

iSENSE: A Web Environment and Hardware Platform for Data Sharing and Citizen Science

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Abstract

The Internet System for Networked Sensor Experimentation (iSENSE) enables users to store sensor data on the web, view data from other contributors, and combine data from multiple sources to examine regional, national, and global phenomena. Intended for educational use and citizen science applications, the system is compatible with a wide range of classroom probes and sensors. We have also prototyped a custom data-logging device—the Portable iSENSE Network Point, or PINPoint—which features on-board sensors, a GPS receiver, and a connector for external probes. By pooling their data on the web, users can create an expanded sensor network and engage in collaborative research on STEM topics ranging from human health to environmental science and energy conservation.

Background

Inquiry-based learning activities, which challenge students to pose their own questions about the world and then actively observe, measure, and analyze real-world phenomena, have been shown to increase student engagement and retention (Pizzini et al. 1991; Brown 1992). In inquiry learning, students gain a practical understanding of and appreciation for the scientific method, developing the ability to formulate hypotheses, test those hypotheses, and analyze the results of their investigations (Chin and Kayalvizhi 2002; Feldman et al. 2000; Ruopp et al. 1993). This in turn leads to broader gains in critical thinking, problem-solving skills, and creative abilities (Lewis 2006).

Classroom probes are widely used in high school and university science labs to help students engage in inquiry-based science learning (NAEP 2002). A wide variety of sensors are commercially available, enabling students to

measure, among other things, physical properties of matter (e.g. temperature, pH, and humidity), the forces acting on an object (e.g., velocity and acceleration), metrics of human health (e.g., heart rate and respiration), and electrical phenomena (e.g., current, voltage, and magnetic fields). When transferred to a desktop, laptop, or handheld computer, probe data can then be analyzed and plotted. This combination of active data collection, followed by visualization and modeling, has been shown to enhance students' understanding of observed phenomena and related science topics (Adams and Shrum 1990; Friel et al. 2001; Russell et al. 2003; Hegedus and Kaput, 2004).

In typical classroom practice, probes are used in isolation, with a single probe attached to a single personal computer, generating a local and private pool of data. This significantly constrains the scope of scientific inquiry, essentially limiting students to the observation of local and temporary phenomena—for example, a known physical property of matter or a law of motion. In contrast, the iSENSE project enables students to create and share a permanent repository of shared sensor data online, opening up inquiries based on geographic and temporal variables. The project leverages emerging Web 2.0 technologies to produce dynamic, visually engaging representations of shared data. With data storage and analysis handled on the web, physical computing hardware costs are kept to a minimum. The iSENSE project's hardware component—the PINPoint—costs less than \$100 to manufacture, including the GPS receiver. The system is also compatible with the large installed base of existing classroom probes.

We are working closely with educators at the middle school, high school, and university levels to create meaningful contexts for collection and analysis of sensor data, and encourage our students to become citizen scientists, as they measure phenomena in the world outside their classrooms. The remainder of this paper presents the

design of the iSENSE system, including the web site and our PINPoint data collector, describes several of the contexts in which the materials have been used, and presents initial evaluation results.

iSENSE Web Site

The iSENSE web site provides a platform for collaborative experimentation using classroom probes and other sensor hardware. It offers tools for identifying experiments of interest and potential collaborators. The system also provides tools for creating dynamic visual representations of shared data. These and other system features were built using HTML, JavaScript, and Flash to ensure broad accessibility.

Collaboration

In designing the iSENSE system, the project team confronted a considerable informatics challenge: making sense of streams of sensor data uploaded to the system by geographically widespread users at different times. A decision was made early in the development process to implement a simple framework for data storage, based on two concepts: the *experiment* and the *data session*. In iSENSE, an experiment is essentially a placeholder for sensor data. Each experiment has a name, a description of the data-collection procedure, and a set of measurements to be taken. Sessions are series of data points, generally collected over a continuous period of time. Like experiments, each session has a name and a brief description of the data-collection procedure and the data collected from that procedure. For sessions without GPS data, street address information is used to identify the data's geographic location.

To help users identify experiments of interest to them, the iSENSE web site provides a search tool that allows users to find experiments based on keyword tags associated with each experiment by its creator. These tags can encapsulate a variety of attributes of an experiment, from its location (“outside” or “inside”) to its STEM topic area (“chemistry” or “biology”) to more specific identifiers (“polycarbonate”). Experiments can also be searched and sorted by their geographic location and their owner. This functionality allows users to rapidly find experiments taking place in their local communities or those initiated by their friends or colleagues.

In order to provide additional context for experiments, iSENSE allows users to contribute media related to their experiment. Users may contribute a video of their experimental procedure, providing other users with guidance on how data should be collected. Likewise, a photo upload tool allows contributors to upload images related to their data session. The iSENSE site also provides a tool for associating web links to resources that may be relevant to an experiment. This provides a way to link background information that a user can examine before contributing, exploring, or visualizing data.

