Work In Progress – Integrating Undergraduate Research and Education with the TeamTrak Mobile Computing System

Jeffrey Hemmes, Douglas Thain, and Christian Poellabauer
University of Notre Dame, Department of Computer Science and Engineering

jhemmes@nd.edu, dthain@nd.edu, cpoellab@nd.edu

Abstract **- To better prepare undergraduate students for graduate school and careers as computer scientists, we have undertaken an effort to increase both expertise and interest in research through a novel course format. The course weaves an active research project in mobile computing with a senior class on distributed systems. To facilitate the instruction, we use a mobile computing platform, TeamTrak, which consists of tablet computers that collect and display information from sensors such as GPS receivers and share data via an ad-hoc network. Students participate in outdoor field tests as a group and individually design and execute their own measurement experiments and engineering projects.**

Index Terms – Mesh Networking, Mobile Computing, Research/Education Integration, TeamTrak, Sensor Networks

We have begun an effort to increase the level of interest in research and an understanding of and appreciation for the scientific method by integrating a research project in mobile computing with a senior-level class in distributed systems. By participating in an ongoing research effort, students not only gain experience formulating hypotheses and designing and executing experiments, but in the classroom setting we can take advantage of any teachable moments that arise and explain why students observed the results they obtained.

The TeamTrak mobile computing platform [4], shown in Figure 1, is an array of tablet computers augmented with sensors mounted on a helmet. Each node collects sensor data, shares it via an ad-hoc wireless network, and displays the state of the entire network back to the user. Students deploy the system by spreading out across campus, each student carrying one node and its sensors. Each device keeps a second-by-second log of its location, sensor state, and peer data, as well as any specific data of interest for a particular exercise, so that sessions can be archived, re-constructed, and evaluated at a later date, as shown in Figure 2.

We have scheduled a series of outdoor lab exercises using TeamTrak over the course of a semester. Each lab consists of a briefing on the overall problem of interest, the hypothesis to be tested, the procedures to be followed, and the data to be collected. A sample exercise is to arrange the nodes in various configurations, then observe how the routing protocol stabilizes over time. Students initially carry out predesigned exercises but proceed to later design and execute their own.

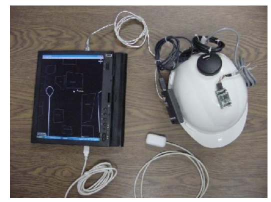

Figure 1 *– The TeamTrak hardware consists of 24 tablet computers, each connected to a pedometer and a sensor helmet mounting GPS, compass, and video camera.*

With this format, we intend to produce these outcomes:

- Improved understanding of distributed algorithms such as routing protocols by access to a tangible example.
- Improved understanding of the scientific method through experiments where the "correct" results are unknown.
- Experience in proposing, conducting, and evaluating experiments and engineering projects in small groups.
- Benefit to the research project by exposing the system to real users and unexpected situations.

A pilot of this course format is taking place in spring 2007. Students complete a series of instructor-led exercises. They also independently design and execute two projects using the TeamTrak equipment: one a quantitative measurement of a sensor or communication device; the other an engineering project in which they design, implement, and evaluate a new capability within the platform.

CLASS EXERCISES

To date we have conducted three class exercises. At the beginning of the semester, students received a lecture describing the system architecture, the routing and network protocols, and possible applications of the system. Each was also issued a tablet computer and sensor devices for the duration of the semester. Before each exercise, students are briefed on the purpose of the exercise, procedure to be followed, and data to be collected by the system. After a short opportunity to download software and get ready, the class proceeds outdoors. After each exercise, students upload their log files for archival. The following class session is used to debrief the students on the exercise, present any results from log data, and collect qualitative feedback from the students.

