BioIoT: Communicating Sensory Information of a Coffee Machine Using a Nature Metaphor

Carla Alexandra Souta Barreiros
Interactive Systems and Data Science Institute
Graz University of Technology
Graz, Austria
cbarreiros@Know-center.at

Eduardo E. Veas
Know-Center GmbH
Inffeldgasse 13/6, Graz, Austria
eveas@know-center.at
vpammer@know-center.at

Viktoria Pammer
Know-Center GmbH
Inffeldgasse 13/6, Graz, Austria
eveas@know-center.at
vpammer@know-center.at

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Abstract
In our research we explore representing the state of production machines using a new nature metaphor, called BioIoT. The underlying rationale is to represent relevant information in an agreeable manner and to increase machines' appeal to operators. In this paper we describe a study with twelve participants in which sensory information of a coffee machine is encoded in a virtual tree. All participants considered the interaction with the BioIoT pleasant; and most reported to feel more inclined to perform machine maintenance, take "care" for the machine, than given classic state representation. The study highlights as directions for follow-up research personalization, intelligibility vs representational power, limits of the metaphor, and immersive visualization.

Author Keywords
Sensors, visual language, holograms.

ACM Classification Keywords
H.1.2 [Models and Principles]: User/Machine Systems—Human information processing; H.5.1 [HCI]: Multimedia Information Systems—Artificial, augmented, and virtual reality

Figure 1: BioIoT using AR: Trees representing machine states are visualized through an augmented reality display over a factory floor.

Introduction

Following the Internet of Things (IoT) concept, industrial environments are becoming increasingly equipped with a vast number of electronics and IT systems [1]. In the IoT paradigm, all industrial machinery has embedded sensors and can communicate real-time sensory data. As machinery grows increasingly complex, tasks as machine configuration and maintenance demand higher human expertise and operators have to specialize in handling complex systems. However, the IoT concept of connected machines extends beyond industrial environments to daily life. Domestic machines are equipped with chips and sensors and servicing them may be rather demanding. As they become more complex, people are less inclined to take care of them. Yet they fill their environment with living beings, pets and plants and enjoy tending to them.

The goal of our research is to communicate information about complex, real-time processes in an engaging, interactive and apparent manner. The representation should be aesthetically pleasing and should increase overall well-being.

The ”Biophilia Hypothesis” postulates that people tend to focus on life and life-like processes [2]. Moreover, being close to (representations of) nature has beneficial effects on humans’ emotional, cognitive and physical well-being. Even contact with artificial plants, natural-light-like illumination and nature photography contribute to a healthier workplace [3].

Research has been conducted to understand how people interact with machines (e.g., robots). The perception of a machine’s intelligence and consciousness combined with anthropomorphic factors (appearance, gestures and emotions) can change the dynamics of human-machine interactions. Since machines tend to be seen as social actors [5], social rules and dynamics should be applied to designing systems that can change

Our Coffee Machine

Figure 2: The coffee machine *Dolce Gusto Mini Me* enhanced with three types of sensors: A) Ultra-Sonic Sensor HC-SR04 is placed in the water tank; B) Two-Force Sensitive Resistor. The first one placed at the top of the capsule drawer, the second one over the On/Off button; C) Temperature Sensor LM35 is inside the machine.

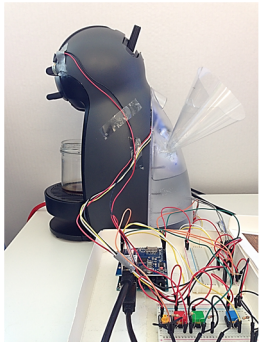

Figure 3: An Arduino Uno and Arduino Ethernet boards are used to collect the data from the sensor and transfer it to a MQTT server (lightweight message protocol).

the user's behavior [6]. For example, the reciprocity rule (If you help me, I feel that I should help you.) is also valid for human-machine interaction [7]. Humans are hardwired to be social and to experience emotions, such as empathy and compassion, with regard to others humans and living beings.

Nature representations (e.g. artificial gardens and pets) and easily accessible feedback to data can lead to reflection and posterior behavioral change [9] [10] [12]. Also, plants displays have been used successfully to represent data and provide affective feedback [11].

Our work is based on the premise that if machines are perceived to be more like living beings, operators will take better care of the machine's condition, which ideally would translate into better maintenance. Thus, we intend to endow a machine with a representation that makes it alive.

Ideally, we would conduct a field study involving industrial machines and operators on an industrial plant floor, but there are many constraints related to safety, production issues, costs, etc. As such, we followed a user-centric approach and created similar operative conditions in the lab to test our concept. To that end, in this study we connected an off-the-shelf coffee machine to a holographic display, which shows the real-time sensory information encoded via the BioIoT nature metaphor.

Enhanced Coffee Machine

As a replacement for a real industrial machine, we used a coffee machine. Although it does not have the same level of complexity as an industrial machine, several operational aspects are transferrable: raw materials are used to produce a product (e.g., coffee capsules to produce coffee), fluids must be maintained within acceptable ranges (e.g., water for the coffee), waste materials have to be removed (e.g., used coffee capsules), temperature of the machine must have acceptable values and maintenance episodes are required (e.g., decalcification). An advantage of using the coffee machine is that people use it in their daily lives. They have a common understanding of its operational factors and do not require expert training.