To facilitate user-to-user interaction, iSENSE provides each user with a profile page detailing his or her activity on the site, including experiments created, sessions contributed, visualizations saved, and media uploaded. These profile pages allow users to explore what other people on the site are doing, in order to find inspiration for individual or collaborative work.

The iSENSE site also provides tools that make it easy for users to share their iSENSE activity on social networks. On every experiment page, users have access to a tool that will allow them to broadcast their thoughts or involvement on Twitter or Facebook. The iSENSE web site itself also drives the iSENSE project's social networking presences. For instance, whenever an experiment is featured, it is not only promoted to the homepage, it is also broadcast across the iSENSE project's Twitter page and Delicious account. Other administrative activities, like publishing news items and events, also result in updates to the project's social networking accounts.

Data Visualization

Data visualizations are generated using the Google Visualization Toolkit, along with controls that allow the user to customize how the data are presented. Data are encapsulated in a JavaScript Object Notation (JSON) object by the web site and passed to the visualization system. The JSON object contains all the data about each session, including meta data. The system parses the JSON object to extract the various components, such as the data itself, the person who uploaded the data, and where the data were collected. The data are then preprocessed to determine which visualizations are available; for example, a timeline would not be an appropriate visualization for experiments not involving time data. Once the visualizations have been chosen, they are pre-loaded from the Google service and prepared for display. When a user selects a visualization mode, JavaScript is used to dynamically create controls based on the type of data in the session and the capabilities of the visualization mode. Default values are then used to populate a data table object, which is loaded into the Google visualization object. As users manipulate settings, the data table is rebuilt to reflect the changes, and the visualization is updated. Users also have the ability to save a visualization to view later. When this occurs, the current state information is serialized into a string. When this string is present in the URL, the visualization system parses it and recreates the saved state. After loading a saved visualization, the user still has full controls of the visualization and access to others, with the ability to save any reconfigured data view.

Several visualization tools are available—all based on Google's visualization toolkit. Figure 1 shows four of the visualization tools:

- **Map.** The Map tool displays data on a Google Map, with individual readings represented by map pointers. Users can pan and zoom, as in any Google Map, to view data pointers in different locations. Clicking on a pointer displays the associated data values in a pop-up box.

- **Annotated Time Line.** The Annotated Time Line shows how data values change over time, with a line connecting each value. If multiple sessions are displayed, each session is represented with a different color line. A scroll bar along the bottom adjusts the start and end times in the time line.
- **Scatter Chart.** The Scatter Chart plots data points on an X and Y plane according to any two attributes. This tool can be useful for detecting correlations among data values, interpolating or extrapolating trends, and identifying outliers.
- **Bar Chart.** The Bar Chart tool displays rectangular bars with lengths proportional to the values that they represent.
- **Motion Chart.** The Motion Chart uses multiple visual cues to show relationships among data points. In addition to their X and Y positions, the size and color of the points on the Motion Chart can be linked to values. Moreover, a Motion Chart can be animated to show changes in data over time. The Motion Chart is best suited for representing complex data, collected from multiple sources over long periods of time.
- **Histogram Chart.** The Histogram Chart groups similar data into categories and shows the frequency of these categories against one another. Controls are provided that allow users to select the data to display and the conditions of each category.
- **Data Table.** A Data Table is provided to show the raw data underlying the visualizations. Users are able to sort the data by any field.

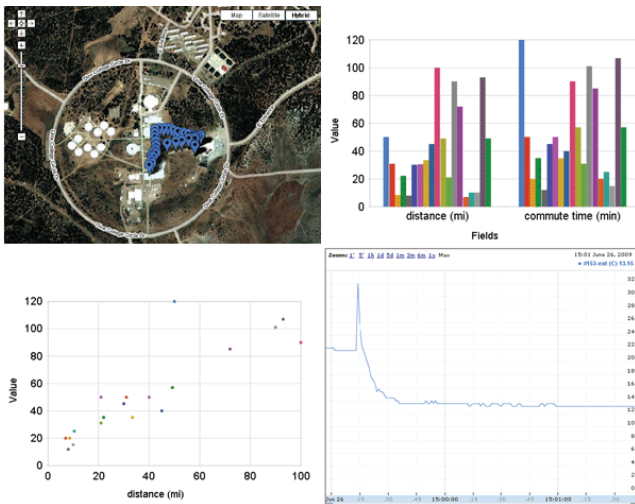


Figure 1: iSENSE visualization tools.

Users explore data by selecting one or more sessions from a given experiment and choosing and customizing visualizations to discover relationships in the data. After creating a visualization, a user can save it and share it with others.

