martian surface is highly oxidising, any organic material will have degraded - it is thus necessary to penetrate beneath this oxidised layer to search for evidence of life that may have existed in Mars' distant past. By adopting scientific instruments such as the laser Raman spectrometer, it is possible to obtain a geochemical, mineralogical and organic depth profile. Furthermore, this type of instrumentation eliminates the requirement for recovery of the mole from the borehole. The adoption of three moles provides for redundancy and replicability of the scientific data. Furthermore, the mission concept took on further significance with the discovery of sub-surface water by Mars Odyssey which could potentially be extracted robotically for in-situ resource utilisation (ISRU) in support of robotic and human Mars missions. Such a mission represented one possible post-Beagle2 Mars mission in which the UK could play a significant part. In particular, Ellery stressed that bringing together scientists and engineers was critical to the UK's success in such ventures and further stressed that the engineering research community, roboticists in particular, have a unique opportunity to contribute. For astrobiology-focussed missions such as Vanguard, the engineering community should be playing their critical role in helping shed light on the question of the existence of extra-terrestrial life as one of the biggest scientific questions of the 21st century.

4. The View from Aberystwyth University

Dr David Barnes of Aberystwyth University followed to talk about his group's work, focussing on their activities in aerobots and in the Beagle2 mission. The talk provided details of the Beagle2 ARM (the robot manipulator), and PAW (the ARM end-effector containing scientific instruments) kinematics modelling, simulation and calibration, together with information on other space robotic activities within the Department of Computer Science. The Aberystwyth group have received Beagle2 CAD data from Astrium Ltd., and the Space Research Centre, Leicester. This they have imported into a robot simulation software package to create a

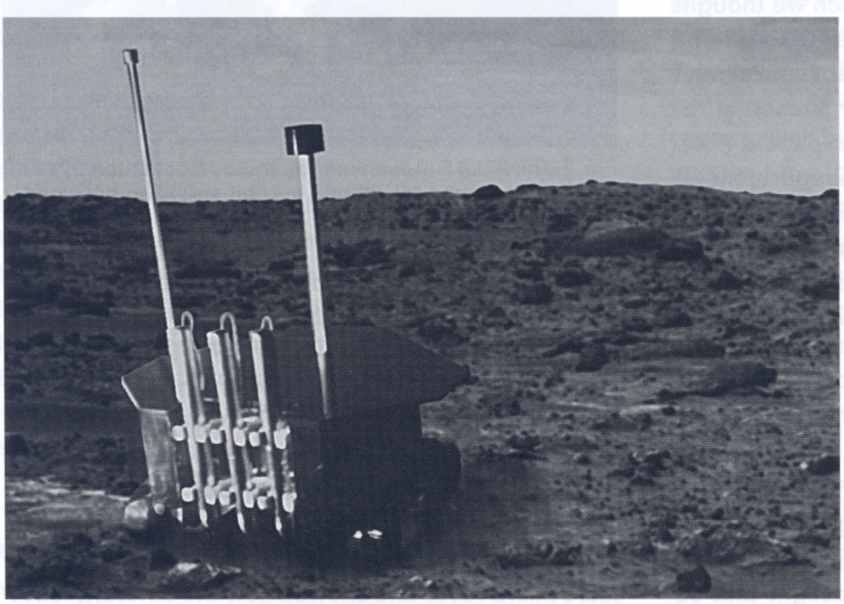

Fig. 3 The proposed Vanguard Mars micro-rover with three mounted ground-penetrating moles to be deployed to search for life beneath the Martian surface. (courtesy Ashley Green)

