Publ. Astron. Soc. Aust., 2000, 17, 119–124

The Future of Robotic Telescopes for Education

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Received 1999 October 1, accepted 2000 May 3

Abstract: The development of robotic telescopes for education is reviewed. The problems associated with providing a service for students at different levels of education are discussed. Consideration is made of the hardware requirements in the students' institution and the compromises that are made to allow the maximum number of students to use facilities. The demands on teachers are considered along with the available methods of delivering educational projects related to curricular demands at the various stages. The likely developments in the technology are considered and estimates made of the probable timescales. Proposals are made to optimise student access to observing facilities that would involve the development of a linux-like collaboration around astronomy software and the development of low cost telescope systems. Proposals are made to realise such systems with the objective of providing universal access for students with Internet access.

Keywords: robot telescopes—instrumentation—astronomy education—internet access—real-time observing—remote observing

1 History and Developments

The first call (Bok 1955) for the development of a 'small automatic monitoring telescope' was made by Bart J. Bok in 1955. The earliest telescope automation was used for tedious, time consuming and uncomplicated photometry, e.g. in the provision of standards for photographic plates (Reddish 1966) and the study of variable stars (Maran 1967). The objective of this work was to automate the photometric process which collected light from a star centred in an aperture and counted photons with a photomultiplier tube. This process required data to be collected from the target star, one or preferably two standards, and from nearby comparator stars, all of a colour and magnitude similar to the target and yet known to be reasonably stable, i.e. without variability. The observation process then requires the telescope to take a stream of repeated observations of the target object, the sky background, the standard star and the comparators through the range of required filters. The objective was to compensate for the sky background and the varying levels of atmospheric extinction as the air mass changes with the Earth's rotation, and so derive the magnitudes in the different colours with respect to the standards.

This process was an ideal candidate for automation, and others followed the early work of Reddish and Maran. In the 1980s Martin & Hartley (1985) evaluated the remote control of a telescope using the telephone system to link a local computer to the remote computer controlling the telescope. These early aspirations never defeated the complexities of a remote multi-tasking system. A survey in the late 1980s had listed seventy projects that would benefit from robotic observing and a robot telescope was recommended for the UK astronomical community by Mitchell (1989). In the early 1990s the first effective robotic telescope was operated by a team at the University of Bradford in the UK (Baruch 1992). The Bradford system was built as a technology prover to demonstrate how to service the observing requirements that had been outlined by the UK professional astronomical community as appropriate for a robotic telescope. The telescope was funded by the UK Particle Physics and Astronomy Research Council.

A key development that was not envisaged by the early enthusiasts for automatic and robotic telescopes, and that had matured by the late 1980s, was the cooled CCD camera optimised for astronomical observations. The CCD camera is an area device that can be used for comparative stellar photometry of the different point objects within a single field. For fields of about ten arcminutes square, there are generally at least two twelfth magnitude objects, and even for fields far from the Galactic plane these are accompanied by many more fainter stars.

The Bradford team clearly defined their robotic telescope system as an 'autonomous observing system for photometry' which, apart from regular servicing, requires no human intervention to respond to the observing requests that it receives. In particular, this means that the telescope is surrounded by a system of environmental monitors linked to a protective enclosure which ensures that the telescope is not damaged by the weather (e.g. wind, rain and snow) or stressed by exposure to sunlight, and that it is protected from unwelcome human visitors. It also used environmental monitoring and schedulers to exploit observing conditions to the full. This required the development of effective cloud, dew and humidity sensors to supplement the standard rain, wind, lightning and pressure sensors. These environmental monitors were linked to the enclosure control system which gave a positive confirmation to the telescope system that conditions for observing were suitable or the system was safely garaged and protected from the weather and failed-safe when power was lost.

 10.1071/AS00029 1323-3580/00/020119$05.00

The telescope system generated an observing schedule based on weather conditions, the time of the start of the observing run and the priority given to the particular observing requests. CCD images of the required fields were recorded in FITS format which included extensive details of the CCD camera, filters, exposure time and weather conditions at the time of the observations. The FITS files were then transmitted to the base station over an ISDN telephone link.

