Prototyping Ubiquitous Biosensing Applications Through Speculative Design

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***Abstract*— Biosensing technologies, under development since the 1960s, are now moving into the mainstream IT domain. It is only a matter of time before biosensors become as ubiquitous as mobile phones. While biosensing is inherently a technical domain, the acceptance of biosensing technologies in everyday life will more likely be determined by social and cultural factors.**

In order to imagine how such acceptance (or the opposite thereof) might occur, we have designed an online resource on biosensing and topics related to it. We then asked students of media design and architecture to speculate on future biosensing scenarios with the help of this resource. This experiment was performed at three universities, one in the United States, one in Canada and one in Indonesia. This paper describes results from this experiment and considers implications for the design procedures of ubiquitous sensor systems in general.

Keywords - biosensing, ubiquitous sensing, architecture, sociology, speculative design, prototyping

I. Introduction

Biosensors are chemical sensors in which the recognition system utilizes a biochemical mechanism. The biological recognition system translates information from the biochemical domain, usually an analyte concentration, into a chemical of physical output signal with a defined sensitivity [1]. Since Clark and Lyon devised the first glucose sensor in 1962 [2], biosensors have matured and are applicable to the analysis of many bodily conditions. More recently, third generation biosensors (sensors for which there is a direct charge or energy transfer between the biological component and the organic semiconductor [3]) have become robust enough for select commercial use.

While biosensors are no longer a technical novelty, they remain exotic IT devices when compared to silicon systems without biological transduction. Moreover, biosensor systems are unique in that they connect people to technical systems more intimately than most other sensor classes. They operate in close proximity to (sometimes inside of) the body to assess conditions below the veneer of social norms. Because of the scale (health and environment) and intensity (ubiquitous distribution) with which biosensing can be expected to operate in the 21st century, biosensing systems will likely have a significant impact on the general public's relationship to technology. Furthermore, there is strong evidence to assume that biosensor systems will shift from their currently established territory of personal health care for essential needs (where they have already been investigated by ambient system researchers [4], [5], [6]) into non-health domains, such as environmental monitoring, wearable computing, and even fashion and entertainment.

II. A WORKBENCH FOR UNDERSTANDING BIOSENSING IN EVERYDAY LIFE

In order to study this shift from essential to non-essential biosensing, we created a repository of materials on biosensing (SiReBi) [7] and asked students from design disciplines (media arts and architecture) during a semester-long course to consider possible near-future biosensor-informed systems and scenarios beyond applications in personal health care.

The materials collected in the repository contain, as of 2012, approximately 250 documents, about 40% of which pertain directly to biosensors, transducers, materials, and manufacturing processes, with a focus on recent publications (2009 to 2012). The course made available additional background materials focusing on a qualitative understanding of biosensing systems. Students were furthermore exposed to a simplified general biosensor model [Fig.1] as well as several of the most common biosensor and transduction configurations. However, the course did not delve into the quantitative and highly technical aspects of biosensor design, nor did it focus on novel materials and material structures important for the fabrication of biosensors [8], [9].

The remaining documents in the SiReBi resource cover topics related to but distinct from biosensing. The rational for this is that many lessons on biosensing can be learned by studying questions that have not yet appeared in biosensing systems, but are well documented in other areas. For example, the domain of wearable computing is being altered by the advent of biosensing. Wearable glucose sensors and wireless cardiovascular monitoring systems [10] collect data about the body that previously required a visit to the doctor's office. Inversely, these new wearables become subject to time-proven requirements of comfort, unobtrusiveness, and style. Once a wearable biosensor becomes ubiquitous, it is subject to the requirements of garment culture, including fit, aesthetics, and durability - criteria established over thousands of years of design, clothing, and materials development [11].