virtual Beagle2 – see fig. 4. The strategy is to use this virtual Beagle2 during the 2003/2004 mission so that engineers and scientists can validate, and plan the operation of Beagle2, before commanding the real Beagle2 ARM to move on Mars. Stereo cameras mounted on the PAW will capture images of the Martian terrain, and software developed by Joanneum Research, Austria, is able to convert this data into a terrain digital elevation model (DEM). When in this format, terrain information can be imported into the Beagle2 virtual model. Once this has been achieved, scientists and engineers will be able to 'fly' around the Beagle2 virtual environment to look at rocks and the Martian surface, as part of their search for good science targets. When these have been selected, the virtual Beagle2 can be used to ensure that these targets can be reached by the ARM, and that no part of the ARM and PAW will collide with neighbouring rocks, or any other part of the Beagle2 lander. For the virtual Beagle2 model to be used in this way, its software model must be calibrated with the real Beagle2, so that the virtual and real Beagle2 kinematics are identical. The Aberystwyth group has completed the generation of the virtual Beagle2 model, and is in the process of performing the necessary kinematics calibration.

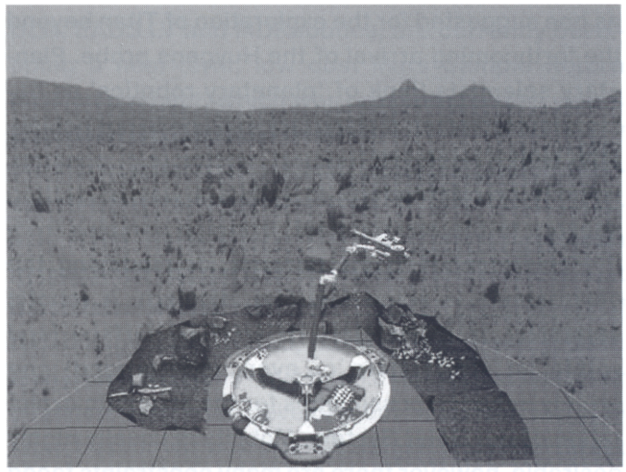

Fig. 4 A screen dump from an early version of the Aberystwyth Beagle2 virtual model. This shows part of the Beagle2 lander base, with ARM and PAW. In front of Beagle2 are an imported DEM (spot the ruler), and a Martian panorama. (image data courtesy of NASA/JPL)

Fig. 5 The Aberystwyth Lighter Than Atmosphere Intelligent Robot (ALTAIR) prototype being flown at the ESTEC Planetary Test Bed (PTB) facility during the ASTRA 2000 workshop. (courtesy Dave Barnes)

In addition to the Beagle2 work, Barnes went on to describe briefly the aerobot research being undertaken at Aberystwyth. Work includes laser scanning terrain navigation, inertial sensing for aerobot science and control, aerobot airdata measurement, and soaring aerobot control – see fig. 5. In addition to a real laboratory based aerobot, Aberystwyth make extensive use of a software flight simulator to conduct experiments before trying out their ideas on the real aerobot. Barnes concluded his talk with a brief overview of the EPSRC Technology Programmes Networks scheme. EPSRC aims to encourage the transfer of ideas, experimental techniques and insights within all aspects of the relevant community, to encourage mobility between disciplines and universities, and between academe and industry, leading to the possible creation of a new research community. EPSRC will provide funding up to £60,000 for 3 years to support the running of a network. Barnes invited all attendees to become members of a proposed EPSRC funded Space & Planetary Robotics Network. A case for support will be submitted to EPSRC, and all interested attendees will be contacted during this process.

