Remote laboratory and animal behaviour: An interactive open field system

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Received 3 November 2005; received in revised form 26 January 2006; accepted 17 February 2006

Abstract

Remote laboratories can provide distant learners with practical acquisitions which would otherwise remain precluded. Our proposal here is a remote laboratory on a behavioural test (open field test), with the aim of introducing learners to the observation and analysis of stereotyped behaviour in animals. A real-time video of a mouse in an experimental arena is streamed over the Internet from a server computer connected with the laboratory apparatus to a client computer managed by an instructor. Learners observe the video projected by the client computer and record on their PCs the positions of the mouse in the arena and the behavioural patterns produced. Input–output interactions with the test apparatus are made possible by a remote, concurrently operated digital interface. Learners’ recordings can be individually and collectively analysed, to assess behavioural trends and effects induced by client-commanded experimental treatments; the quality and the improvements in accuracy of the learners’ recordings can also be estimated. A first implementation of the remote laboratory, carried out on two groups of undergraduate students, gave positive indications on the feasibility and the efficiency of the project, and on its didactic efficacy.

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Keywords: Computer-mediated communication; Distance education and telelearning; Media in education; Post-secondary education

1. Introduction

Laboratory activities implemented using the Web as a primary interface medium have undergone a large development in the last years, mainly due to the rapid evolution of Web technologies. Projects and proposals are now numerous, and involve the activity of many centres and consortia.

In the first place, the possibility of accessing distant laboratories is interesting in the field of distance education, where it can be a compensation for the well-recognized difficulties in attaining adequate acquisitions of practical skills and knowledge.

A converging interest in the use of laboratories accessible through the Web originates from more traditional educational situations, when direct involvement in practical activities is difficult or dangerous, owing to potentially harmful or uncomfortable conditions.

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Implementing distant laboratories can provide further advantages if practical activities require expensive or rare equipment, or are technically complex and need specialized personnel. A distant laboratory may be shared by a large number of users, located in different places, so consequently the costs pro capite can be reduced; moreover, concentrating efforts and resources in a specialized site may boost quality and effectiveness.

High-quality distant laboratories may also draw the attention of researchers who need rare instrumentations or carry out particular types of experiments. This might turn a distant laboratory into a centre for specialized services, in which activities tailored to specific demands would be added to the more obvious – and presumably prevailing, at least in the next future – educational applications.

Descriptions of distant laboratories can be found in Internet or in educational journals (Cartwright & Valentine, 2002; Casini, Prattichizzo, & Vicino, 2001; Esche, Chassapis, Nazalewicz, & Hromin, 2003; Scanlon, Colwell, Cooper, & Di Paolo, 2004; Shen et al., 1999; Tan, Lee, & Leu, 2000). Their development is mainly due to physicists, computer scientists and chemists. Less attention has been paid to life sciences, mainly due to the difficulty in experimentation linked to the complexity and unpredictability of the biological material, and possibly also to lesser attraction exerted on biologists by this type of approach.

The project that we present in this paper concerns a life science sector – the study of animal behaviour – which has noticeable educational relevance but might appear particularly exposed to the above-mentioned difficulties. As we will try to show, this is not necessarily true, however, and some types of implementation in this sector may even outperform more traditional solutions.

The project that we present in this paper concerns a life science sector – the study of animal behaviour – which has noticeable educational relevance but might appear particularly exposed to the above-mentioned difficulties. As we will try to show, this is not necessarily true, however, and some types of implementation in this sector may even outperform more traditional solutions.

The proposal is based on an experimental test denoted as “open field”. This is a standard procedure, in which the locomotor activity and the behavioural patterns produced by a rodent moving freely in a delimited space (“arena”) are recorded and analysed in relation to behavioural traits or states, and also to variations induced by a number of factors, such as habituation, stress, or the action of drugs.

In our project, real-time video of the behavioural activity is transmitted over the Internet to the learners, who record and analyse displacements in the arena and behavioural patterns produced, and can also interact with the experimental apparatus through commands mediated by a general-purpose interface.