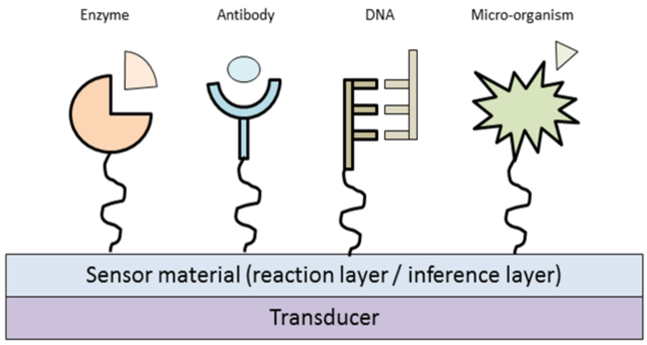

Figure 1. Biosensor model

Other topic areas included in the resource are: privacy, environmental monitoring, public health (as opposed to personal health care), participatory systems, sensor networks, and numeracy as each of these topics (meriting a discussion beyond the scope of this short paper) provided a means to investigate potential challenges awaiting biosensing in everyday life. Here we understand the everyday life condition as biosensing that considers the environment in which it operates, other biosensors, the ways it will be data-mined and globally networked while deployed on and in people individually and in groups [Fig.2].

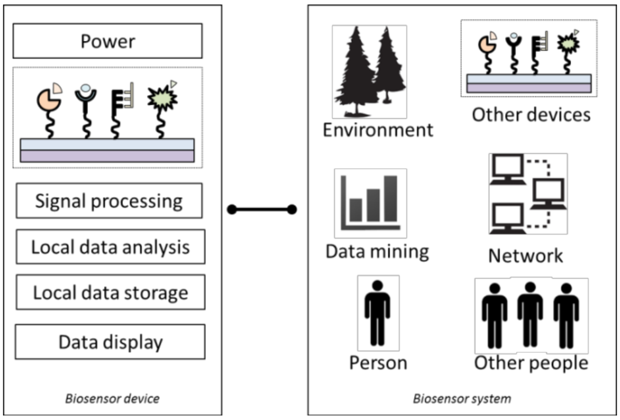

Figure 2. Biosensor model as a situated and relational object in everyday life.

III. CONTRARIAN POSITIONS

The focus of this experiment is not the technologies of biosensing themselves, but rather the design of situations in which biosensing systems operate, or could operate, in the near future. This is premised upon both the observation that some biosensor systems are effectively market ready and the hypothesis that the acceptance and wide distribution of biosensing systems will be primarily a function of their ability to integrate into social and cultural contexts. Based upon these assumptions, the project postulates that not all possible biosensing applications of the future reside in technical literature. For this reason, the resource and instruction materials include contributions from the social sciences and literature. Sociology, for example, has a long history of investigating various linkages between science and technology and the social structures in which they operate [12], [13], [14], [15] as well as the research methodology and social structure [14], [16]. Observations from these lines of inquiry are significant given the explicit goal of this project.

The SiReBi resource also covers contributions from novelists [17], and futurists [18] as these technology investigators invest more deeply in considering technical dystopias. The technophile community of engineering professionals tends to overlook negative side-effects of technical inventions. They usually do not consider the more gritty aspects of human nature. Imagining future scenarios of pervasive biosensing systems requires a broad and cross-disciplinary view with the curiosity to consider what might 'go wrong', especially given the potent combination of intimacy and ubiquity that biosensor applications will entail.

IV. SELECTIVE IGNORANCE AND SPECULATIVE DESIGN

Designers have little background in science and engineering. However, they are trained and encouraged to focus on system-level considerations of technical problems. Architecture, in particular, has a rich history of operating in technical territories while focusing on comfort and livability delivered by technical systems. Indeed, designers and architects collaborate with technical specialists in order to isolate themselves from technical details beyond their expertise. While such 'selective ignorance' is anathema to engineering, it is operational in the arts and design disciplines. Designers routinely envision situations for systems they only qualitatively understand, choosing to leave technical system details to others. Inheriting this approach from architectural and graphic design, interaction designers tend to focus on the 'big picture,' or on the creation of a particular kind of experience, trading the lack of depth selectively for increased breadth.

There is an established history of artifact design that attempts to challenge preconceptions about how human-made systems operate in everyday life. The field of *critical design* [19] is influenced by radical and non-commercial design activities from the 1970s onwards [20]. *Speculative design*, sometimes used synonymously, is equally critical of standard design assumptions but is further concerned with imaginary, future qua exploratory-hypothetical approaches to designing artifacts. While both critical and speculative design attempt to respond to the experience of political, economic, and social change, speculative design is more focused on technological conditions and more willing to engage them. As such, the speculative design approach is a useful vehicle for investigating novel sensing systems and a viable tool for mining the SiReBi repository of biosensing materials.