5. The View from the Open University

James Garry provided light entertainment by showing a remarkable video montage, reminding us of the different Soviet/Russian robots that have flown in the past and been developed such as the Luna, Lunakhod, Mars and Phobos missions. Although these older craft, such as the Lunokhod rovers, were much less sophisticated than current designs, the 'tools of the trade' have changed little. At the heart of planetary science robot missions is the need to gather and handle samples, and forthcoming spacecraft such as the Rosetta cometary lander will carry coring tools little different from those used by the Soviet Luna landers of the early 70s. The PSSRI has an interest in such robotic tools and has built a unique vacuum chamber equipped with a cryogenic drilling rig, in which martian, or cometary, or Europan (!) sampling technologies can be tested under flight conditions.The subsequent coffee break was marked by a frenzy of animated discussions between people from different disciplines who had never met, an activity that characterised the whole day. Dr John Zarnecki of the PSSRI, Open University talked about planetary robotics from a planetary scientist's point of view, including some mission scenarios for exploration of exotic and challenging environments, such as one suggested for the exploration of Titan beyond the forthcoming arrival of the Huygens probe. Planetary scientists think of 'planetary robotics' as being required when a planetary mission is not achievable with a vehicle's 'natural' vector (e.g. position, velocity or orientation). It is thus a way of getting sensors to the environment, bringing samples from the environment to the sensors, or modifying the environment in some way (e.g. digging). A robotic capability on a planetary or satellite surface (and within an atmosphere or even underground) can greatly enhance possibilities for the scientific exploration of our Solar System. Mobility is usually highly desirable, however there are many constraints faced by robotic solutions. The robotic solution to a particular problem is often very sensitive to the measurement or sampling strategy needed to address the chosen scientific goals. However, new robotic technologies may inspire the scientific community to create new experiment designs not previously considered, so the process can be iterative. There are many potential payload experiments large and small, with widely varying demands in terms of robotics. A high degree of integration between system and payload aspects is often needed.

6. The View from Logica

Jonathan Gebbie of Logica was the first speaker to discuss UK industry's involvement in robotic science missions, stressing their accumulated expertise in developing software for Entry, Descent and Landing on other planets. Logica has developed software to control Entry, Descent and Landing (EDL) for both of Europe's planetary landers to date: Beagle 2, scheduled to land on Mars in late 2003 and Huygens, due to land on Titan in January 2005. The EDL phase of a mission is high risk and poses a number of engineering problems: there are hard real-time constraints, mission-critical decisions must be made autonomously, electro-mechanical-chemical devices must be controlled and it is generally not possible to realistically test the complete system before launch. He explained in detail how Beagle 2 will land on Mars. After entry into the Martian atmosphere, the probe will be decelerated by an ablative heatshield and parachutes, and its impact on the surface cushioned by airbags. These are controlled by the on-board software, using data from accelerometers and a radar altimeter. The pilot parachute must be deployed explosively within a time window of less than a second in order to stabilise the probe through the turbulent subsonic transition regime. He evaluated the pros and cons of the Beagle 2 EDLS, and outlined technologies which may be used to increase the likelihood of a successful landing, improve the accuracy of the landing and enhance the scientific data gathered during the descent. These include the use of rockets to enable a probe to actively steer itself to a desired landing site, descent cameras for hazard detection, and the use of a constellation of in-orbit spacecraft for precision navigation. All of these technologies are currently under consideration for future missions. The conclusion was that through Huygens and Beagle 2, UK industry and academia has accumulated experience in navigation and guidance which is unrivalled in Europe, and that we should build on this strength for future planetary landing missions.

7. Public Outreach

Talks gave way to a number of discussion groups involving all the delegates. Each group discussed a different question relevant to space robotics led by a facilitator who presented the main points of each discussion in the late afternoon. The questions varied from: "How can we make space robotics pay?" to "Does Framework 6 offer opportunities for space robotics?". The great utility of this phase of the conference was to bring speakers and delegates together "up close and personal" and to highlight how scientists and engineers can interact positively and swap ideas. This was followed by lunch during which there was much networking and interviews with members of the press.

Dr Ashley Green, formerly of Oxford Brookes University, was the first speaker after lunch. He discussed his many years in educational outreach to schools in utilising space robotics as a tool to inspire children into careers in science and engineering. His innovative use of Lego Mindstorms and Meccano in building mobile robots was inspirational and drew strong praise from the PPARC representative on the Public Understanding of Science. Green stressed the need for educational opportunities that will be generated by intense interest in the forthcoming high-profile robotic missions to Mars, Saturn, Titan, etc. He outlined some of his ideas for enabling youth and educators to feel fully informed and personally involved in these exciting voyages of discovery.