The project proposed is rather demanding as to bandwidth requirements, and is therefore better implemented if broadband Internet connection or access to a high-speed network are available. On the other hand, the application is designed to be compatible with limited budgets; it is based on commercially current or easy-to-build hardware and instrumentation, and on freeware or programs written in high-level language.

The project includes a validation phase. At present, this has been carried out exhaustively on the structure and effectiveness of the hardware and software, and to a lesser extent on the educational functionality of the system, thanks to a first realization of the distant open field test, with a class of third-year, undergraduate students.

2. Description of the project

2.1. Summary of the project

A mouse moves freely in a square arena subdivided into sectors.

A video camera pointing to the arena is connected to a server computer: the latter transmits the video to a client computer, managed by an instructor. A digital I/O interface connects the server to the experimental set-up.

The client computer visualizes, on its monitor and on a screen by means of a projector, the real-time video transmitted, together with the graphical display for remote management of the I/O interface.

The learners, using their PCs, record the arena sectors entered and the behavioural patterns produced by the mouse.

The experimental situation in the arena can be modified by the client computer through the digital interface (as detailed below).

The data recorded are then individually analysed by each learner, and are also fed to the instructor’s computer, where pooling, global statistics and further analyses are carried out.

A schematic representation of the system is given in Fig. 1.
2.2. Open field set-up

The open-field used is a 60 × 60 cm square arena with 15 cm high walls. It is subdivided into 16 square sectors labelled by letters. A male laboratory mouse is placed in the centre, covered by a small dome which is pulled up by an operator when the learners’ recording activity begins.

A video camera is positioned at about 1.5 m above the arena, immediately inside the vertical projection of a wall, covering the entire view of the arena.

2.3. Real-time video streaming and interactivity

2.3.1. Hardware

The server computer, equipped with Intel Pentium 4 processor, is connected with a video camera (Sony TRV-8) through the S-video input connector of an analog acquisition board (Pinnacle Studio PCTV/RAVE); the streaming video is transmitted to the client computer by means of a network adapter (3com905b-tx 10/100).

The server is also equipped, through the parallel port, with a digital I/O interface, which provides five input pins and eight output pins; these may be connected to sensors and actuators of the experimental set-up.

The client computer is located in the classroom and is managed by the instructor. The learners can view a copy of the computer monitor projected onto a large screen on the wall.

2.3.2. Software

The video stream is transmitted and received by means of the free software “VideoLAN VLC” for Windows. VLC started as a student project at the French École Centrale Paris but is now a worldwide project with developers in 20 countries.

The modalities of transmission are established at server side. The parameters adopted are the following: 640 × 480 pixel video resolution, 25 frames/s, 2¹⁵ colours, and 3 Mbit/s bit rate, mp4v video compression format.

Interactions through the digital interface are made possible by two programs written in Visual Basic running concurrently with the VideoLAN VLC, at the server and client site.

The server and client computer simultaneously display the streamed video and the graphical I/O interface, respectively located on the left and right hand side of the monitor (detail in Fig. 2). The graphical interfaces at the server and client site are similar, but commands to modify the output pins can only be issued from the client site. A text box displays all input and output variations, as well as short text messages which can be exchanged between server and client.

2.4. Procedures for learners: behavioural recordings

The learners use PCs equipped with software written in Visual Basic for behavioural recordings and individual analysis. Each learner records either the behavioural patterns produced by the animal or the sequence of sectors entered. For the first task (Fig. 3A), the monitor displays six large buttons, each containing the label.
of a type of behaviour associated with a specific colour; for the second task (Fig. 3B), it displays a sketch of the arena, with $4 \times 4$ sectors labelled by letters. The learner “clicks” either on the appropriate button or sector when a behavioural activity begins or a sector is entered; label and time value are stored. The end of a condition is assigned by the successive click, or by the “end of recording” button. If the same button or sector is consecutively “clicked” more than once, the clicks successive to the first one are ignored.

Time zero for the recordings is given by the server, which switches on a LED close to the arena and included in the visual field of the camera, but out of sight of the rodent. This allows synchronization between the learners’ recordings, as well as between the video streaming and the graphical interface.

