Ambient Intelligence at the Beach

Marc Böhlen[1], Joseph Atkinson[2]
Departments of Media Study[1] and Civil, Structural and Environmental Engineering[2]
University at Buffalo
marcbohlen@acm.org, atkinson@buffalo.edu

Abstract

We describe an experimental public resource monitoring system that combines sensor data and human input to create a new descriptor of ambient water conditions. We call this new metric the swimming pleasure measure. We give an overview of how it is composed, how it relates to existing public water health monitoring efforts and how it is shared with the public.

1. Introduction

This research investigates the potential of ambient intelligence in the outdoors, and in particular at sites of public leisure in urban settings such as city beaches. Our approach combines best practices of environmental monitoring of public resources with ambient intelligence technologies and experiential intelligence harnessed from collectives of human beings. The goal of the work is threefold: (1) to investigate the potential of ambient intelligence technologies to augment the monitoring of public resources; (2) to find new ways of notifying the public of possibly dangerous situations through ambient systems combined with social networking activities; and (3) more broadly, to investigate the potential of combining data collected by sensors and evaluated by computers with data generated intuitively by people to develop a form of intelligent representation of ambient conditions neither is capable of creating in isolation. All three of these goals should ultimately contribute to a more refined understanding of our impact on and benefits from limited natural resources in the 21st century.

2. Background

Environmental monitoring usually occurs out of reach of the public. People are informed by anonymous government agencies about water and air quality via occasional news releases, usually after critical thresholds have been exceeded. Most official sources of environmental information are updated too infrequently and the data are usually not collected directly where people experience their environment.

An underlying thesis of this research is that new ways of appreciating shared natural resources can help to move governments and the public towards sustainable use of the environment. Furthermore, we are operating under the assumption that local knowledge [1] can enhance existing monitoring systems. Furthermore, our project seeks an altered role for information processing technologies. Here we seek to inform and engage at once. This is best achieved, we believe, by giving human knowledge agency where people physically experience their environment.

3. Intelligent environmental monitoring

Environmental management systems have an established practice of combining sensor based knowledge with regulatory requirements to develop complex decision support systems [2, 3]. Within the domain of water management several different systems have been developed for particular areas, including reservoir operations [4] and irrigation [5]. Urban informatics [6] has employed mobile media to bring environmental observation to parts of the city that official sources monitor insufficiently.

3.1. Augmenting environmental monitoring with human intelligence

Not all aspects of water quality can best be assessed via automation technologies alone. For example, the *Alaska Department of Environmental Conservation* launched a recreational beach survey in 2007 to gather information from coastal communities [7]. Residents were invited to volunteer information about beaches, including levels and seasons of recreational use, beach access and size as well as potential pollution sources.

Projects that involve people to monitor systems and collect data are becoming more commonplace. An example of this approach is the River Captain project organized by the *Buffalo-Niagara Riverkeeper* [8], a non-profit environmental organization overseeing cleanup and restoration activities in the Buffalo and Niagara Rivers. People in the lay community who volunteer to be River Captains submit observations (qualitative and quantitative) of a particular site, thus providing much greater sampling frequency in both time and space than would otherwise be possible.

4. The Glass Bottom Float Project

A test system called The Glass Bottom Float (GBF, Fig. 1) has been designed as a prototype system to investigate new approaches to combining human and computer intelligence in ambient monitoring. GBF functions as both a conceptual platform with which to sharpen ideas, as well as a practical experimental platform for testing under natural conditions. GBF is currently deployed at Beaver Island State Park, on Grand Island in the Niagara River near Buffalo, New York. GBF comprises a floating buoy with networked instrumentation described below.

4.1. Sensor generated data

The GBF platform senses a variety of parameters including turbidity, pH, water temperature, dissolved oxygen, and chlorophyll (as a measure of the presence of algae) with a YSI 6600V2-2 data sonde. The platform can robustly monitor these parameters according to best practices of beach-side recreational water quality assessment. Meteorological data are provided by an onboard weather monitoring system, and we also query a local NOAA weather station.