Ultimately, the choice to engage designers, as opposed to engineers, for this exercise is further justified by the belief that the development of biosensing systems in built environments will in due course fall to those already tasked with integrating technical systems into houses, offices, and public buildings. In this regard, future applications of biosensing systems will be no different than biometric access and surveillance systems routinely deployed today around the world today.

This experiment is not the first attempt to consider bionsensing as a cultural endeavor. Artists such as Christian Nold have experimented with galvanic skin response based sensing to query the relationship between sentiment and place [21]. In this experiment the goal is to focus mostly on the kind of experiences that can expected to become possible with third generation biosensors systems operating directly with biological samples, or suggest a different approach to biosensing and sampling altogether.

V. CASE STUDY – MANDATED BIOSENSING

In order to better understand how specific situations and constraints influence a given (biosensing) technology, the seminar performed several case studies, one of which is described here.

The realm of law enforcement is a powerful lens onto side effects of technologies in social contexts, as the applications (but not the circumstances) are clearly defined. A good example is the alcohol monitoring sensor by *BI Incorporated* [22]. This firm delivers monitoring equipment to law enforcement agencies in several countries, offering complete hardware and software solutions for compliance technologies. The company serves both sides of the supply chain, providing services and devices to law enforcement and offenders. One of BI's most innovative products is a tamper resistant, waterproof ankle-worn alcohol monitoring technology called *BITAD*. This device [Fig.3] measures ingested alcohol through a sensor that rests firmly on the skin. *BITAD* continuously monitors alcohol use via vaporous or insensible perspiration passed through the skin as detected by a proton exchange membrane checking oxidation current [23], [24]. Despite the fact that biosensors can be rather delicate devices and have at least as many degrees of freedom to malfunction as generic electronics, *BI* has secured single-source admissibility in courts of law, making secondary or backup testing unnecessary and second opinions unwarranted. Whether or not an offender returns to jail is dependent solely upon readings from a single device. Furthermore, *BITAD* easily interfaces with a GPS system for location tracking. This configuration also supports text messaging and voice calling. However, the flow of information follows the prescribed hierarchy: officers use one-way voice calling to communicate with the client when they want. Clients, however, can only respond when spoken to by pressing a button on the unit's keypad.

Figure 3. An ankle-worn alcohol detector (source: BI Incorporated)

While the reliable results from the biosensor module allow a new degree of precision in detecting alcohol through the skin, the boundary conditions into which this sensor is placed, and the extraordinary degree of confidence in its performance, endow it with a level of invasive and uncontestable control the application itself does not warrant. The inherent intimacy of biosensing operations is particularly vulnerable to this kind of *control creep*.

VI. SITUATED AND RELATIONAL BIOSENSING

Section 2 briefly listed several biosensor-related topic areas included in the SiReBi resource. As previously mentioned, this array of topics is vital to anticipating concerns that might arise as biosensing systems occur more pervasively in everyday life and to attempt to proactively address such problems. There is yet another dimension to this 'relational' approach. As Latour emphasizes, all systems created by people operate in relational contexts. Similarly, ubiquitous biosensing will not occur in isolation. It will be integrated into the IT paradigms of big data and cloud computing and, as such, will be subject to similar discussions regarding the need for and limits of personal privacy. Thus, there is no better way to get 'the big picture' on biosensing than to relate it to other areas upon which biosensing will be dependent or that have gone through similar development cycles prior to becoming ubiquitous.

In order to understand just how important local and cultural conditions will be for ubiquitous biosensing, the design experiment was performed simultaneously in North America (Buffalo, USA as well as Toronto, CA) and Yogyakarta (Java, Indonesia) [1]. The US students were more inclined to find negative aspects of biosensing in everyday life, while the Indonesian students were more interested in practical applications and the potential for palpable improvements to life quality in food, air, and water. Interestingly, concerns regarding privacy were hardly shared at all on the Indonesian side. Students seemed largely unperturbed by the potential of bio-sensed data to be misused. The language *Bahasa Indonesia* does not even have a term for the English word 'privacy', and many habits of daily life seem agnostic to the concept. Furthermore, several biosensor design proposals from the Indonesian students explored topics related to religious belief systems, translating into, for example, portable biosensors to detect halal foods sold informally at public food stalls on street corners. Viewing biosensing in everyday life through the lenses offered by these reference domains, as well as varied cultural conditions, is the practical consequence of the situated relational biosensing paradigm alluded to by the title of the SiReBi resource.