The data files, in a format suitable to be copied into a spreadsheet program like MS-Excel, are stored inside the learner’s computer and also transmitted to the instructor’s computer: they are stored there in a temporary folder, and then transferred into a protected one.

Learners’ activities include a training phase, and a real-time recording phase.

2.4.1. Training phase

At the beginning of this phase, the software is presented, and the behavioural categories to be recognised are illustrated by short video clips.

After this, the learners are directly involved in recording activity, using three-minute long, archived video clips of the activity of a mouse in the arena. Each learner is alternatively trained in recording behaviours

Fig. 2. Detail of the client computer monitor, including part of the arena and of the graphical I/O interface.

Fig. 3. Graphical interfaces for recording the behavioural patterns (A) and the positions of the mouse in the arena (B).
produced by the animal or sectors entered. The same clips are replicated several times; learners can evaluate their training status and progress by comparing their successive recordings on the same clip, and/or by referring to archived recordings on that clip obtained by well trained operators.

2.4.2. Real-time recording phase

In this phase, the real-time video is transmitted and displayed. A part of the learners are assigned the task of recording the behavioural patterns, the others the sectors entered by the animal. The recording session is subdivided into blocks of three minutes. Between blocks or during a block, modifications of the conditions in the arena may be induced by commands transmitted through the digital I/O interface.

2.5. Behavioural data analysis

2.5.1. Analysis of individual recordings

Once recording activity is over, each learner can visualize and analyse the data collected, using software written in Visual Basic, which includes:

(a) Visual display. Data collected, either on the behaviours produced or on the arena sectors entered, can be visualised. The sequence of behaviours in one block is shown as consecutive segments on a bar, each one coloured by the behaviour-associated colour. The sequence of sectors is visualized on a schematic arena, in a step-by-step mode or all at once, by lines connecting each sector entered with the one following in path; lines are scaled spatially to avoid superposition, and vary progressively in colour.

(b) Analysis of the recordings. The global time and the frequency pertaining to each behavioural pattern and each arena sector entered are evaluated. Evaluations can be limited to single blocks of recordings or extended to sequences of blocks, so as to reveal trends or effects induced by user-commanded experimental variations. Pooling concerning sectors included in a region of interest can be carried out (a classical pooling concerns the four central, or the 12 peripheral sectors).

2.5.2. Analysis of cumulative recordings

This analysis is carried out by the instructor, in collaboration with the learners, using the copies of the individual data files fed to the client computer. It may be applied to the learning phase, too, but it is particularly designed to process the experimental results. It is carried out by software written in Visual Basic.

Data processing includes computation of mean and range of variation. In addition, correlations between behaviours produced and sectors occupied can be investigated.

The cumulative analysis extends the scope of individual analysis, and also provides an estimate of the precision of the evaluations obtained (Caro, Roper, Young, & Dank, 1979). It allows learners to compare their own evaluations with the mean values yielded by the class (although, it should be remarked, the best performance is not necessarily the one closest to the mean).

3. First implementation of the project

The project described here was implemented on two groups of third-year level undergraduate biology students. The first group was composed of 15 students, and the second one of 12.

The type of experimental interaction chosen was rather simple. It consisted in commanding, through the activation of a lever, the overturning of a small container, filled by sawdust scented by the urine of another male and placed above the two right-side sectors of the second and third row of the arena.

Ten consecutive three-minute long video blocks were examined; the container of the sawdust was overturned at the beginning of the sixth block.

Figs. 4 and 5 give examples of the results obtained. Fig. 4 shows the percentage distributions of behavioural patterns, as resulting from the data collected by two of the students (A and B) on the series of 10 blocks. Fig. 5, which also concerns two students (A and B), shows the results pertaining to the sectors entered by the mouse, giving their total numbers as well as the raw and percentage values relevant to the pooled four central sectors and to a region of interest formed by the four sectors lying below the sawdust container.
Indications on the recording performances, obtained by correlating data simultaneously collected by different students, pointed towards a good level of accuracy. For instance, the data shown in Fig. 4, concerning behavioural categories and collected by two of the students, yielded correlation coefficient $R = 0.97$; analogously, the data concerning sectors shown in Fig. 5 yielded $R = 0.98$ for the total arena sectors entered, $R = 0.99$ for the internal sectors, and $R = 0.99$ for the sectors lying below the sawdust container.

