Pervasive Sensing in Healthcare:
From Observing and Collecting
to Seeing and Understanding

Steven R. Rick
Dept. of Computer Science and Engineering,
UC San Diego
La Jolla, CA, USA
srick@ucsd.edu

Nadir Weibel
Dept. of Computer Science and Engineering,
UC San Diego
La Jolla, CA, USA
weibel@ucsd.edu

Vishwajith Ramesh
Dept. of Bioengineering,
UC San Diego
La Jolla, CA, USA
vramesh@eng.ucsd.edu

Danilo Gasques Rodrigues
Dept. of Computer Science and Engineering,
UC San Diego
La Jolla, CA, USA
gasques@ucsd.edu

Abstract
From analyzing complex socio-technical systems, to evaluating novel interactions, increasingly pervasive sensing technologies provide researchers with new ways to observe the world. This paradigm shift is enabling capture of richer and more diverse data, combining elements from in-depth study of activity and behavior with modern sensors, and providing the means to accelerate sense-making of complex behavioral data. At the same time novel multimodal signal processing and machine learning techniques are equipping us with 'super powers' that enable understanding of these data in real-time, opening up new opportunities for embracing the concept of 'Data Science in the Wild'. In this paper we present what this transition means in the context of Health and Healthcare, focusing on how it leads to the 'UbiScope', a ubiquitous computing microscope for detecting particular health conditions in real-time, promoting reflection on care, and guiding medical practices. Just as the microscope supported key scientific advances, the UbiScope will act as a proxy for understanding and supporting human activity and inform specific interventions in the years ahead.

Author Keywords
Sensors, Pervasive Health, UbiScope, Stroke-Kinect, Augmented Reality, Surgery, Ubiquitous Computing, Data Science
Introduction
Throughout history the advancement of science and technology has granted humanity new lenses through which to better understand the world. The telescope granted access to the macro-scale world, the huge and distant cosmic bodies. The microscope granted access to the micro-scale world, the tiny and close cells and bacteria which were responsible for illness and disease. While each of these micro and macro lenses have evolved and advanced, it was not until recently that a third lens was introduced at the level of human beings. Pervasive and ubiquitous means for sensing and computing, as enabled by new compact and mobile sensors which can see beyond the range of our own eyes, can nowadays detect imperceptible motion, signals, or patterns that a human alone cannot. But observing and sensing are not enough on their own. Incredible advances in machine learning, multimodal signal processing, and mobile computing, are producing the ‘perfect storm’ of conditions that allow us to go beyond sensing, introducing new opportunities to see the world and generate real understanding in ways that were not possible before.

It is important to note that the microscope was not enough to directly drive healthcare outcomes, but required considerable efforts in translational research to generate important findings in medicine. Similarly, we must be thoughtful as we design pervasive sensing technology to integrate with ubiquitous computing systems that seek to support and positively influence patient outcomes, improve quality of healthcare delivery, or reduce adverse events. To support this move from simply observing and collecting data, to actually seeing through this lens and generating better understanding of health and healthcare, we introduce a new conceptual framework that we call UbiScope, a ubiquitous computing microscope for real-time seeing and understanding of situated interactions. The UbiScope is instantiated as a combination of three main components: (1) data collection with unobtrusive sensors and off-line analysis, (2) machine learning and modeling to generate lightweight classifiers, and (3) the implementation of these focused detectors for real-time applications. The application of this conceptual framework in healthcare provides a means for leveraging ubiquitous computing and sensing as a microscope that enables real-time characterization of particular behaviors, diseases, or disabilities.

In the remainder of this paper we lay out existing work that informs the introduction of the UbiScope, and we introduce three example that instantiate this idea in specific healthcare settings. We then discuss the reach of this approach, concluding with next steps and future outlook.