8. The View from Astrium

Dr Mark Smith, leader of Astrium's Science Division, outlined their many activities in past science missions, Beagle2, and post-Beagle2 mission proposals. He stressed that Astrium had not been aware of the research activities in robotics by many academic groups, highlighting the necessity for academic institutions to make effort in forging links with industry. Looking to the future, Astrium is involved in a number of planetary mission proposals ranging from near-term Mars and Near Earth Object (NEO) missions, many of which are building on the heritage obtained from the unique Beagle-2 design, to long-term opportunities such as a Subterranean Europa probe, Venus aerobots and manned Mars missions. With this innovative approach to developing low cost lander technology, Astrium Ltd is offering its experience to the proposed NASA Scout mission Artemis – see fig. 6. The mission, due for launch in 2007, is part of NASA's continuing program for the exploration of the planet Mars and comprises a number of small planetary landers that will obtain scientific data from the planet's surface. Astrium Ltd is part of the UCLA-led proposal team, together with TRW and JPL, and is responsible for developing the lander platforms. The Artemis probe offers a low cost, simple solution for a multi-lander mission to Mars. The design allows the probes to be easily integrated onto the carrier spacecraft and released from Mars orbit to target a desired landing site on the surface to within 10km.

The lander platform is derived from the Beagle 2 lander, which will become the first semi-commercial lander mission when it is launched in mid 2003 on ESA's Mars Express. The design of the Beagle 2 lander enables it to carry a payload that represents approximately 33% of the total landed mass, thus enabling the total mission costs to be greatly reduced whilst maintaining scientific performance. The highly integrated approach that was adopted has also resulted in a simplification in the overall system design and the number of components required in the construction of the lander. This has the added effect of reducing and simplifying the build and test schedules for the lander and further reducing the cost and risk to the mission. In addition, the UK's involvement in the mission is strengthened by University of Leicester, who are providing a science instrument funded by PPARC.

Looking further into the future, Astrium, together with University of Leicester, the Open University, DLR, EADS LV and MDRobotics, are currently developing a near-term, low cost Mars Sample Return mission concept, which was presented at this year's European Geophysical Conference in Nice as part of the Mars Exploration session, generating much interest as ESA. The idea of a Mars Sample Return mission is not a new phenomenon and plans have been in existence for the last 30 years. The trouble is that these have always been restricted on the grounds of technology, politics and, more predominantly, cost. Many such missions have been estimated at well over $1billion, with huge development times and multiple launches for various mission stages. Plans for direct return missions from the Martian surface had the drawbacks of (a) being too expensive in terms of the launch costs required to lift the propellant needed for return and (b) being too slow if an in-situ resource propellant production technique was used. The alternative solution was to return via a rendezvous in Mars orbit, thus reducing the mass to be transported to and from the Martian surface. The most popular of the orbital rendezvous options involved the launch of a combined Mars Ascent Vehicle/Mars Rover mission to gather samples in readiness for a subsequent return to Earth via a second mission that would deliver an Earth Return Vehicle into Mars orbit with which to transport the samples back. This method had the disadvantages of incurring large costs from the prolonged stay at Mars and high launch costs due to the necessity of two separate launches. The Astrium-led concept of the study is to utilise the orbital rendezvous method but incorporate each of the elements into a single mission (i.e. one launch) using mature and affordable lander technology to return a small regolith core sample. This not only reduces launch and development costs, making the mission more 'affordable', but also lowers the risk of mission failure compared to the two-launch method. An additional change to the previous scenario is that of returning the sample almost immediately after its acquisition in a "grab and go" fashion. This not only simplifies the lander design by minimising the time spent on the Martian surface,