The base station provided an interface to the outside world. The base station received observing requests, generated a macro observing schedule for the telescope, archived the observations when they were returned by the telescope and emailed to the user to inform him or her where they could access their observations.

The system was inaugurated in December 1993.

2 The Bradford Experience

The Bradford Robotic Telescope was installed at the University of Bradford experimental site in the Yorkshire Pennines between Haworth and Hebden Bridge at an altitude of 440 metres and a latitude of 53 degrees 47 minutes North. In the first month the requests from school students and teachers exceeded by a factor of 10 the requests from professional astronomers. Students and teachers were interested in the Moon, the Planets and the objects in the sky that had attracted the attention of the media. Many of these requests could be serviced by observations taken in a few clear hours each night. The professional astronomers were interested in variables of all types, from eruptive completely unpredictable systems like the gamma-bursters and the cataclysmic variables through Cepheids to the long period Mira and quasar variables. The weather in the English Pennines is unsuitable for the regular observation of variables on any but the longest time scale and, at the time of the telescope coming on stream, many of the professional astronomical community moved their priorities into the arena of 8 m telescopes and space observatories. It was the teachers and students at schools and universities, along with undergraduates and research students, who maintained an enthusiastic interest in astronomy with robotic telescopes.

The Bradford team, which had not previously been concerned with the processes of education, found themselves invited to numerous education conferences. They were also subject to a growing chorus of requests for collaboration in the development of teaching resources to support the use of the robotic telescope in the classroom and to deliver data for student projects up to and including degree level. The team made links with the major UK science education groups through conference presentations and joint projects that exploited the enthusiasm of large numbers of active teachers. Collaborations were built with the UK association for Science Education; the Institute of Physics, the Nuffield Foundation, the Gatsby Trust and the Sheffield Hallam University Pupil Researcher Initiative, funded by the UK Engineering and Physical Sciences Research Council and the Particle Physics and Astronomy Research Council. Collaborations and funded research projects were developed to use the robotic telescope for curriculum based learning experiences for under 12s, under 14s, under 16s and under 18 year-olds.

Further projects investigated how students could pursue real research projects using the telescope. PhD programmes were supported to investigate how remote access to real systems supported the learning process and the contribution that could be made to learning by replacing reality with increasing levels of virtual reality delivered through cyberspace or from a local CD-ROM. A second telescope project in the Canary Islands investigated whether the cost of the system could be dramatically reduced from £350k to £50k and still provide a valuable resource for teaching and research.

The telescope system evolved to provide a number of basic services, which exploited the autonomous nature of the robot and its rapid processing of observing requests. Initial ideas about the way the telescope would operate were modified. The initial objective of providing comparative photometry with the CCD images being processed at the telescope was sidelined. Everyone wanted the original image. The initial idea was that astronomers would only want the reduced data accompanied by enough supporting information to convince them that the process had been performed within defined limits, all of which were inserted into the FITS file header. It was the images that school users wanted and the tools to process the images themselves. These were provided.

The normal mode of operation is termed Service Observing. The pool of observing requests is used to generate a schedule for each night. This schedule is transferred to the telescope each evening. The telescope is normally in a condition of waiting until the conditions are suitable for observing, at that point it generates a micro-schedule and starts observing. The micro-schedule re-evaluates the priorities of the observing requests ensuring that objects are observed before they set and the highest priority objects are observed first, before the conditions deteriorate or the dawn makes observing impossible. At the end of the night the images in the FITS format along with the details of the images are transferred to their data archiving location. The user is then informed by email and invited to view their requested observations.

The other new requirement partially generated by the media was to drive the telescope remotely. This created new challenges and opportunities, with a 56 kbaud link to the telescope, it took about 40 seconds for complete single images to appear on the screen of the user. The telescope worked much more rapidly than single users could view the images and generate new requests. If the scheduler gave an overriding priority to a single user the telescope responded much faster than the single user could generate new requests. The telescope could accept

https://doi.org/10.1071/AS00119 Published online by Cambridge University Press

a number of individual users simultaneously who each made observing requests to the telescope and received a service that gave the impression to each user that they were controlling the telescope. In this way the telescope behaves as an autonomous robot responding to its users and operating within the constraints of its environment.