It should be noted that, as shown in Figs. 4 and 5, the sawdust fall, remotely produced at the start of the sixth video block, did not result in clear-cut modifications of the behavioural parameters measured.
4. Discussion and conclusion

4.1. Primary and secondary objectives

The open field laboratory described in this paper is intended as an educational contribution concerning a scientific sector, the study of animal behaviour, which, although of considerable interest in itself, is not frequently taken into account under the profile of remote implementation of practical activities.

The main objective is to foster conceptual and procedural understanding of the fundamentals and methodologies of behavioural observation and analysis, also introducing the possibility to meaningfully interact with the experimental object.

The design of the laboratory is oriented by secondary objectives, also. One is the empirical demonstration of the variability and lack of precision which, besides the unavoidable experimental error, affect recordings based on subjective evaluations. This is complemented by the illustration of the improvements in accuracy and stability which can be attained through patient training. In order to maximally emphasize these points, all recordings are left to the “manual” activity of the learners, including tracking of the position of the animal in the arena, which is now usually performed by automatic systems.

Thanks to the implementation through the Web, a further secondary objective can be added, consisting in a familiarization with the technical resources offered by this medium, and in particular with real-time data transmission and instrumental interaction at a distance.

The goals of the project are not negatively affected by a counterpart which is often inherent in remote laboratory activities, namely the lack of an immediate and concrete contact with the experimental environment and its components, or, according to a concise and effective expression, the lack of “the smells of a chemistry laboratory or the physical manipulation of a soldering iron” (Colwell, Scanlon, & Cooper, 2002). In fact, as for the biggest part of behavioural experimentation, a direct contact of the observer with the experimental set-up, far from being advantageous, would be detrimental for the open field test, unintentionally but unavoidably generating interferences and biases.

It should be remarked that, as a consequence of the inopportunity of a direct contact, it might be convenient to implement the remote version of the open field laboratory even if the experimental set-up and the class of learners were both placed inside the same educational institution. In this case, the learners’ classroom and the open field set-up might conveniently be located in two separate, not contiguous sites, and one or the other might be easily and independently moved to a new location, if opportune.

4.2. Validation phases

The validation procedure foreseen for the distant open field laboratory proposed here includes the following phases:

(a) evaluation of the technical aspects linked to the equipment which transmits and receives the video recording and permits the interactions with the experimental set-up;
(b) evaluation of the practical possibility for the learners to carry out the task assigned to them and to obtain meaningful and consistent measures;
(c) evaluation of the conceptual and technical acquisitions attained by the learners, compared with the levels foreseen by the project;
(d) evaluation of the perceived usefulness, ease of use and user acceptance.

The implementation and first application described in this paper yielded positive indications on the feasibility of the project and on its functionality, quite exhaustive for points (a) and (b), more partial and suitable to be developed in depth and width for points (c) and (d). We plan to complete the evaluations of these latter points in the next future, through a replication of the distant open field test, envisaged with a more thoroughly standardized procedure.

Concerning point (a), the parameters chosen for resolution, frame rate, and colour (see Section 2.3.2.) largely exceeded the minimum acceptable values (Kies, Williges, & Rosson, 1997). They were fully respected by
the video streaming, allowing accurate data collection. The experimental interaction was also seamless and carried out regularly, although the effects resulting from the planned treatment were not so clear-cut as we had expected.

As for point (b), activities of the students, both in the training phase and during the real time recordings, went ahead without noticeable difficulties. Data collection occurred with regularity, and usually attained a satisfactory quality; the analyses required more time and were somewhat more laborious than we had hoped, but could be developed to a degree sufficient enough to include the main evaluations.