VII. MAPPING OPPOSITIONAL FORCES WITHIN BIOSENSING IN EVERYDAY LIFE

While it is not possible to predict how biosensing in everyday life will actually occur, one can consider which concerns might be more significant than others. The results from the experiment suggest that the following four major oppositional forces will be of importance.

A. Voluntary vs mandatory biosensing

Biosensing applications in mandatory contexts have a different valence than those in voluntary situations. For example, the bio-monitoring practices of self-trackers [25] are perceived as a new means of liberating individuals from medicinal practices that are unable or unwilling to focus on individual needs and interests, while the bio-monitoring of parolees, as the example above describes, seems pre-arranged to limit all possible forms of individual agency.

B. Recreational vs essential biosensing

In essential biosensing, such as diabetes management, there are immediate and obvious benefits from biosensing systems. Survival is a stronger instinct than fear of data misuse and, thus, privacy in essential biosensing is only a secondary concern. Recreational biosensing applications, however, are more prone to scrutiny regarding misuse of biosensed data through data brokers or data miners. Companies such as *PatientsLikeMe* [26] that navigate between essential and recreational health care have marketing strategies that address this condition. *PatientsLikeMe* openly announces its practice of selling data to insurance companies, health care providers, and medical device manufacturers, making the rules of the exchange transparent. However, the incentive to disclose information is made particularly seductive by linking access to other patients' experiences (an urgent need for some patients) to the 'volunteering' of one's own personal health data.

C. Technological vs cultural constraints

Biosensing is an essentially technical endeavor, but the ramifications of biosensing reach deep into cultural domains. This is true of many other disruptive technologies, but the chasm in biosensing is larger, as biosensing data are 'harder to argue against' than, for example, data protocols of mobile phone networks.

While every biosensing application will be adapted to the regions and cultures in which it operates, the adaptation might occur in fits because of the *qualculation* (the qualitative change in culture created by the prevalence of computing procedures, coined by Callon and Law [27] and popularized by Thrift [28]) particular to biosensing. There will be no room for old beliefs and old habits. The Ganges in India, for example, is incredibly polluted, and state-of-the-art environmental biosensing could detect bacterial contamination with unprecedented accuracy, yet many inhabitants are uninterested in these biosensing-based opportunities because the river is revered as a symbol of spiritual purity [29].

[1] The course was held in North America and Indonesia. At the University at Buffalo, 12 graduate (masters and PhD) students participated (including visitors from Weimar Germany); at the University of Toronto 7, and at the Universitas Islam Indonesia 22 graduate students participated.

D. Private vs public applications

It is likely that the discussions associated with privacy in ubiquitous informatics [30], [31], [32], [33] will be inherited whole-scale by ubiquitous biosensing. As in IT, one can expect privacy to be compromised through data use, analysis, and aggregation as much as through the collection of the data itself. However, in biosensing applications in everyday life, the positions of private vs. public seem to be more polarized. Private data from one human body is truly private and unique, but when *aggregated across a population* of a region, the data set speaks to and of the body public on a level of intimacy that even confidential financial data does not. The diabetes map of the USA created by the Institute for Health Metrics and Evaluation [34] might be one example of the new biosensed public, hinting at yet more complex dependencies between the private and public sphere.

VIII. IMAGINING FUTURE BIOSENSING SCENARIOS

A. Biosensing and social media

In the past, IT systems have been accused of giving preferential treatment, as it were, to the mind over the body. Biosensing was seen by some during this experiment as way to alter this imbalance.

A hallmark of social networking is the option to assume a persona different from one's real-world identity. By introducing bio-sensed data into this equation, identity becomes more directly entangled with a social network participant. The trade-off in a biosensing-enhanced social network would be the ability to share that which 'words can't say.' Such a system might be attractive to social network users if it could be integrated into existing online habits and comfort requirements. This could happen, for example, by integrating the sensor directly into an interaction device, such as a computer mouse, that is already in direct contact with the body [Fig.4].