The services offered by the telescope system are:

- Service observing, the normal mode of operation where a request is serviced as soon as it can be, the data are archived and the user informed of their location.
- Prompt observing, where the telescope responds in real time to the user. This requires the user to log on when it is dark and the sky is clear at the telescope site.
- A series of projects generally suitable for the teaching of astronomy but related to the UK national curriculum and including research projects with archived satellite data.
- Archived data.
- Discussion areas.

The whole basis of this provision and the research associated with it is to enable the largest number of people to benefit from the resources by using the telescope to the maximum for every second that the environmental conditions are appropriate with a clear sky and a windspeed low enough to allow effective operation of the telescope. This approach differs significantly from that of other teams in the USA. Typically the Mount Wilson Observatory allocate their telescope to a school or group of users for half the night and it is then up to the users to obtain their data.

3 Why a Robotic Telescope?

The origins of the Bradford Robotic Telescope lie in a research programme to understand the mechanisms behind eruptive variables, especially gamma-ray bursters and cataclysmic variables. These research interests are still active but have been supplemented by the development of robotic telescopes for education.

The reasons for the eruptive variables programme were clear, but supplementing this programme required us to revisit our aims and objectives to ensure that the allocation of resources could be justified and to inform our funding applications. It is clear that the major science funding bodies are reflecting a government concern with the falling number and quality, in terms of A-level scores, of the undergraduate students in the physical sciences, mathematics and engineering and with a faltering public acceptance and support for science and science funding.

There is little doubt that astronomy along with amateur radio introduces young people to science and engineering and is a key motivator in bringing young people into science and maths at school. It gives them rewarding experiences and encourages them to choose a career in science, maths and engineering. The universal accessibility of astronomy in particular provides a potential tool to redress the failure of society to encourage young women in the UK to choose a career in the sciences. In all these areas there is a serious loss of talent that can only make the sciences the poorer and compromise the achievement of economic objectives.

It is the accessibility of the Sun, Moon and stars and the counter intuitive nature of reality that raises questions in the minds of young people, but not only the young. Access to a robotic telescope coupled with projects, explanations and activities can do much to dispel confused and mistaken ideas and bring the wonder and beauty of our planet and the surrounding Universe into active and enquiring minds. Access to the telescope reinforces the reality by supporting student centred learning processes in which the student interacts with and evaluates the real world.

4 Role of Robotic Telescopes

It is not easy to provide access to the stars with a telescope at normal daytime school. The stars come out at night. There are problems of students working after school. Many students need transport and they often have responsibilities at home or in the community when they have finished school. Even the best laid plans are invariably confused by unpredictable weather conditions which require planning to be made only a few hours in advance, a luxury not available to most students. Robotic telescopes avoid these problems. To access the Moon or any other object in the sky with a robotic telescope, it is only necessary to select the object from a catalogue. The telescope will set defaults for everything else. These defaults are easily over-ridden if specific filters, exposures or observing times are required. This robotic system thus removes any necessity for the student to know about the details of stellar coordinates and motions or the setting of clocks. The complex process of acquiring the object by the telescope is automated and the astronomy is made much more accessible. Of course for those who wish to follow the process manually, all the elements of telescope pointing and tracking are displayed in the default values and the FITS headers on the generated images.

It is the development of the telescope as an autonomous robot, i.e. one that responds to high level commands, e.g. 'Moon', that makes astronomy accessible to the widest range of students and teachers. In the UK, the National Curriculum and the system of exams at 16 and 18 years of age include aspects of science that can easily be delivered through astronomy. Only A-level examinations taken at 18 include an astronomy elective. In the UK, teachers no longer have the luxury of deciding what to teach. They have a degree of flexibility in deciding how to teach, but the innovative inspirational teacher who excited and motivated generations of students with journeys into the unknown has been hobbled and hamstrung by a deluge of paperwork. Teaching is now focused on checklists and reports that have driven many out of the profession but have

https://doi.org/10.1071/AS00119 Published online by Cambridge University Press

also provided a set of crutches to support teachers who are striving with the new and often working outside their areas of prime expertise.