As for points (c) and (d), overall evaluations obtained from conversations with the students and from final examinations were positive. The guiding principles of the laboratory were generally well understood, and a fair familiarity with the technical aspects was attained. The meaning and aims of the analysis were sufficiently understood. When asked to provide an overall evaluation of the open field laboratory, the students showed a quite positive attitude. Their overall satisfaction, scored on a scale of 0–100, attained a mean value of 86.7, clearly higher than the mean score for the other courses of the same year.

4.3. Improvements and future developments

The first implementation of the distant open field laboratory yielded concrete indications concerning possible modifications and integrations, and further developments.

One of the most important points to be developed consists in assessing more thoroughly that participants have the appropriate theoretical background for an adequate understanding of the general principles underlying and guiding their practical activity, and in providing further support in this sense, if necessary.

The background needed should include at least the following topics:

(i) theoretical foundations on animal behaviour, with particular attention to the production and organization of stereotyped behavioural patterns and to the distribution of activity in space;
(ii) essential concepts of statistical analysis and main guidelines for experimental error estimate;
(iii) fundamental knowledge about computer-assisted experimental systems, computer programs and programming languages, and Web functions.

A brief account on these subjects, possibly resulting from cross-disciplinary collaboration between teachers and aimed at clarifying the purpose of the practical work that is proposed, might be provided; together with practical instructions on the laboratory activities and on the use of the software, it might constitute a useful tutorial for learners.

The training phase should be planned with great care, to allow achievement of the necessary mastery of data recording techniques. To this aim, learning sessions guided by the instructor might be complemented by activity self-managed by the learners, working alone or in small groups. Cooperative learning might allow development of fruitful collaboration and feedback from peers (Strijbos, Martens, & Jochems, 2004). In addition, autonomous activity by the learners could largely compensate for the time limits inherent in the participation of an instructor.

The behavioural analysis might be refined with respect to its present status. The number of behavioural categories might be increased, although not to the point of compromising the ease of actuation. An effort should be made to choose them in a more precise consideration of the ethogram of the species used, to reduce artificiality induced by laboratory conditions.

Data processing might be extended with the addition of sequence analysis, aimed at highlighting preferential locomotor paths or associations between behaviours. Our software does not presently allow this type of analysis, but several programs are available to this purpose.

Interactivity should be more widely exploited, within the limits set by the unavoidable transmission delays. More varied and numerous modifications of the experimental situation might be envisaged, to obtain diversified behavioural effects. The output pins available near the arena could be remotely used to drive up to eight switches, and to command various, possibly combined stimulations. Light, sound, or chemicals stimuli could be chosen to elicit specific behavioural effects, and delivered either with pre-programmed timing or in response
to particular actions performed by the animal. Interaction might also involve the use of analog signals, which could be transmitted by the interface used, after small modifications.

It would be conceivable to extend interactivity, which in the present version is reserved to the instructor’s computer, to the computers used by the learners. However, this would require careful planning of the experimental interventions and of the rules for the interaction, to ensure that the learners’ contributions produce meaningful effects and do not conflict with each other.

Where interactivity extended to the learners’ computers, the tasks of the client computer would become less important. The role of the instructor would become less important, too, and he might be substituted by an operator not necessarily endowed with a thorough knowledge of the laboratory content. Conversely, additional tasks might be assigned to the server computer, which could provide instructions and educational material, and receive, cumulate and analyse the files individually recorded by the learners. The shift of the centre of gravity from the client computer to the final users and to the server computer might offer the possibility to carry out the laboratory activity even with a geographically quite dispersed class, and without the need for qualified assistance at the users’ site.

Finally, the theoretical and practical achievements of the learners and their level of interest and satisfaction should be assessed with a more detailed evaluation, tightly related to the primary and secondary objectives. To this purpose, individual schedules might be adopted usefully, containing a report on the recordings and the analyses carried out, together with the responses given to a questionnaire aimed at testing the acquisition of technical and scientific concepts. An additional, anonymous interview schedule might allow learners to express their level of interest, ease of participation, and general attitude towards the open field laboratory, and to formulate comments, critics and proposals on specific points.

Acknowledgements

We are very grateful to Dr. Paolo Luschi for his valuable contribution to the arrangement and first implementation of the open field test.

References