Sampling for all inputs is controlled by a single laptop computer with a solid-state hard drive in a water tight box. Two marine-grade, deep-cycle rechargeable batteries (12V, 55A/hr each) deliver the necessary power for the system to operate for a full day without recharging.

NOAA weather updates occur every 60 minutes (NOAA's own update rate), the YSI-sonde and local weather station data are currently queried every 12 minutes, and the sonar transducer is queried at one second intervals for 300 data points every 30 minutes for an approximation of the water depth and average wave height. Together these sensors and their readings give a fine grained description of important water quality properties.

The database can be queried from any internet-enabled device, including mobile phones. This access is based on a web-based application developed for Linux-Apache-SQL-PHP environments.

Fig. 1. GBF operating at Beaver Island (July 2009)

4.2. Human generated data

People experience the beach waters in a holistic way that sensors cannot. Human bodies function as sensor systems that relate multiple inputs directly to intuitive and cognitive experience. Because of this, it is important to collect these data and evaluate whether they contains insights the sensor-based data are unable to represent. During the swimming seasons of 2008 and 2009 we interviewed swimmers and beach goers for their opinions on the water conditions at the beaches in which our buoy system operated. We queried approximately 12 swimmers per day on about 3 days per week from the beginning of July to the end of August. We queried them briefly as they exited the water by first introducing the project objective and asking for permission to ask a few anonymous questions. We asked them about their beach visiting habits, their swimming ability, location of residence, and also noted gender and age bracket. Then we asked for their personal assessment of the current swimming conditions using both words (awful to excellent) as well as corresponding numbers (1 to 10). Finally, we offered visitors the opportunity to add comments and observations beyond our own questions and transcribed those responses into short sentences. Each interview took between 3 to 5 minutes. In total we interviewed 260 beach goers (consisting of 160 women, 100 men; 207 adults, 17 teens, 19 elderly visitors and 17 children) in the summer of 2009 alone. Since the interviews were short and the settings favorable (a sunny beach), we believe that there was generally no incentive to purposely falsify data and that the results reflected the beach goers experience fairly accurately. Furthermore, the mobile phone based collection method allowed beach visitors who volunteered their opinions transparency into the data acquisition process.

4.3. Responding to regulatory requirements and remaining adaptable to new research

The US Environmental Protection Agency (EPA) stipulates that public swimming waters contain no more than 235 cfu (coliform forming units) of e-coli [9]. Normal practice at state beaches is to monitor e-coli concentrations daily or weekly at beaches with empirically low contamination levels. Park employees send water samples to an external lab for processing. During the summer of 2009, the park manager entered the fecal contaminant results into a log and into our system via a simple web-based interface, integrating the data from the external laboratory into our water, weather and experiential data. This approach allows our system to include ambient parameters that our own sensors cannot capture. It also allows for the system to grow organically with the emergence of experimental or future, currently unknown, environmental impact descriptors.

4.4. A descriptor of ambient conditions

The result of all of the data collection efforts described above is a 30-dimensional swimming experience descriptor represented through time-stamped records in SQL database tables (water input, weather input, bacterial contamination input and human experiential input). Each day at the beach is represented by approximately 95 individual measurements/input samples. From this high dimensional data set we define a new metric of representing the perceived quality of being in the water, the *swimming pleasure measure*.

4.4.1 The Swimming Pleasure Measure (SPM)

Water quality assessment strategies currently in use in the USA and Europe are built on health based quality criteria and the concept of *acceptable risk*. Procedurally, risk in water is assessed through water parameters that are directly or indirectly indicative of a particular risk, as in the risk of bacterial infection.

The swimming pleasure measure is a new qualitative metric of the experienced pleasure of being in the water. GBF integrates (separately obtained) e-coli counts into its definition of experienced pleasure of the beach resource. With this input the SPM becomes an alternate, intuitive proxy for the health of beach water. The SPM is defined by a moving average of the recorded values given by the beach visitors (as described above), controlled by regulatory requirements, in this case maximum bacteria concentrations. While the subjective pleasure of being in the water may well be independent of any kind of regulatory requirement, the absence of unwanted consequences of pleasure (such as infectious diseases) necessitates in public settings the inclusion of components that one can not directly perceive. Other environmental data described above (wind, rain, turbidity, chlorophyll) function as fine grained, situated descriptors that attempt to capture the most salient and machine recordable real-time characteristics of the beach waters.