PINPoint

The PINPoint, shown in Figure 2, is a compact data-logging device designed specifically for use with the iSENSE web system. It features light, temperature, and sound sensors, a three-axis accelerometer, and connectors for a GPS receiver and external probes. The device has 2MB of flash memory—sufficient to store more than 90,000 data readings. The unit’s rechargeable lithium-ion battery has a life of about 12 hours per charge

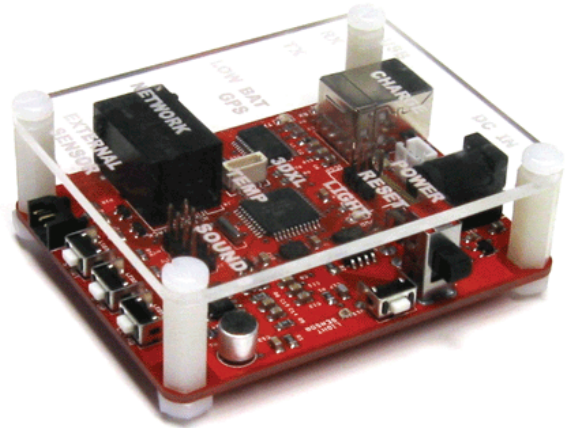


Figure 2: PINPoint data collector.

Operating the PINPoint

When the PINPoint is turned on, it automatically schedules periodic sensor readings based on configuration values in EEPROM. When the PINPoint is put into recording mode, these sensor readings are grouped into data “packets” and stored in flash memory. Each sensor can be subsampled and averaged at independent rates within a single packet.

Configuring the PINPoint

The PINPoint can be configured to change recording behavior to meet the needs of different experiments. This includes the type of external sensor, minimum satellite count, packet recording rate, and sensor subsampling rates. These values are stored in EEPROM and can be accessed through a serial protocol. The PINPoint can record data packets at rates from one per second to one per 60 seconds.

Retrieving Data

Data are retrieved from the PINPoint using an easy-to-use Java program, informally called the “PINCushion.” The user connects the PINPoint to the computer with a USB cable. A connection to the PINPoint can then be established using a custom serial protocol. All recording is halted during communications with the host computer to avoid race conditions. Data stored in the flash memory are requested on a page-by-page basis until the end of the data is encountered. The PINCushion includes a sensor-conversion file with formulas for converting raw sensor readings into standard units of measurement. This file can

be modified as new sensors are added to the system. The PINCushion program stores the result as a comma separated value (CSV) file, ready for upload to the iSENSE system.

Classroom Activities with iSENSE

We have developed the iSENSE system in conjunction with science teachers and other education practitioners. More than 100 teachers have participated in professional development workshops to learn about the technology, including events on the University of Massachusetts Lowell campus and at iRobot's corporate headquarters in Bedford, MA.

The iSENSE technology has been deployed and evaluated in a combination of university, middle school, and high school classrooms:

1) UMass Lowell (Lowell, MA). A total of 40 undergraduate students in an undergraduate social science course interacted with the iSENSE hardware and web system during the 2008-2009 academic year. In the fall 2008 semester, the whole class measured the pH of water collected at selected sites along the banks of the Merrimack River, and uploaded their data to the iSENSE web system. Other students collected soil samples from areas in Lowell, Lawrence, and Methuen, MA, measured levels of petroleum contamination in these samples, and shared the data using the iSENSE web system. During spring 2009, a second group of students used iSENSE to conduct a campus-wide survey of indoor environmental conditions, including temperature, light levels, and sound in UML classrooms, labs, and residences. In each of these instances, class time was subsequently devoted to group data analysis and interpretation, using the iSENSE system.

2) Sanborn High School (Kingston, NH). In May 2009, the iSENSE team and two high school teachers led two days of iSENSE activity in two forensics classes and two anatomy classes at Sanborn High School. Participating students (11th and 12th graders) conducted a variety of experiments using the iSENSE technology: a) a warm-up activity involving the collection of light readings in different areas of the classroom; b) measurements of the oxygen content in the air exhaled by students after holding their breath for different periods of time; and c) measurements of water-cooling rates under different experimental conditions (room temperature, refrigerator, and a heated incubator). Students uploaded their data to iSENSE, created data visualizations, and interpreted the results.

3) Engineering Summer Camp (Boston, MA). Students from three Boston-area high schools worked with the iSENSE technology as part of an engineering summer camp at UMass Boston during July 2009. Students practiced collecting data at various sites around campus, and then took the PINPoint devices to a forested area outside of Boston to record environmental data while searching for geocaches. Later, the group uploaded their data to the iSENSE web system, and created map

visualizations to plot the exact location of the hidden geocaches.