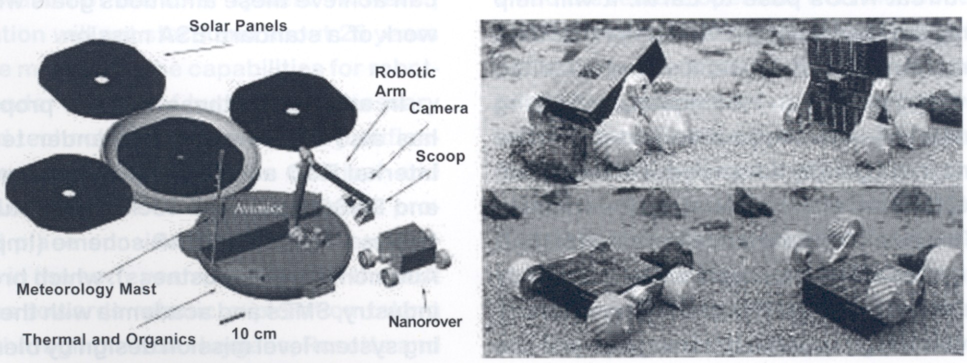

Fig. 6 The Artemis Lander and Nanorover. (courtesy Astrium)

but also reduces costs and facilitates a faster recovery of results. Hence the rover is replaced by simpler acquisition method. Currently under development by DLR is a hybrid of Beagle-2's mole that could extract a subsurface core sample when deployed from the lander. Given modern analysis techniques, that are capable of working on very small samples (i.e. mg to mg), the return of a small subsurface core sample of soil could be a valuable precursor to a later mission that would return rocks. Such a mission would lead to a high scientific return due to the aeolian nature of Mars as any such sample would conceivably contain a large number of different types of materials. Hence the size of sample envisaged for return is as small as 250g. The mission concept utilises an orbiter that releases a lander on Mars approach that will target a specific landing site identified by existing Mars orbiters (Mars Global Surveyor, Mars Odyssey, Mars Express). The lander will be dedicated only to collecting a core sample of regolith, loading it into a return capsule on an ascent vehicle and launching this vehicle into low Mars orbit. The capsule will then rendezvous with the orbiter and return to Earth orbit where it can be brought safely to Earth either directly or via the Space Shuttle/ International Space Station (ISS). In order to minimise costs, time spent on the Martian surface and to facilitate early results, the mission strategy is to enable departure and return within one Mars opposition opportunity; most likely 2007 or 2009 under ESA's Aurora programme.

In addition to Mars, Astrium have also targeted NEO missions. ISHTAR (Internal Structure High-resolution Tomography by Asteroid Rendezvous) is an Astrium led mission study funded by ESA and developed together with the Observatoire de Paris and Uppsala University. The ISHTAR concept is centred around a Radar Tomography payload able to probe the interior of a small asteroid to depths of 100-200m. This will allow the first detailed characterization of a NEO and will give valuable insights into the origin and evolution processes that govern the NEO population. ISHTAR will also address key issues related to the threat NEOs pose to Earth: it will help assess the impact hazard, by providing the first data on the internal strength of NEOs, it will provide the basis for devising mitigation techniques, by helping to discriminate between destructive and deflective strategies and it will greatly advance our understanding of how NEOs form and collide with other planets – see fig. 7. The detailed information from the ISHTAR mission will be collected through a small, but highly targeted set of instruments. The ground-penetrating radar will provide high-resolution tomography of the asteroid interior. A stereo imager will characterize