If astronomy is to be brought into the classroom through access to robotic telescopes, it is essential that teachers are provided with an array of high quality project and learning resources relevant to the specific student curriculum. In this way the teacher can select appropriate material for each group of students supplemented with enough material to ensure that those at the extremes of the class ability range are challenged and rewarded by their work. But this is not enough. The normal teaching load with the vast input of additional time required from teachers who aim to deliver interesting lessons and meet the requirements of the bureaucracy means that few teachers will step outside the tramlines of convention.

It is necessary to reward teachers who invest even more of their personal time in their work by reducing and automating the administrative process of delivering the paperwork necessary to satisfy the bureaucracy. It has been impressed upon the group that such are the starting requirements of educational projects that will make robotic telescopes accessible to students in the normal classroom. It is clear that some students will access the telescope from clubs in astronomy, science, technology, computing or engineering run outside the curriculum at lunchtime or after school. Recognition of this leads to the provision of supplementary student projects.

Much more common is the teacher who is not an amateur astronomer and who was not trained as an astronomer or a physicist and who requires focused support appropriate to building confidence to the level necessary for innovation.

With educational projects set in this environment it is hoped to build a growing constituency of English speaking users through a series of training workshops. Such a programme of work should provide a basis on which there can be similar high grade learning material for Scottish, Irish, Spanish and other cohorts of European students.

It is clear that from such a base the material can be expanded to support teacher training, and undergraduate programmes to help the teaching of astronomy to non-scientists and to scientists, technologists and engineers who are not majoring in astronomy. All this is not expected to make excessive demands on the telescope time since the students will move along well recognised paths and single observations will be relevant to many users on many different programmes.

Research programmes pose different problems, whether for the 16- plus student at school, the undergraduate physicist or astronomer or trainee teacher. The major research opportunity is to work with data from the non-visible wavebands that can be associated with observations in the visible wavebands to ascertain the cause of variability. In the radio wavebands there are catalogues of quasars and stellar objects such as those observed by the UK Merlin project. There are similar catalogues from many satellites working in the infrared through to the gamma-ray wavelengths. A first evaluation of the provision of such research projects in the classroom has proved very positive. For classroom projects the telescope observing time requirement increases linearly with the number of schools involved. There is also a significant overhead required from the centre to provide study frameworks and support material to make the catalogues and their underlying science accessible to students.

For undergraduate projects at final year level and to provide support for postgraduate students it is probable that each institution will have to provide their own robotic telescope.

5 The Normal School/University and Future Trends

The common concept of using a robotic telescope is that one person uses a computer to drive the telescope and await the results. This is the method that has been developed in the USA and a good example is the Telescopes in Education Programme at the Mount Wilson telescope in the USA (see http://www.profjohn.com/see/tie.htm). Similarly, access to a completely robotic telescope in the normal classroom could be delivered to one user, either singly or representing the class, e.g. the teacher, working on behalf of the class.

At the present time the link a school has to the Internet is normally a single 56 kbaud telephone-line connection. This provides an adequate link for one or possibly two people to use the Internet at the same time, but with more than two students, their individual access will be dominated by the capacity of this single link and they will start to be frustrated and feel their time is being wasted. It is therefore not possible to link a whole class through such a link unless the multiple use and the data access is organised differently. It is possible that future developments will change this, but the numbers are daunting. In a pedagogical sense there is much benefit to be derived from collaborations or small group efforts which fits in with a low bandwidth link to the Internet.

For the future, if one person requires a 20 kbaud link then a class of thirty requires 600 kbaud and a school of 1000 pupils with only one day per week on the Internet would require the equivalent of a TV channel of 4 Mbaud. Such links are currently very expensive and a normal school would not be able fund such services. It is likely that there will be extreme pressure to reduce the cost of such links and make them the norm through the leisure industry interest in TV-on-demand, which would give a 4 Mbaud link one way supported by a 56 kbaud return. Unless schools are exchanging real time video, this would support 1000 pupils typing at 20 characters per minute whilst viewing Internet pages.