Although there are several models of coffee machines that belong to the new generation of IoT machines, there are no open source APIs to access their sensor data. As such, we decided to enhance a basic model of a coffee machine with three types of sensors: a Ultra-Sonic Sensor HC-SR04 in the water tank to measure the water level, two Force Sensitive Resistors (one at the top of the capsule drawer to detected the presence/absence of the capsule and the other one over the On/Off to indicate when the user press the on/off button) and a temperature Sensor LM35 inside of machine to measure the machine temperature.

An Arduino Uno and Arduino Ethernet boards were used to collect the data from the sensor and transfer them to a MQTT server (lightweight message protocol). For convenience, a hardware interface was built to set the "status" of the machine to a desired condition. This feature allows to manipulate the sensors data (e.g., increase temperature) and simulate critical errors merely by pressing a button.

BioIoT Tree Metaphor

In our nature-inspired metaphor, trees represented single machines and a forest represented a factory floor. The machines sensory data were encoded into the

BioIoT Visual Language

Figure 4: Foliage density encodes the water level

Figure 5: Color of the leaves encodes temperature

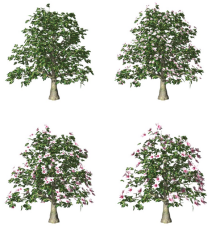

Figure 6: Flower size encodes time to maintenance episode

Figure 7: Sun highlights indicate the presence of a coffee capsule

Figure 8: Dead tree indicates a Critical Error

various visual features of the BioIoT tree metaphor. The operator was expected to infer the general state of a machine by assessing the tree appearance. For more details, a specific property of the tree should be visually examined.

Figure 4 to Figure 8 depict the visual metaphor designed to encode the machine status. We considered three main dimensions:

Water level of the tank is represented by the amount of leaves of the tree. Three levels are considered: dense foliage means the water level is higher than 2/3 of the water tank capacity, medium density foliage means the water level is between 2/3 and 1/3 of the water tank capacity and low density foliage means the water level is less than 1/3 of the water tank capacity.

Temperature is represented by the color of the leaves. We considered the operational range of the temperature between 20 and 60 C°. If the machine's temperature is within this range, the leaves are green. If not, the leaves are red.

Number of coffee cups made is represented by the presence/absence of magnolia flowers. The number of coffees brewed indicate when the machine requires maintenance (maintenance status). The absence of flowers means that the machine is running under duress, because the maintenance episode is long overdue. The presence of flowers means that the machine is operational. The size of the flowers encode when the next maintenance episode is required. Three possible states are encoded: small flowers indicate that maintenance will be required soon, medium-size flowers indicate an intermediate state and big flowers indicate that the machine will not require maintenance for a while, possibly because it has just been performed.

Additionally, a coffee capsule can be present or absent in the container. Before brewing the coffee, the operator should place the capsule in. When the capsule is inside the machine, the tree is highlighted, simulating via animation the sun light hitting the leaves. Finally, if a critical error occurs, the machine is represented by a "dead" tree, indicating that no coffee can be brewed and that the machine requires technical service.

3D Hologram Pyramid

We followed an immersive approach to enhance the environment with artificial nature visualizations. Initially, we chose augmented reality to display the metaphor (see Figure 1), because it has been used to encode multivariate, real-time sensory data using conventional visualizations [4]. However, the disadvantage is that a device is required to actually mediate the view and putting the device down disrupts the metaphor. Therefore, for the first working prototype, a holographic display was built to host the BioIoT tree metaphor. Figure 9 depicts the prototype structure.

It consists of a flat panel monitor connected to a PC, and an acrylic pyramid that reflects the four-side rendering of the 3D object, creating the illusion that the projected object is floating in mid-air.

A Unity desktop application creates a multiple-surface projection of 3D tree models. Four cameras with a 90° interval capture four views of the 3D tree model. The variations of trees were created with the SpeedTree Modeler for Unity. Figure 10 depicts the 3D tree model that represents a certain state of the machine. The application runs a MQTT client that can subscribe to the coffee machine sensor stream and make updates in real time.

3D Hologram Pyramid

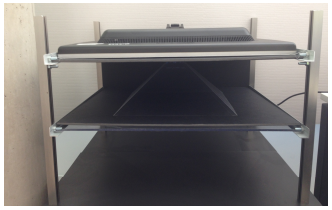

Figure 9: A cubic metal structure (50x50cm) with two shelves. The first shelve holds a 17’ display and in the center of the second shelve lies an acrylic pyramid (base 29cm, height 12,5cm). Black K-line is used to protect the interior of the structure from external light.