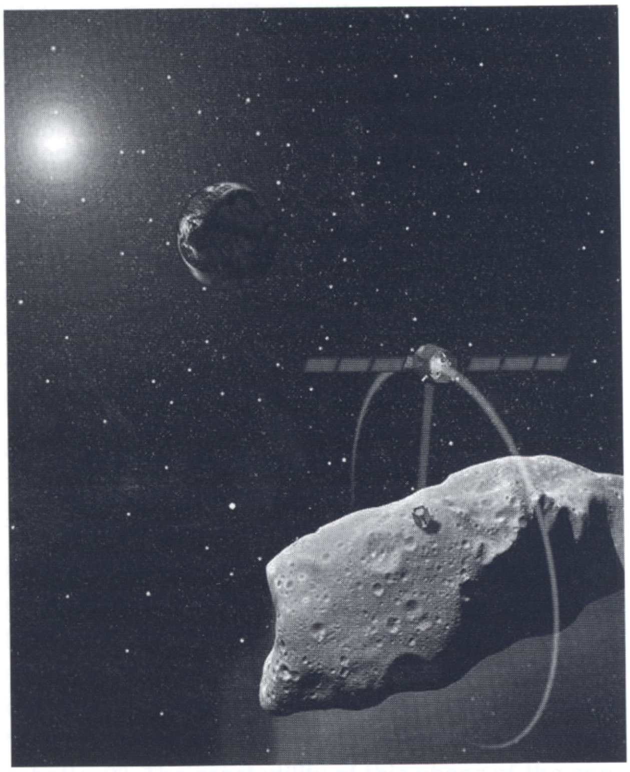

Fig. 7 The ISHTAR Mission (with its original lander configuration). (courtesy Astrium)

the surface topology and a radio science experiment will determine the asteroid mass. The whole mission is possible within the constraint of a small (315kg) spacecraft and the financial envelope of an ESA 'flexi' mission.

Further work by Astrium on NEO missions includes the mission concept APIES (Asteroid Population Investigation and Detection Swarm), carried out in response to a recent call for ideas by ESA – see fig. 8. It is a swarm mission comprised of a flotilla of microsatellites aimed at exploring the main asteroid belt in great detail; measuring mass, density and imaging over 100 asteroids, more than doubling the number of solar system bodies visited by man-made spacecraft and finally providing data on a statistically significant sample of asteroids. Using the latest technological advances in miniaturization, solar sailing and spacecraft autonomy, the APIES mission can achieve these ambitious goals within the framework of a standard ESA mission.

In addition to these mission proposals, Astrium has also been developing lander technologies via internal R&D activities, sponsored private research and BNSC Advanced Technology Studies. Such activities include the IMAR scheme (Improved Mission Autonomy and Robustness), which brought together industry, SMEs and academia with the aim of improving system level mission design by blending research into intelligent systems, evolutionary robotics and

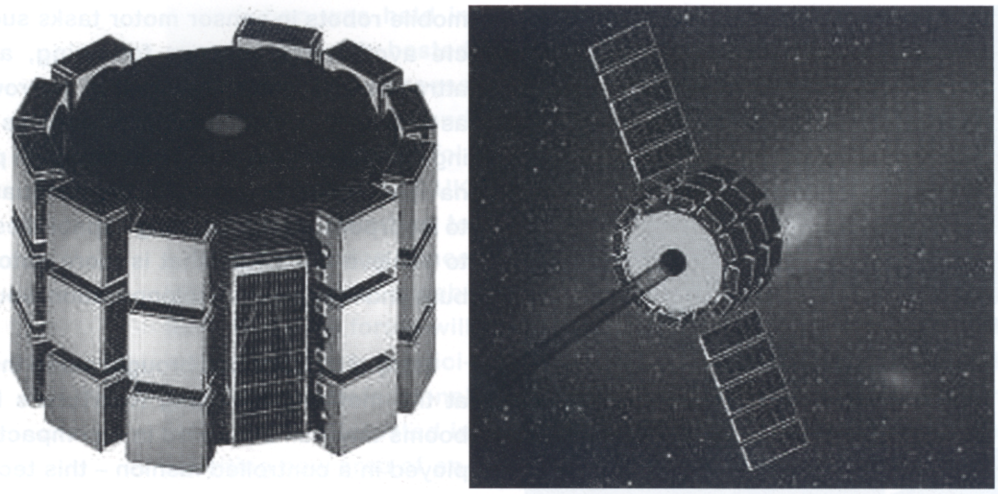

Fig. 8 Possible APIES configuration with the BEEs (BElt Explorers) attached to the HIVE (Hub and Interplanetary VEhicle) [left] and during the interplanetary voyage [right].
(courtesy Astrium)

bioengineering with traditional space mission design methodology. As mentioned earlier, ESA's Aurora programme is paving the way for technology development targeted in the area of solar system exploration. As part of the initial stages of the programme, Astrium was awarded a support contract to help define the roadmap for such an elaborate exploration initiative. This involved documenting all past and planned missions, identifying key technologies needed for exploration, and developing a number of mission scenarios that satisfy both science goals and the need to prepare for future human exploration. As Aurora enters the next phase, Astrium will remain at the forefront of the programme, elaborating more on the exploration framework and monitoring the SME's selected for technology development. Such close-linked collaboration is imperative for the bright foreseen future to become an even brighter reality.