Current estimates are that it will be five years before such links will be available to the normal user. Schools with their limited budgets will have to wait and, in the mean time, effective delivery of the Internet to the students will rely on various tricks and data compression or they will be required to share.

The Bradford Robotic Telescope programme is mainly targeted at service observing and providing images for large numbers of users. The request process requires only a small amount of data to be transmitted. The system obtains single images of the moon, planets and major objects every night. Where students have overridden the default parameter values additional images will be taken, but most students use the standard nightly images. It is intended to provide software to support the users' browsers that will first look at the local server to see if the required image has been downloaded already. In this way large numbers of users can be satisfied.

6 A World Wide Web of Telescopes

The telescope systems with the supporting projects and software, all of which have been developed by the Bradford Engineering in Astronomy Group, form the basis for delivering astronomy to the classroom with robotic telescopes placed on good sites. If the students are only interested in service observing, it does not matter where the site is, provided that there is a high probability of clear skies every night.

With growing interest in on-line access to the night sky it is necessary to place robotic telescopes on appropriate good sites. The Great Dividing Range of mountains along the Australian east coast provides an ideal site for a telescope to provide images for the UK and Europe in the time zones between eight and ten hours behind, and for the USA with time zones between seven and ten hours ahead, but a day behind. The Australian east coast is accessible from Sydney and Melbourne and is ten hours in advance of GMT. It provides a location that is dark for school students in Los Angeles and the US west coast during school morning. It provides a dark location for the whole school day for the US east coast and western Europe. It is dark in the Great Dividing Range during afternoon school hours in eastern Europe.

For observations requested during the Northern Hemisphere winter, the daylight saving time in Australia makes little difference and in the Northern Hemisphere summer, the longer nights in the Southern Hemisphere winter compensate for the northern clocks being put forward by an hour.

A telescope placed on a good site in Europe, e.g. the Canary Islands, could provide a similar service for Australia, New Zealand and Japan. As the programme builds up momentum, it is likely that the most enthusiastic and demanding students will be those developing their own research programmes. It is their enthusiasm and commitment that brings in other students and puts science at the top of the interest agenda for their peers. It is unlikely that a single telescope could provide the necessary resources for long, and ways will have to be found for using the resource more efficiently, for rationing it, or expanding it especially for the groups of students pursuing their own research programmes.

One method of using the resource more efficiently is to share the data and share the ideas concerning its significance. This would require a conferencing area on the Web site. What little has been seen of students sharing data and ideas, whether in different institutions in the same city, in the same country or just with a common language, indicates that it is an extremely motivating experience. Sharing data in a conference area on a Web server does require professional moderation and help, and the restrictive nature of guiding the discussion can undermine the objective of allowing the students to find out for themselves.

It must be recognised that a popular resource will always be rationed in one sense or another. Widespread use of robotic telescopes will require there to be a low cost source of robotic telescopes that enthusiastic groups can acquire for their students. Considerable time has been expended by the Bradford group to develop such a low cost robotic telescope. It has been called the model 'T' telescope after the early Ford motorcar that revolutionised personal transport in the USA. In this paper it is only possible to give a broad outline of the conclusions; a more detailed paper has yet to be completed.

7 A Model 'T' Telescope

It has been recognised that the lower the cost of the telescope system, the larger the number built and the larger the number of people using them to access the stars. The model 'T' telescope is designed to exploit the best of modern materials and design with the aim of providing a precise system optimised for comparative photometry with CCDs. The objective is to provide a route into astronomy that is not normally available at the price. The target has been to deliver a one metre telescope for about £250,000, that is a 'plug and play' peripheral to the Internet, to use an analogy from the world of computing peripherals. The telescope site is prepared with a suitable base for the enclosure and the telescope mount accompanied by a supply of electricity, with a connection to the Internet and a telephone.