Related Work
A rapidly growing body of work surrounds the idea of implementing advanced computing and sensing in order to improve human understanding in healthcare. This has often materialized in the usage of offline machine learning for disease detection, such as Mazilu and colleagues’ work on classifying Parkinson’s Disease related gait symptoms via smartphone sensors [7]. Another example is the work of Suk, Lee, and Shen who performed multimodal feature extraction to model and diagnose Alzheimer’s Disease and Mild Cognitive Impairment [9]. Work has also been pursued in terms of quantification, rather than detection, of disease progression. One such example is the work of Kontschieder and colleagues evaluating patients with Multiple Sclerosis with depth sensing devices [5]. Moving beyond specific diseases to assess the overall environment, we find our own
work focused on the deployment of a range of multimodal sensors into outpatient clinics to capture and characterize physician-patient-computer interaction [10]. All of this work, while incredibly informative, relied upon techniques that were computationally too expensive to easily permit adaptation into real-time evaluation systems.

More ubiquitous computing methodologies are being utilized in order to promote change and learning within the delivery of healthcare. Work like Maiden and colleagues’ deployment of tracking technologies to improve medical staff awareness of how they were delivering care to patients with dementia [6], is one example in this setting. This research leveraged a more people-centered approach, raising awareness of current practice through self-reflection. As pointed out by Elf, Frost, Lindahl, and Wijk [1], by considering the current practices within the context of the environment where the work naturally occurs, design and deployment of new models of care or new technologies which seek to improve care are more readily adopted.

In our research leading up to our concept of the UbiScope, we integrated the knowledge from preexisting work focused on sensing within the health and healthcare domains. By combining those learned lessons with our own situated data-collection and analysis, we found means to augment and empower patients, clinicians, or medical practices while respecting their work environment. This approach allowed us to effectively shift data science into the real world in an ecologically valid way.

Algorithms and procedures that allowed multimodal and multi-dimensional data collected in the field to be analyzed through post-processing, have now been rebuilt in order to be deployed in the field and work in real-time. Optimization methods for producing faster signal processing and more lightweight classifiers enable real-time on-line analysis and ultimately support the design and development of data-driven interventions informed in real-time by pervasive sensing.

**Data Science in the Wild: the UbiScope**

With an emphasis on the natural augmentation of health and healthcare, it is essential to understand the needs of modern day health practitioners as they go about their work in their natural environments. Growing literature [4], as well as our own experiences point to time being one of the key factor that drives many of the decisions, especially in critical settings. With both costs and patient outcomes strongly related to time taken, care teams must move quickly while maintaining high precision. This temporal demand, however, can occasionally lead to subtle clues being missed which are highly relevant to the detection of specific conditions.

In order to resolve these concerns, we propose a new framework that combines methodologies for sensing and sense-making from Computational Ethnography [11], with interactive and interventional systems that have been co-designed alongside the medical care team members who will use them. In this section we discuss how these factors lead to the UbiScope, and it’s core concepts of detection, reflection, and guidance through three distinct tracks of work: (1) neurological disease classification, (2) surgical assessment, and (3) surgical training. All of these areas of work emphasize different forms of real-time and near-time interactive feedback, informed by expert inquiry and in-situ observation, and realized through the use of ubiquitous sensing and computing devices.

**Neurological Disease Classification**

In the area of acute neurological disease diagnosis and treatment, speed and accuracy are both incredibly impor-
Figure 1: Top-Left: Body tracking data collected from a patient during a neurological assessment visualized in the multimodal analysis tool ChronoViz [2]. One of the arms of the patient was abnormally asymmetric during analysis, indicating higher likeliness of stroke conditions. Bottom-Right: envisioned characterization of problematic moments in time, across modalities.

This is especially true in the case of stroke. The drugs and procedures used to treat stroke often carry very high risks related to internal bleeding (especially the brain). Therefore, diagnosis of stroke must be made by highly trained and specialized neurologists before treatment can be administered. Unfortunately, experts are frequently unavailable and current solutions rely heavily on support staff to triage and prioritize patient evaluations. This often leads to stroke not being treated on time, with only 5% of acute strokes treated with the standard medication (rt-PA), primarily due to the narrow therapeutic time window for intervention [3].

