Zensei: Augmenting Objects with Effortless User Recognition Capabilities through Bioimpedance Sensing

Munehiko Sato[1], Rohan S. Puri[1], Alex Olwal[1]*, Deepak Chandra[2], Ivan Poupyrev[2], Ramesh Raskar[1]

[1]MIT Media Lab
Cambridge, MA, USA
{munehiko, rohan, olwal, raskar}@media.mit.edu

[2]Google ATAP
Mountain View, CA, USA
{dchandra, ipoupyrev}@google.com

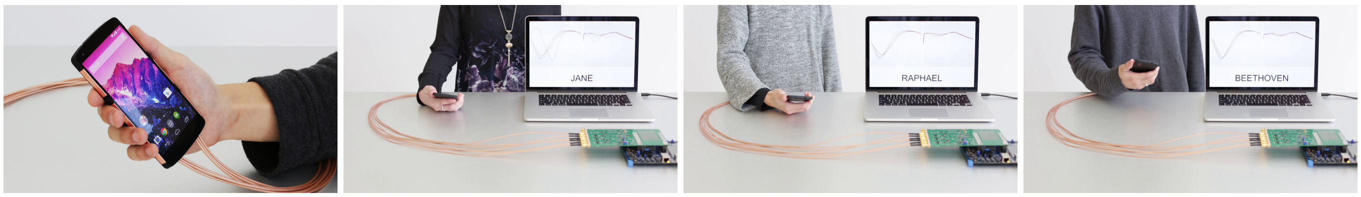

Figure 1. *Zensei* enables effortless and uninterrupted user identification and personalization with almost any object, such as a smartphone.

ABSTRACT
As interactions with smart devices and objects become increasingly common, a more seamless and effortless identification and personalization technique will be essential to an uninterrupted user experience. In this paper, we present *Zensei*, a user identification and customization system using human body bioimpedance sensing through multiple electrodes embedded into everyday objects. *Zensei* provides for an uninterrupted user-device personalization experience that is difficult to forge because it uses both the unique physiological and behavioral characteristics of the user. We demonstrate our measurement system in three exemplary device configurations that showcase different levels of constraint via environment-based, whole-body-based, and handheld-based identification scenarios.

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces - Graphical user interfaces; Input devices & strategies.

Author Keywords
User identification; bioimpedance sensing; customization

INTRODUCTION
People interact with more and more smart devices every day. This includes personal electronics, such as mobile phones, tablets, laptops, desktop computers, and public displays. In scenarios in which user interactions are frequent, such as with personal devices, it is critical that user recognition procedures do not repeatedly interrupt the interaction. The ideal interaction should not be interrupted by toggling a switch, inputting a password, or any other explicit procedure. There are interesting opportunities now that everyday objects are being augmented with computational power and network connectivity, and we envision that implicit identification and automated customization will be of significant importance for human-computer interaction.

Zensei is a fundamental sensing technology that enables physical objects to identify their user instantly by sensing the user's touch behavior and bioimpedance. It makes almost any object capable of effortless identification – for example, a smartphone that recognizes you as soon as you pick up your phone, a car that knows who is sitting in the drivers seat so it can change to custom user settings, or a shared tablet that toggles into the child-safe mode when a child is holding it. With *Zensei*, one does not need to type in a username or password, scan an ID, or even align the correct fingertip with the fingerprint scanner.

SYSTEM AND IMPLEMENTATION
Bioimpedance and capacitive sensing technologies have been used for various applications including tomography [1], multi-user touch surfaces [3], and wearable devices [2]. Unlike conventional capacitive sensing, *Zensei* peers into the body tissue by measuring the bioimpedance between a pair of electrodes. Therefore, *Zensei* can know who is touching the object using the differences in body tissue composition. We advocate an approach to capture a user's electrical characteristics by implementing a sensor into the physical objects around us. Our approach shares some similarity with SFCS [5, 4], however, we measure both the amplitude and phase components of electrical frequency response and do so among all combinations of six embedded electrodes (Figure 3) with shielded cables. Our implementation uses an AD5932 wave generator, custom analog circuitry, and AD8302 RF gain and phase detector to capture the frequency response over a wide range of frequencies (1 KHz to 1.5 MHz in 150 linear steps) (Figure 4).

In our approach, we created three prototypes to demonstrate three different form factors that evaluate and exhibit *Zensei*'s versatility. These include static sensing with relatively stable and controlled user touch behavior (hand pad), semi-static

*Secondary affiliations: KTH – Royal Institute of Technology (Stockholm, Sweden); Google Inc.(Mountain View, CA, USA)

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Figure 2. Three prototypes of Hand Pad, Chair, and Smartphone, and their electrode arrangements.