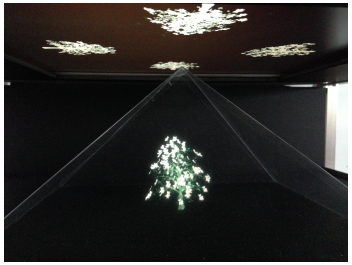

Figure 10: The display projects four views of the 3D tree model. Each surface of the pyramid reflects one side of the tree, creating the hologram.

Research Questions

This study aimed to answer the following research questions:

- RQ1 - Can the machine operators correctly interpret the sensory information encoded with the BioIoT tree metaphor?
- RQ2 - Do machine operators consider BioIoT tree metaphor engaging and pleasant to interact with?
- RQ3 – Do machine operators believe that the BioIoT tree metaphor could stimulate them to take better care of the machine?

Experiment

Our experiment settings was created to validate the concept and investigate the participants’ response to the encoding of machine states. We measured errors in interpreting the BioIoT tree metaphor encoding, as well as engagement and overall satisfaction (subjective) with the machine.

Apparatus

The BioIoT working prototype was used with the sensor-equipped coffee machine connected to the Holographic tree display. The experimenter could set the machine to any desired state using the available hardware interface to control the sensory data. The ingredients and equipment were ready for participants to brew their own coffee, including: capsules with different types of coffee, mugs and spoons, sugar and cream. A pot of water was available for the participants to refill the machine.

Procedure

The study was organized as a showcase with a cognitive walkthrough of the possible states of the machine. Participants were invited in groups of three. Each group was introduced to the machine and the concept as part of the showcase. The participants received an illustrated description of the encoding. After a brief introduction period, the participants were invited to brew themselves a coffee, giving them the chance to interact with the coffee machine.

The possible states of the machine and their representations were randomly distributed to fourteen experimental conditions. Participants took turns to approach the machine, which the experimenter set to the appropriate state. Participants were asked to observe the tree hologram and mark the machine status on a sheet of paper. Thereafter, the participants had to fill out a questionnaire.

Twelve participants (8M, 4F) took part in the study, four aged between 20 and 29, seven between 30 and 39, and one between 40 and 49.

Results

The participants interpreted correctly 120 out of 168 machine states (RQ1). The median of fully correct answers by participant is 11 (range between 6 and 14). The maintenance status determined by the number of coffees presented more incorrect answers (130 out of 168; median=12), followed by the water level (155 out of 168; median=14). The presence/absence of the capsule, the temperature and the critical error representations were easily identified by the participants (correspondently 165, 168, and 167 out of 168; median=14). Seven of the participants mentioned that it was hard to

Experiment Setting

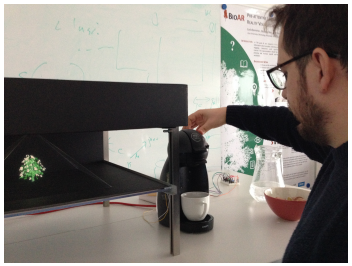

Figure 11: One participant interacting with the enhanced coffee machine, while the holographic display shows the correspondent BioIoT tree metaphor.

Figure 12: A group of three participants interpreting the sensory information encoded with the BioIoT tree metaphor during the experiment.

distinguish between the four different states related to the machine maintenance status based on the size of the flowers. One of the participants commented that adding more dimensions (increasing the number of sensors) would turn the visualization more complex and therefore harder to interpret.

All twelve participants considered the interaction (RQ2) with the BioIoT pleasant (5P – Strongly agree, 7P - Agree). Moreover, the participants considered the machine states representation aesthetically pleasant (8P – Strongly agree, 4P – Agree). Eight participants feel more compelled to take care of a machine (RQ3) which communicates the sensory information using the BioIoT tree metaphor (2P –Strongly agree, 6 - Agree). Four of the participants commented that they would feel even more compelled to care for the machine if a virtual pet (e.g., cat, dog) was used to communicate the sensory information. Three of the participants would like to be able to define their own metaphor, emphasizing the freedom to define the relationship between each sensor and the visual representation as an important feature.

Two of the participants mentioned that it would be interesting to include a gamification approach into the BioIoT concept, promoting a competition between the machine ”care takers” (operators).

The usability was measured using the System Usability Scale, which can effectively differentiate between usable and unusable systems. The BioIoT nature metaphor to communicate sensory data scored 71.25 points (median) on this scale, which is clearly above the SUS average score of 68 obtained from 500 studies [8].

Discussion

This work is a preliminary step for a longer study in which people are free to try out the setup over several days. The results encourage us to continue exploring the BioIoT nature metaphor as an innovative way to communicate real-time sensory information.

Four major issues were identified in this work: 1) the ability to personalize and configure the sensory data encoding is very important to the participants; 2) the amount of sensory information that can be integrated into a single visualization increases the interpretation difficulty, especially when differentiating between intermediate states; 3) a tree has few properties that can be used to encode sensory data, such a metaphor limits the amount of possible sensors; 4) the connection between the BioIoT tree and the coffee machine has to be improved, either by incorporating the coffee machine into the holographic display prototype or by using a head mounted display (e.g., Ms Hololens) to overlay the 3D tree model on the coffee machine.

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