To help solve this problem, we are studying how to computationally characterize stroke features by observing patients’ multimodal behaviors. We are currently collecting behavioral data from patients while they are assessed by neurologists [8] (see Fig. 1). As the patients run through a battery of speech-based, motor-based, and coordination-based tasks and tests to assess neurological condition, we isolate features indicative of positive and negative stroke diagnosis. We aim to provide tools that help augment doctors’ diagnostic abilities.

The application of the UbiScope conceptual framework in this setting will guide us towards deploying a system which can autonomously aid in triage through detection. If a neurologist cannot immediately be seen, the patient can first engage with our tools, which will interactively guide the patient through a basic battery of tasks previously found to elicit the strongest signals for stroke diagnosis. This in turn will provide just-in-time support to clinical staff through reports which highlight the positive and negative signals detected (see envisioned chart in Fig. 1, bottom-right).

Figure 2: Data from the tracking of two laparoscopic surgeons working together with an abdominal training simulator played back in ChronoViz. In the bottom-right panel shows problematic ergonomics moments (in green) automatically recognized by the system.
Surgical Assessment in Laparoscopic Operating Rooms

Moving away from explicit disease detection, we also see the UbiScope framework providing support directly to care clinicians and medical personnel. Our research in this setting is focusing on the assessment of ergonomics and human-factors during laparoscopic surgical procedures. Our approach successfully combines body-tracking sensors with standards such as ANSI Z-365 in order to generate an ergonomic ‘score’ at each moment in time. This will direct analysis to moments when a surgeon’s ergonomics were particularly poor (see Fig. 2 for an example).

This in-situ data collection and post-evaluation is very informative of what shortcomings preexist in the practice of surgery. While direct attention to the practices that attribute to long-term injury is important, the post-capture analysis is limited in it’s ability to directly influence change.

By extending this work through the UbiScope’s focus on reflection, the assessment algorithms can be optimized to run in real-time. This will then make it possible to design real-time or near-time interventions on top of these scores. We are currently experimenting with the idea of ambient displays or other passive environmental cues as an interventional tool that can be leveraged to raise awareness in real-time without increasing cognitive burden or distracting from the task at hand.

Surgical Simulation and Augmented Reality

Beyond assessment in the operating room, it is important to also focus on teaching the required skills through simulations. Embedding teaching in high fidelity simulations is very effective but requires specialized facilities and expensive equipment. For this reason our work is looking at the augmentation of surgical training through pervasive sensors which can track students actions and overlay informative visualizations onto low-cost mannequins. Specifically we make use of new Augmented Reality devices such as the Microsoft Hololens to provide a more realistic means for interaction within the simulated world. Information and visualizations are provided at the locations where it is most relevant (e.g. we show CT scans inside the body of a patient, or views from an ultrasound probe projected longitudinally within the patient’s body), rather than on remote displays and screens which require effort to mentally transform the information from the digital realm to the physical (see Fig. 3).

Experiences such as augmented teaching in surgery, informed by both pervasive sensing and augmentation of the environment, drive UbiScope’s focus on just-in-time feedback and guidance. Whether occurring while the skills are taught in simulation, or during actual patient cases, leveraging sensors to track activity and human interactions will support the design and deployment of means for visually augmenting various medical procedures. This will support interactive visual guides, including feedback mechanisms when erroneous behaviors occur.

Figure 3: CT Scan image integrated within the body of a mannequin during a simulation training with medical students.
Discussion and Conclusion

In this paper we presented UbiScope, a conceptual framework that shifts the power of sensing and data collection towards seeing and understanding, exploiting the concepts of detection, reflection and guidance. The three examples outlined in the paper demonstrate the transformative potential of applying data science in the wild, and how this enables us to move toward interactive and interventional applications of sensing within the healthcare environment.

While health presents an environment for high impact, it is also very likely that advanced systems supported via the UbiScope conceptual framework could contribute significantly to other areas of work, such as behavioral science, disease prevention, child development, and linguistics.

All in all, we believe that the UbiScope represents the start of a new era where it is increasingly possible to exploit advances in machine learning, signal processing, and mobile computing to support new ways to see and understand situated interactions in real-time. The application of Data Science in the Wild to healthcare, as we outlined in this paper, makes it evident that the impact of UbiScope in years ahead will be exciting and important.

References