The project is to provide the detailed drawings and construction plans to an institution to enable the telescope to be made through the available facilities. The design envisages that the whole telescope system includes a container for transport that is part of its enclosure at the observatory site. The container enclosure opens up when the weather is suitable for observing. The system can be completely assembled in the workshop and tested. The system is then ready for transport inside its container and ready for operation when it arrives at the observing site. All that is required is for the enclosure and the telescope to be attached to the base and the electricity, Internet and telephone connected.

It is important to recognise that any telescope system will have a considerable lifetime. If it attracts an enthusiastic cohort of users there will be many ideas for changing the system and improving it. Systems that make such change possible enable the users to develop new and innovative research programmes feeding their enthusiasm. The main changes that can arise with the hardware are the addition of further instruments and detectors to a basic system that can point to any part of the sky and follow the rotation of the earth with small corrections for the movement of the Moon, comets or planetoids. These additions to the hardware must be supported by software with further requirements to change the way the system operates or processes data. All this is in the software and so most additional work will probably be in the software.

8 Telescope Software

Most telescope manufacturers provide a system in which the software is completely defined and only restricted, if any, changes are allowed by the user. The user is always free to contact the manufacturer and pay for an upgrade or the development of a new facility in the software. This is most unsuitable for educational institutions, which are generally short of funds, but brimming over with enthusiasm and talent of varying quality. The model ‘T’ telescope must be able to use this considerable resource to the benefit of all and it is suggested that the form of software development that has produced the linux operating system provides an excellent model.

First it necessary to set up the basic telescope system that can accept innovation and development. It is assumed that this system will be based on the IBM personal computer standard. Not that this is the best possible, but it is the lowest cost industry standard system and there is a profusion of peripherals and plug-in cards available to run a host of instruments and sensors to work with the telescope. With the pentium versions of the PC, networking them and linking them to the Internet with TCP/IP software is standard practice with low cost, easily available networking cards and software.

The basic telescope software system is the operating system. It is the robustness of this system that underpins the whole of the telescope operations. The system needs to be multi-tasking and support multiple computers with a TCP/IP facility. Early work used a system based on Microsoft DOS which is no longer available and is not compatible with modern operating systems or the plug-in cards that support systems like the telescope drives, sensors and cameras. Later versions of Microsoft Windows and NT have not completely solved these problems and more importantly do not display a significant improvement in robustness and require regular rebooting. This is not desirable, but it should be installed for automatic and remote operation over the telephone link to cover all situations and emergencies.

It has been found that the only robust operating system is UNIX. UNIX has one additional advantage and that is that it has a number of public domain variants which are available at low cost, especially the linux variant. Linux has advantages over other versions of UNIX. The main disadvantage of UNIX is that the PC plug-ins rarely have drivers for UNIX operating systems and intermediate computer interfaces have to be used or drivers written. Linux has now become so popular that there is a growing constituency of peripherals and plug-in card systems for PCs that include linux drivers and interfaces.

The linux operating system is available ‘code free’, i.e. with all the basic software coding. Linux is one of the few operating systems where it is possible to add and integrate new operating functions to the telescope system relatively easily. Linux has been developed by enthusiastic computer professionals and is available for further development and improvement over the Internet (see e.g. http://www.linux.com/) and thousands of related sites. It is now highly successful and this method of software and system development is recommended for telescope system software and all the associated peripherals and drives.

This linux approach means that new software additions can be made generally available. New users can try them, comment on them and add and improve them. This approach of making all the telescope systems available means that as the number of robotic telescopes increases along with the number of people interested in developing software for them, then the quality and diversity of the available software will increase way beyond anything that a commercial organisation could provide. The present Bradford telescope systems are in the process of being converted to UNIX operating systems.

9 A Base for Collaborations

Supporting the development of the telescope it is necessary to run an Internet site accepting the requests, distributing observing schedules to telescopes and sending email notification to the observer requesting the data when the images are available and the location from which the images can be obtained. This facility is already available at http://www.telescope.org/ and can easily be made available to collaborators as http://www.collaborator.telescope.org/. The Bradford group is prepared to share this facility with others for the mutual benefit of all, reducing the probability that cloud on one site will undermine the acquisition of data.

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