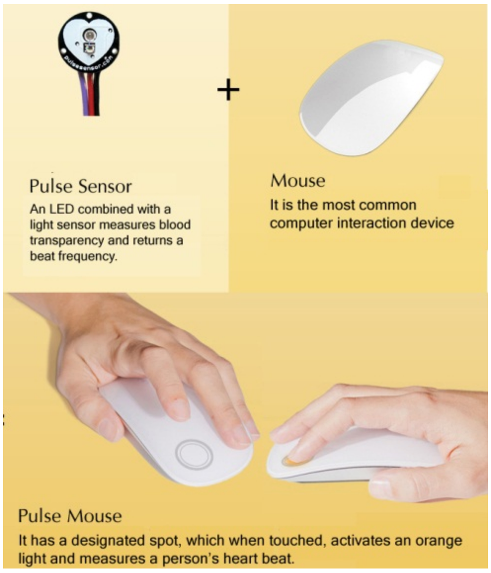

Figure 4. Pulse Mouse

B. Biosensing and sex

Advances in Lab-on-a-Chip (LOC) technology might one day make possible new interfaces that combine diagnosis and notification. For example, a multipurpose wearable biosensor "smart condom" could serve as both a traditional prophylactic against the spread of sexually transmitted diseases (STDs) and as a diagnosis device to explicitly indicate the presence of a set of contagions. This *SexPOCkeT* design [Fig. 5] proposes an integrated microfluidics biomaterial prophylactic, or Lab-on-a-Condom that seeks to exploit human social behavior patterns to "spread" diagnosis (as well as possible follow-up treatment) in parallel with the modes of transmission of the infectious social diseases for which it has been engineered.

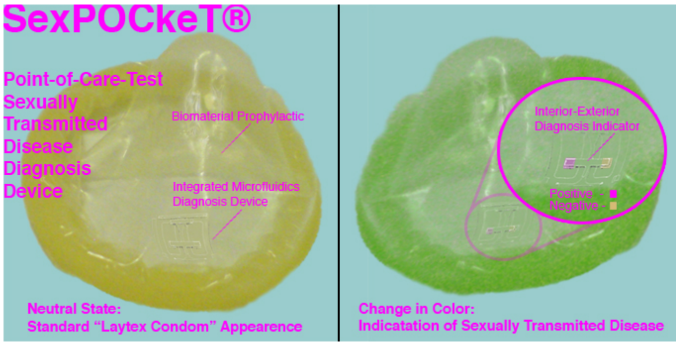

Figure 5. SexPOCkeT

The condom model is only one of many possible wearable designs to operate upon a human social behavior set, but serves as an illustration of this concept due to the social contract and intimate proximity central to sexual behavior. Diagnosis of a particular set of STDs is marked by a change in condom color as well as an indication of the source ("Interior-Exterior") such that partners are distinguishable. The return of a negative result reveals no visible change in the condom, while the color green, for instance, might signal a positive result for the Human Papillomavirus Virus (HPV). Similarly, the color red might indicate Syphilis, the color blue, Gonorrhea, and so forth. Though at first blush such diagnosis, unambiguously indicated to both parties, might seem exceedingly awkward for this intimate setting, it is the intent of *SexPOCkeT* to apply a symbiotic "peer pressure" toward seeking treatment for an indicated disease.

C. Biosensing and mass transit

As opposed to considering biosensing for personal use, the following design imagines a biosensing application for public use. This proposal calls for surface mounted sensors integrated into handrails and seats in public transportation systems [Fig.6], allowing pathogens to be detected during daily commuting where large segments of the population share small spaces and diseases can easily spread. While the system could not prevent the spread of infections, it could record occurrences of infection events. In severe cases where urgent action is warranted, it might inform mass transit users immediately as it posts its data to public health authorities. While the system could not prevent pandemics, it could track the flow of pathogens in critical public spaces and provide an early warning system. In this regard the proposal is similar to other indirect tracking systems [35].