4) Consentino Middle School (Haverhill, MA). In July 2009, iSENSE project members ran a half-day workshop for 18 middle school students in a remedial/enrichment summer program. Using the PINPoint, students measured temperature changes when baking soda and vinegar were mixed together, and graphed the results. They also performed a "data walk" around the school and uploaded the data to iSENSE. In group conversation, students interpreted their data.

5) Dine College (Tsaile, AZ). In July 2009, incoming first-year college students on the campus of Dine College in northeastern Arizona used the iSENSE technology in a one-day workshop. Students performed a "data walk" activity, visiting various parts of the campus and collecting environmental data (light, temperature, altitude). The workshop was part of a larger summer session on environmental science, and the iSENSE activities were a significant hands-on component.

Undergraduate Implementation Details

The iSENSE implementation at UMass Lowell was in an undergraduate social science course focused on active learning approaches to social and environmental problems. Students came from a wide variety of majors; most took the course in order to satisfy a distribution requirement. In a week-long introduction to iSENSE, students walked with their professor and the iSENSE team to the nearby river, which is a key feature of the city. Students collected multiple water samples near a dam, looking for differences in the measurable characteristics of the water in order to compare stagnant water behind a building near the dam with free flowing water above and below the waterfall cascading over the dam. At the next class meeting, the iSENSE team showed the student-collected data, uploaded to the iSENSE web site.

Students were excited to see their data aggregated and represented on the Internet. The many questions they asked about what they were seeing online indicated both strengths and weaknesses in their science and visual literacy, as well as pointing the team to possible improvements in functionality and "legibility." One team of students was so intrigued they decided to use iSENSE for their term project, renting a meter that could detect petroleum contamination in soil, then mapping the levels of contamination found at different sites in their old industrial city and its wealthier suburban neighbor. By measuring contamination levels and linking the readings to income and land use history in the sites tested, the students discovered for themselves that there is a correlation between contamination levels and community income, with lower income communities generally more contaminated. They also observed that there was more contamination in a public playground they tested than at an abandoned gas station. The next semester, one of the students in the team asked to borrow the poster they had

made, so she could present her findings to her chemistry class.

The following semester, students in a similar course were given a hands-on introduction to working with iSENSE, uploading data themselves, then analyzing and presenting the data. All students were required to work with a partner on a term project that incorporated iSENSE. Students were generally very engaged and eager to investigate their surroundings. Environmental conditions in classrooms and hallways was of particular interest, and one team confirmed a professor's complaints that lighting levels had become far too low in some locations as a consequence of steps taken by the university to reduce energy use.

In both classes, iSENSE materials supported student inquiry and helped to develop a sense of agency in the students. They became more aware of the characteristics of their surroundings, and when they found disturbing results they expressed interest in doing something about the problems they discovered.

Evaluation

Project goals center around changes in student learning, student self-efficacy as it relates to their abilities to investigate citizen-science questions, as well as understanding of the nature of science and scientific activity. A pre/post survey to assess student learning was developed and a structured interview protocol was used to gather feedback from participating teachers. The instrument comprised 32 Likert Scale items, asking students to rate their level of agreement with various statements about science and scientific inquiry. Choices ranged from 1 (strong disagreement) to 5 (strong agreement). Sample items include:

- I would feel comfortable interpreting scientific data
- Scientists make different interpretations based upon the same observations.
- Scientists follow the same step-by-step scientific method
- Scientists question each other's data interpretation

Preliminary results indicate that activities involving the iSENSE technology increased students' confidence in asking and answering their own science questions, as well as interpreting scientific data. They also expressed more confidence in their readiness to participate in citizen science activities.

The teachers involved in the project used iSENSE materials to facilitate student scientific investigations in a variety of areas, including petroleum pollution in urban areas, pH of river water, heating and cooling curves in water, forensics, abiotic components of tree growth, respiration rates, and schoolyard ecology. Teachers reported that their students' ability to pose scientific questions was very rudimentary before the iSENSE experience; many of these students had difficulty creating investigatable questions. Overall, the teachers felt that working with the iSENSE materials helped students ask

and answer investigatable questions through the use of data collection and interpretation.

Future Work

With support from Google, the iSENSE team is developing an application for the Android operating system that would allow users to view and contribute iSENSE data using their smart phones. These phones can run third-party software, connect to the Internet through cell phone networks, and display interactive web content. Many smart phones have GPS receivers and cameras, as well as Bluetooth capability, which will be used to capture data from external environmental sensors. The project team views this installed base of smart phones as a largely untapped infrastructure for scientific data collection and a good source of data for iSENSE.

In parallel with this work, the iSENSE team plans to support more in depth and widespread use, motivate students to pursue real-world scientific studies, and evaluate these deeper learning outcomes. The development of middle school and high school curriculum modules and a series of ongoing teacher professional development workshops are also planned.

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