9. The View from BNSC

David Hall of the British National Space Centre outlined the ESA Aurora programme, its vision, the strong robotics component and the UK's activity within it. He reported that the long-term goal of the programme is human exploration of the solar system. However, human exploration will not start until about 25 years from now. In the meantime, the capabilities for robotics may well render the use of humans unnecessary for science and technology objectives. The justification for human exploration would be political and cultural. The UK anticipates that the Aurora programme would place considerable emphasis on robotic activities in the early years, building on the first European steps towards robotic exploration taking place already through the ESA Huygens, Rosetta and Mars Express missions and the "Netlanders" of France. In the short term, the UK would like to see the target of the programme being return of samples from asteroids and Mars. This yields major science benefits as well as providing a major technology driver for the longer term objective of human exploration.

10. The View from Several Delegates

After the discussion group reports by the facilitators, Dr Chris Welch of Kingston University summarised the results of the meeting and to point the way ahead. The most tangible conclusion was that the Space & Planetary Robotics Network is something whose time has come.

Many of the delegates had interesting points to make concerning the meeting. During breaks in the workshop programme Prof Alan Winfield gave a number of live demonstrations of the LinuxBot. Developed at UWE Bristol's Intelligent Autonomous Systems (IAS) Laboratory for conducting experiments in collective mobile robotics, the LinuxBot was demonstrated being tele-operated from a laptop computer, using standard Internet Protocols over an ad-hoc wireless network; an onboard digital camera provided the remote operator with the robot's eye view – see fig. 9. The IAS lab has developed a Linux-based software and communications architecture for mobile robots, and is currently working on a hardware-independent Robot Application Programmers Interface. Winfield believes that, uniquely, this approach allows us to build very small and power efficient mobile robots without having to compromise on networking or other high-level tools and capabilities, at a very low cost in software development effort. The IAS lab has, for instance, built and demonstrated a 5cm mobile robot, running a Web server, which con-

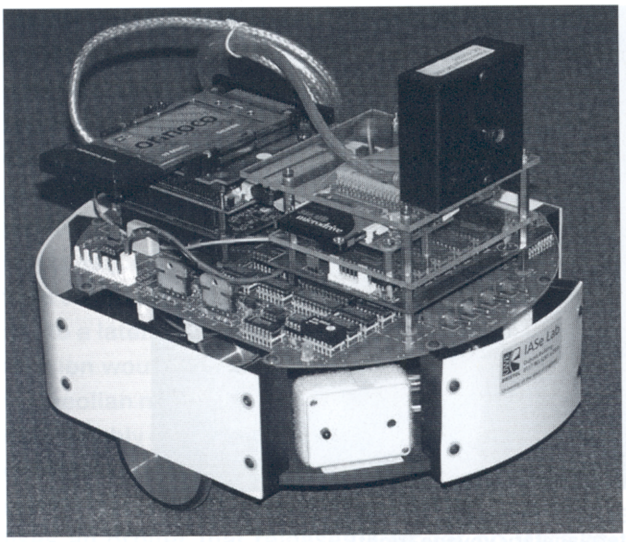

Fig. 9 The proposed SPRN robotic testbed - IAS Linuxbot. (courtesy Alan Winfield)

sumes just 1 Watt. The LinuxBot was offered to the Space & Planetary Robotics Network as a potential R&D platform for allowing groups in the network to work and collaborate on different software and communications modules of a planetary micro-rover testbed in a way that would facilitate integration.