Importantly, the system would have to maintain anonymity of disease carriers to prevent mass panic or vigilantism. Anonymity could be maintained on a system design level by discarding data that can readily be attached to an individual or by delaying the system response until a potential carrier is no longer in the bus or train. Also, the detection event could include methods not directly perceivable to people (via UV light or similar) to prevent people from knowing what they might not need to know. Without a doubt, though, the desire to protect sick individuals will clash with the desire and need to protect a (still) healthy public.

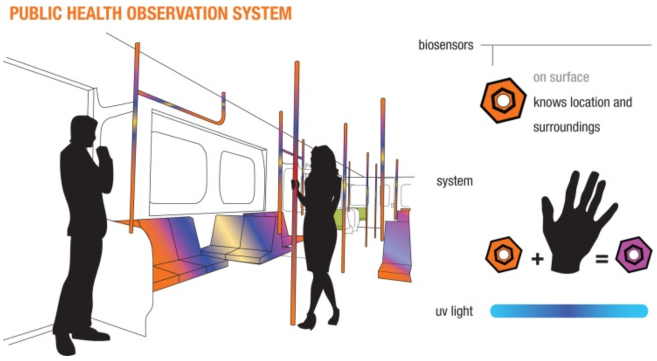

Figure 6. Public Health Observation System

D. Biosensing e-waste contaminants in emerging economies

Biosensors have been proposed to assist in on-site detection of contaminants in hazardous waste sites [36].

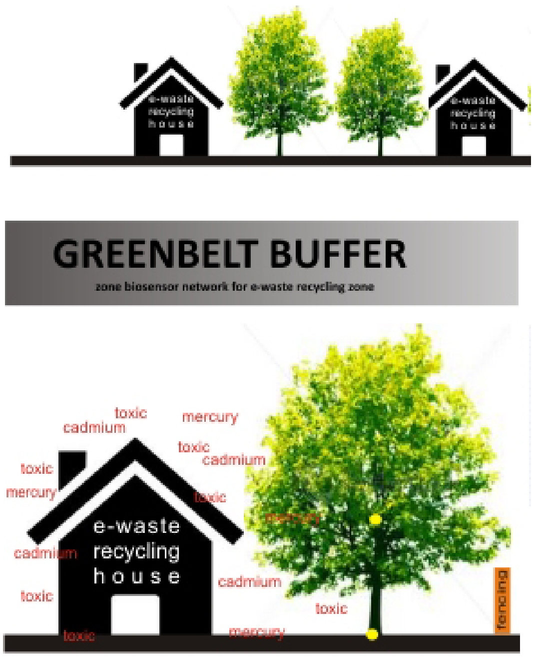

Figure 7. Emerging economies greenbelt buffer

Furthermore, electronic waste (e-waste) has emerged as a source of critical global environmental health hazards because of massive production volumes and insufficient management policies in certain countries [37]. In the 21st century economy, much of the global e-waste is generated in rich countries and disposed of in countries with lacking or poorly enforced environmental standards, to the detriment of the regional population. Responding to this condition, one design proposed a collaborative biosensor-enabled 'green belt' capable of detecting e-waste contaminants. The proposal imagined using trees such as mango, jackfruit, banyan and tamarind as energy sources [38], [39] as well as on-site analysis of leaves and roots, to evaluate both immediate and accumulating threats due to prolonged exposure to e-waste contaminants. The design suggested that this e-waste monitoring data should be collected by community members themselves and shared with other nearby villages [Fig.7].

E. Biosensing as memory management

The course encouraged participants to imagine biosensor scenarios beyond those dictated by immediate needs or emergencies. Outside of essential health care-related scenarios, there is still plenty of room for novel biosensing applications.