For example, the first exercise was simply to observe how the TeamTrak routing protocol, very similar in many respects to RIP [6], would work with a fairly large set of devices; something we had not previously attempted. As such, the results were unknown to both the students and the instructor, especially given the system complexity and the number of participants. Initially, students connected their devices to the network and observed a single routing table on the classroom projector screen that displayed the status of each device. In this portion of the exercise, students made two important observations: First, the reliability of the connection in mobile networks is far from what they were ordinarily familiar with their home internet connections or the university clusters. Nodes would regularly disconnect and reconnect at different points, rapidly changing the topology of the network. This was an important demonstration in that it very effectively illustrated one of the fundamental challenges in building mobile systems. The second observation was that the routing protocol demonstrated the "counting to infinity" problem [5] commonly encountered in distance-vector routing protocols. Although this was a flaw in the system, a tangible example of this problem in the students' hands provides a much better starting point for a discussion than a dry explanation on the chalkboard.

Another class exercise tested the system by simulating two common applications of sensor networks, shown in Figure 2: wide area search-and-rescue, and ad-hoc network bridging. The students used TeamTrak to search for the instructor hidden on campus: as some nodes of the network picked up the location, this information was propagated to others, who then converged on the known position. The students were then given instructors to form the longest unbroken network possible. This exercise yielded several observations previously unknown to students or the instructor. (1) Network drop rates were even higher than expected, leading to much stale data in the routing tables and displays. (2) Network connectivity was highly directional: each node has a much greater range in the direction the user is facing. (3) The human factor is very important in the system behavior: as the network topology changes, students naturally move back and forth to reconnect the network. Although each of these observations are easily stated, we hope that learning them first-hand by operating a real system gives a much richer learning experience and will result in long-term retention.

MEASUREMENT PROJECT

In addition to the field exercises, students select a technology used in TeamTrak, then design and conduct a thorough quantitative evaluation of its capabilities. By completing this project, students gain experience applying scientific practices by understanding and evaluating computer systems and communication devices. We encourage students to hone their skills individually as they add to the overall understanding of the system and its components. In this way, they personally benefit from the experience while making a substantive contribution to an active research effort.

For this project, students were expected to use standard practices such as ensuring repeatability of the results and reporting the mean and standard deviations of such, describing the precise objective of the measurement and the exact methodology. An example project is determining the measurement error of a particular two-axis digital compass for

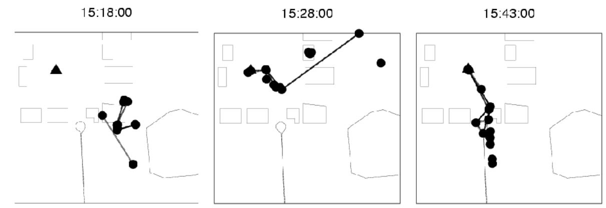

***Figure 2** – A time-lapse map of an exercise plotted from logs. Dots represent mobile nodes, heavy lines indicate network connections, and light lines indicate campus roads and buildings. Each map is about 1km square.*

varying degrees of pitch and roll. Experimental results are presented in a formal written lab report.

ENGINEERING PROJECT

The second project students are asked to complete involves a shift in focus from conducting strictly scientific experiments to taking an engineering approach to extending the TeamTrak platform's capability. Unlike the measurement project, in which students were simply expected to fully understand how a component works and evaluate it, the engineering project requires students to design, build, test, and evaluate a new idea, understand how it fits in with the existing architecture, and be able to describe not only the technical details of how it works, but also any design tradeoffs and the limitations or other implications thereof.

The goal of the engineering project is for students to take the knowledge gained in the measurement project and the whole-class experiments, as well as that from reviewing academic literature and documentation, and applying an engineering approach to building something new. By describing precisely what is to be built, the detailed architecture and specific behavior in select use cases, and an objective, quantitative evaluation, the students further develop skills and synthesize ideas presented throughout the semester.

Engaging students in research has been an important theme in FIE conferences [1,2,3] and is a high priority for national funding agencies, but can be challenging to execute in practice. In this work, we hope to show that mobile ad-hoc networks are an engaging topic for undergraduates, can easily be implemented in the classroom, and produce useful research results from classroom activities. The final WIP paper will include three results: reflections on the course format by the instructor, a selection of comments by the students, and a discussion of the data quality produced by the experiments.

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