Colin McInnes of Glasgow University noted that path planning will present unique challenges for planetary robotics, possibly requiring traditional deterministic planners (such as potential field methods) to be integrated with local reactive behaviours in order to cope with uncertainties in the workspace. Analogies with biological systems may well prove valuable, such as the use of sun compassing. This last is indeed an area in which Kingston University is beginning to become active – biomimetic robotics.

The challenges of remote operation on Mars - in particular long communication delay times, brittle, low bandwidth communication links and limited information feedback to the human operator on earth - suggest that semi-autonomous or autonomous operation of a rover would be beneficial. Competences (low-level sensor-motor competences as well as higher-level navigation and planning competences) should be acquired through robot-environment interaction, rather than being pre-programmed, for two reasons: (i) the human programmer, guided by his experience of the world, may not be able to exploit the robot's perceptual capabilities in the best way possible, and (ii) he may make assumptions regarding the robot's capabilities that do not hold true in practice. Both problems can be avoided by using learning controllers. The research carried out by Ulrich Nehmzow (University of Essex) demonstrates that it is possible to use learning controllers, based on artificial neural networks, to guide autonomous mobile robots in sensor motor tasks such as obstacle avoidance, contour following, approaching attractors (targets), traversal of narrow passages, as well as in navigational tasks such as route learning, homing, mapbuilding and free path planning and navigation. The proposal for the Vanguard mission is to incorporate such learning capabilities in the rover to achieve behaviour that is more autonomous, robust and reliable than teleoperation would be.

Many attendees had brought along things to show at the meeting, including RolaTube's long tubular booms that can be stored in a compact roll and deployed in a controlled fashion – this technology has great potential for spacecraft boom-deployment. Several displays, working models and exhibits were set up in the exhibition area, including models of the Endurance micro-rover, the Viking Lander, Phobos 2 and Sojourner. Mat Irvine (model-maker, author and technical consultant) also brought along the original working prop of K-9, the robotic dog from *Doctor Who*. With K-9's affirmative support the UK surely has a bright future in space and planetary robotics!

11. Conclusions

Space robotics is a discipline whose time has come. One of the strongest messages from the meeting was amazement that this research was happening in the UK. The corollary was that there had not been enough communication between the scientists who want to place their instruments onto other planets, and the engineers who can get them there. One planetary scientist had remarked that he hadn't realised that the robotics community had been doing things that they needed. Furthermore, there had not been enough communication between industry, academia and the national/international space agencies in the past. Dr Mark Smith of Astrium had stated that he had not been aware of the activities of the academic robotics community. This will now change. At the very least, we know of each other and what each group is doing. Our greatest hope is that we can collaborate together to make the UK one of the centres of expertise in planetary and space robotics in Europe. We certainly have the skills and expertise. We just need the will and the framework through which to build our collaboration. At least one representative from ESA was present who I am sure will be relaying a message to ESA that the UK is about to become a major participant in space robotics.

As to the future, the Space & Planetary Robotics Network will be holding a series of focussed workshops to consolidate our work. We will be applying for EPSRC Network funding to support our initial activities. The first workshop was held in early September at Aberystwyth University hosted by Dave Barnes and was a resounding success further illustrating the UK's activities in space and planetary robotics. Subsequent workshops will follow. A report by the UK SPRN on the state of UK Space Robotics activities has been submitted to the British National Space Centre declaring Space Robotics as a UK core skill. Furthermore, a web-based UK Space & Planetary Robotics forum will be established to enable new members to participate – it will be open to anyone with professional interest in this work. Anyone who is interested in becoming involved in this exciting new area of engineering is invited to contact Alex Ellery (a.ellery@kingston.ac.uk) to state their area of interest and will be added to the email distribution list to ensure their future participation.

12. Acknowledgements

The authors would like to thank Rodney Buckland and Dave Barnes for their stirling efforts in realising the inaugural meeting and first workshop respectively. The primary author (Ellery) would like to dedicate this article to the late David Wynn-Williams of the British Antarctic Survey without whose encouragement the SPRN may not have formed.

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