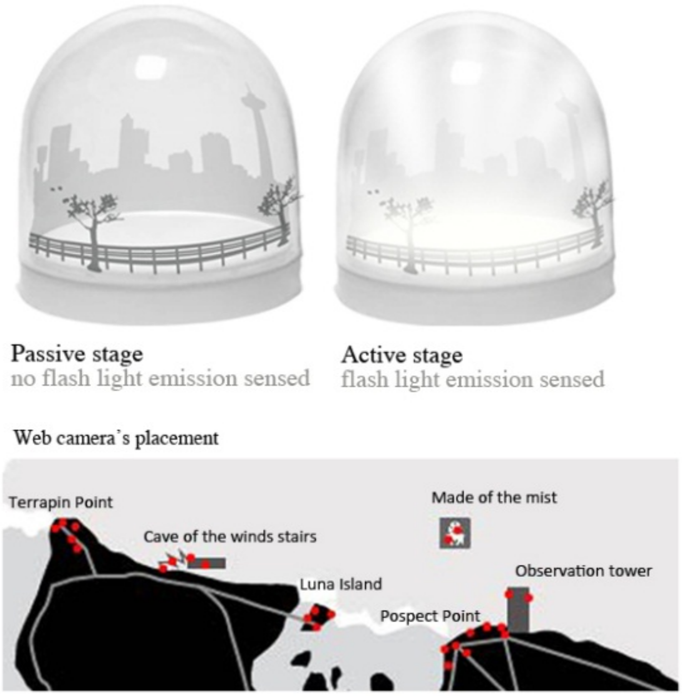

Figure 8. The networked biosampled souvenir

One design expanded the concept of biosensing and applied it to the souvenir industry [Fig.8]. In this design, a networked object would contain a bio-sample of the location it represents (in this case, water droplets from the popular tourist destination Niagara Falls) and manipulate this sample in accordance with events (SMS messages, RSS feeds or webcam surveillance photos detecting tourist activity, uploaded to the internet) occurring at the site to replace the static souvenir model with a dynamic, physical, and real-time connection to a place to be remembered.

IX. OUTLOOK AND FUTURE RESEARCH

The work described above may seem whimsical and even naïve. Some might consider the approach of little merit as it creates many more questions than it answers and not enough depth to effectively solve the problems identified.

It should be clear that the approach described here is not proposed as a replacement for existing design processes; the design ideas themselves are not understood as production level ideas. Rather they are examples of a different way of thinking about developing technologies, and biosensing in particular, before they become prevalent in everyday life.

The speculative design method described here is intended to cover territory, as it were, that other design approaches do not. For example, this approach can be helpful in considering how to deal with the *disruption of established knowledge boundaries* biosensing coupled with ubiquitous informatics will generate. As the example of 'biosensors in mass transit' briefly touched on, the consequences of being able to detect pathogens in public spaces means that these public spaces no longer offer the kind of anonymity they have in the past. In the future, one might be held accountable for a nasty cold (that indeed can spread and infect others). The availability of this new class of information will have unconsidered consequences for the unwritten social contracts and norms that regulate all kinds of exchanges in the public sphere, impacting societies globally as they become exposed to the new realities of ubiquitous biosensing.

While the IT industry invests heavily in user studies to evaluate new products and even to anticipate the potential for new products in untapped markets by various methods (including experimental ethnographic approaches of 'decoding culture' [40]) speculative and critical design methods are still outside of the production pipeline, relegated to magazines and galleries where they can do no harm. The coming global deployment of biosensing systems is an opportunity to reconsider, from the ground up, how we design intelligent systems that interact with people on intimate and global scales. The 'old' approach of building technical artifacts first, then discovering later the side effects they generate, scales poorly to 21st century challenges.

The speculative design method could be integrated into existing design tool chains, and coupled with user studies. Results from these processes could be fed back to the hardware, software, and system engineering levels for alterations, for example, to counteract some of the dystopian potential found in the speculative explorations. This experiment argues that such an expanded design approach, cycling from technical problem definition through speculative design stages through user studies, and then back to the technical design stage, could help generate better overall systems; systems that consider in broad terms the implications of the designs and are as robust technically as they are attuned culturally to the specific conditions in which they will operate.

Our approach opens the door to other contributions as well. This situated speculative design approach is helpful in building not only product ideas but also theories. There remains a lack of formal understanding on how to organize, manage, and represent data on the body, particularly on the scale that mass biosensing will generate. There is a need for a new language that intelligently mediates between the technical sphere of medicine and biology to the everyday understanding of people using biosensing systems on their bodies, or government agencies relying on such systems as a decision making basis. And there is a need to come to terms with the legal ramifications of data mining and data brokerage of body metrics.

Hopefully SiReBi and the speculative design energies emanating from it will be helpful in navigating this new territory.

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