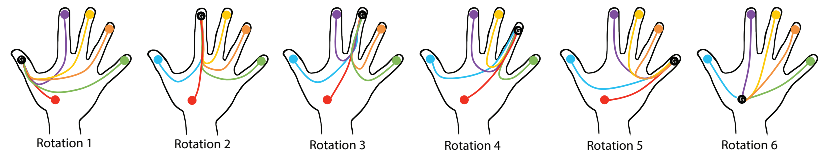

Figure 3. Electrode demultiplexing and ground electrode rotation.

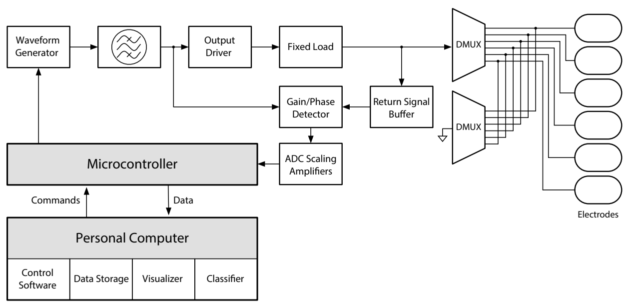

Figure 4. *Zensei* system block diagram.

sensing with somewhat variable touch behavior due to user posture and changes in clothing (chair), and variable sensing with highly variable user touch behavior (smartphone) as shown in Figures 1 and 2 as well as the Video Figure.

To prepare the data for classification, the thirty vectors of 150 frequency response values were first smoothed using a moving average filter (n=5). It was empirically determined that good performance was achieved by feeding just this smoothed data into an SVM classifier with Polynomial Kernel (E = 1.0, C = 1.0). We trained our classifier using SMO implementation in WEKA Toolkit.

APPLICATION SCENARIOS

Various applications can be realized with *Zensei*'s versatile user recognition technology. Specifically, it is particularly useful for "casual" biometrics. When an individual wants to gain access to a system such as an informational kiosk, they just need to place a hand on a hand-shaped pad. As *Zensei* uses multiple embedded electrodes for sensing, users could grab a doorknob in a certain way to unlock the door (Video Figure). By doing this, we can create a powerful user-specific key that is a combination of *physiological* and *behavioral* features. Furthermore, users can *generate* multiple temporary tokens by changing the way in which the doorknob is grabbed.

DATA COLLECTION

Data on all three arrangements was collected on 12 subjects over a time period of 30 days excluding weekends (22 days of data collection, two sessions each day, five samples per session on each arrangement) to evaluate their classification accuracies (CA), false acceptance rates (FAR), and false rejection rates (FRR). Subjects were instructed to touch each arrangement five times in series per session, removing themselves from the arrangement between each sample. The first four days of results of the hand pad were not used in the analysis because its circuit board had malfunctioned and had to be switched. Although a few sessions were missed, each subject participated in at least one session per day.

DATA ANALYSIS

To evaluate the overall performance of the system, we performed a hold-one-day-out validation by training our classifier on 21 days of data and testing on the remaining day for every combination of days and averaging the results of all combinations. As shown in Table 1, the more constrained arrangements (hand pad) tend to outperform those with more user variability. Additionally, the chair showed lower performance likely because of the strong influence of the subject's clothing in the collected signal. Overall, the high accuracies and low FAR prove promising considering the realistic long-term and variable scenarios in which the data was collected.

Table 1. Classification Accuracy

	Hand Pad	Phone	Chair
Classification Accuracy (SD)	96.0% (2.41%)	88.5% (5.51%)	78.6% (7.71%)
FAR (SD)	0.37% (0.20%)	1.04% (0.51%)	2.05% (0.83%)
FRR (SD)	3.97% (2.41%)	11.47% (5.50%)	21.30% (7.88%)

DEMONSTRATION

In this highly interactive demonstration, we will set up all three of our arrangements next to each other (hand pad, phone, and chair) for training and real-time classification on an attached laptop computer as shown in the Video Figure, with a minimum of three participants trained on any given arrangement.

CONCLUSION

We have presented a technique to augment objects to enable automatic personalization through wide-spectrum bioimpedance sensing of the human body. We developed a multi-electrode sensing system and evaluated it with three form-factors with six electrodes each. We then proposed diverse interaction scenarios to highlight the capability of sensing technology along with a long-term evaluation with promising results. We hope *Zensei* will be a useful tool for designing more seamless customized user interactions with a variety of objects.

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