4.4.2 New ways of informing the public

We made a subset of the collected data available on the internet and created a mobile phone compatible interface. The data were updated on the website immediately after being collected by the sensors. This allows potential visitors to check the local conditions, with high granularity, both in terms of locality (because the sensors operate precisely in the waters in which they would be swimming) as well as temporally (because the data are updated much more frequently than through other sources) before embarking on the journey to the beach.

We mapped the result onto a color-coded light system (green, red and blue) installed on the buoy. This colored light system (Fig.2) was noticeable from the shoreline, indicating positive (green light), neutral (blue light) and negative (red light) water conditions in a very intuitive manner, reminiscent of existing beach flag culture where red flags indicate closed beaches and blue flags indicate open beaches.

Additionally, we created an interface to the social networking site *Twitter* that allowed the robot-buoy to send short daily messages directly from the beach. Short messages including the current SPM, pertinent weather data and encouragements to stop by the beach on days when swimming was deemed favorable were created with a simple text generation algorithm. Several dozen people signed up to receive the service during the first weeks of operation.

5. Preliminary evaluation

Park management has shown a keen interest in the GBF system. From beach goers we have (verbal) evidence that the GBF enhanced their appreciation of the beach resource because of the way the system shared its results.

However, preliminary analysis of the visitor data may indicate problems in our visitor data collection approach. For example, none of the environmental inputs seem to relate in a direct fashion with the human generated data. It is possible that the human side SPM includes features (such as non-water related beach experience) we did not design for. We need to parse the human input more succinctly in order to make a precise statement on the relationship between sensor data and human experiential data.

Fig. 2. Blinking SPM at Beaver Island (July 2009)

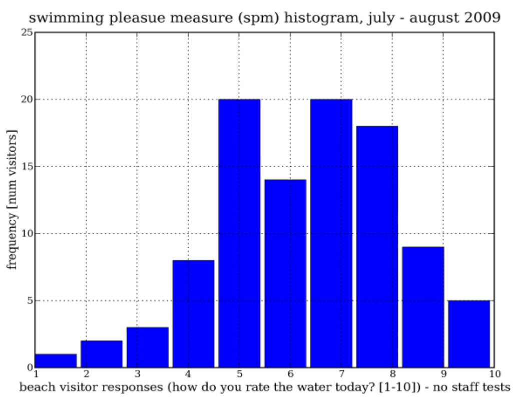

Fig. 3. Histogram of visitor input (human side SPM)

Figure 3 shows an example of the collected data. This frequency plot represents the beach visitors' cumulative response (on a scale of 1-10; 1: bad - 10: excellent) to the question: "how would you rate the quality of the swimming experience you just had?" as they exited the water. The plot shows two modes, indicating two main groups of opinions, where one placed the swimming experience in the middle of the 1-10 scale and the other shifted it to the positive. Analyzing the data along groups is more informative. Women's opinions spread over the complete scale while men tended to evaluate the beach a bit more narrowly and favorably. Out-of-towners on average gave lower scores, but the lowest scores were recorded by people defining themselves as locals. (Male) teenagers and children in particular were uncritical in their evaluations, giving high marks under most all conditions. The e-coli results during the test period were all below the 235 cfu threshold. A more complete analysis across the various beach visitor categories is given in a technical report generated for Beaver Island Park operators [10].

6. Future work

We intend to evaluate machine learning approaches for their ability to model an equivalent of the human SPM. This would allow us to anticipate a SPM for waters that are not used for swimming, i.e. to find new good quality swimming locations. Also, we intend to expand the SPM to include more complex models of the beach environment. Finally, we want to increase the public presence of the system with a beach side information kiosk where beach visitors can chat with water experts and other visitors about their impressions and together think about new ways to address water resource concerns.

7. References

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