Human Nature: The Subject and the Headache of IoT-Based Sociometric Studies

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Abstract

Sociometry has been recently placed on the verge of a new era by first attempts to utilize Internet of Things (IoT) technologies in quantitative studies of social relationships. More and more results of traditional questionnaires and observations, which are prone to bias and human errors, are about to be verified with a supposedly reliable source: data collected by a wireless sensor network (WSN) monitoring individual and group behavior. It may be expected that the potential and availability of sensing devices will soon entirely redefine the practices of sociometry and alleviate its present limitations.

However, this revolution requires much more effort than direct application of common IoT solutions. The collision of curious, yet careless human nature with typical sensing devices leads to unique challenges in WSNs. In this paper we share our experiences from deployments of our sociometric system in two distinct environments. Initially, we studied behavior in software development companies, then we conducted a pioneering instrumentation of emulated space missions in a confined habitat. Despite having developed hardware-software platform dedicated to this end, our research group encountered a number of issues specific to the human nature. While some of them were predictable, but inevitable with a limited budget for the research, others were entirely unexpected and had serious consequences.

Categories and Subject Descriptors

H.4 [**Information systems**]: Sensor networks; J.4 [**Applied computing**]: Sociology

General Terms

Human Factors, Experimentation, Reliability

Keywords

IoT, custom hardware, space colonization, behavioral study, sociometric system, pervasive sensing

1 Introduction

The recent advent of human behavioral data collection revolutionizes social sciences. A new subfield, Computational Social Science [4], aspires to answer principal questions on social behavior through a data-driven approach. More importantly, however, from quantifying and analyzing virtual communities like, for instance, on Facebook or Twitter, the field transfers to investigating real-world human behaviors. This shift has been made possible by miniaturization and popularization of ubiquitous devices. In effect, the Quantified Self movement appeared to create personal feedback loop systems through the quantification of every aspect of one's life with a body-area network of pervasive sensors. The envisioned collaboration among such devices of individuals leads to a new possibility: the ability to sense, understand and shape social behavior of entire groups of people [7]. For instance, by collecting data on face-to-face interactions, we could reliably map social bonds and community patterns, which in turn would allow us to find influential people or to understand and model the spreading of diseases. By quantifying entire crowds, we could detect their dynamics, which could help in designing public spaces [1]. The instrumentation of organizations may in turn lead to revealing factors affecting wellness and performance of employees. Finally, a creation of social feedback systems may foster self-knowledge and personal development.

A few years ago, to facilitate social sensing studies, our research group developed a custom, versatile, wearable platform in a form-factor of a conference badge. The devices have already been used in a series of unique studies in various settings, including software development companies and emulated space colonisation missions. While a single study involved one or two weeks of actual sociometric monitoring with a WSN, this period was preceded by days of careful preparations and followed by laborious data analyses. Moreover, during most of studies we visited the location, listened to first impressions of participants and checked on devices. The case of emulated space missions was, however, an exception – due to the specific nature of the setup we had no direct contact with the participants and we were not allowed to conduct any maintenance works throughout the entire observation. Yet, these seemingly more difficult studies turned out to run smoothly and were more successful overall – we collected data of higher-quality and observed nontrivial social phenomena. Since the setup was almost identical for all the deployments, we suspect that this significant difference had its source mainly in human factors. Therefore, here we present a selection of difficulties related to the broadly understood human nature that troubled our research.

The paper is organized as follows. First, we describe the study setup and present our devices and methodology in Section 2, then we elaborate on deployment settings in Section 3. Next, we share our experience of human nature involved in IoT-based sociometric study in Section 4 and the influence of device design on the study success in Section 5. Section 6, inspired by the lessons learned from the project, sets suggested direction for further sociometric deployments.

2 Study Setup

Initially, at the SocSenSys project we employed eZ430 Chronos Smart Watches for our research. Those were quickly abandoned due to their resource constraints. Another popular approach is to employ smartphones, which are a great platform to validate ideas, but they are missing specialized sensors, which may enable advanced studies of novel techniques. Because of the lack of other available platforms suitable for the project, the team decided to develop our own versatile, power-efficient and interoperable devices. We elaborate on the design in [1].

2.1 Devices

The idea was to provide an open platform with virtually all usable sensors, designed to facilitate experiments in as many and as various social sensing scenarios as possible. Drawing from prior experience, the platform has a form factor of a name badge. Therefore, we refer to it as just "badge". The badge was developed from scratch up: PCB (Fig. 1a) was designed and produced with 3d printed casings and custom leashes. The final device is slightly lighter than a typical smartphone (111g) and was designed to be worn on a leash for a whole day (cf. Fig. 1b). The badge runs on a Cortex-M0 MCU, is equipped with two radios: a main 868MHz CC1101 transceiver used to detect devices proximity and smart-gadget compatible 2.4GHz Bluetooth Low Energy interface. An infrared transceiver is used to detect whether two devices are facing each other e.g. during a conversation, which is also monitored by a microphone. To optimize study subjects' privacy, we do not store raw recordings: only derivatives such as presence of human speech and loudness. We also monitor subjects' physical activity through an e-compass module (accelerometer with magnetic orientation) and a gyroscope. Environmental conditions are quantified by a barometer, a thermometer and a light sensor. Finally, the badge is equipped with a power-efficient e-ink display as a main user interface of the badge, accompanied with 4 tactile buttons, a buzzer and an LED. During our studies we log all of the sensors with high frequency and store on an external SD-card. A 2400mAh@3.7V battery is enough for around 72 hours of continuous data logging.

To simultaneously charge 100 badges we designed a tree-structured charging station: each device is connected to one of 14 leaf 7-port active USB hub, whose are connected to 2 intermediate hubs, connected to a Raspberry Pi microcomputer. The Raspberry Pi acts as a device enumerator, because without it the badges wouldn't draw more than 100mA due to the USB 2.0 specification.

(a) Device's PCB

(b) Worn badge

Figure 1: The sociometric badge PCB created at the SocSenSys project. On PCB: 1) MCU, 2) 868MHz antenna, 3) e-compass, 4) gyroscope, 5) IR receiver, 6) microphone, 7) BLE module.

2.2 Methodology

The participants wore our badges for the whole time they were active at the location, charging them overnight. Every evening, they filled out a short survey asking about their level of satisfaction, well-being, comfort, productivity and distraction on 1-9 scale. To measure spatial proximity between badges we exploit the possibility to adjust transmission power level, thus varying transmission range of the radio. Then, badges repeatedly broadcast their id to indicate presence both with 868MHz radio and the IR transmitter. Yet, it turned up to be of limited use in the described settings, as closeness are usually related to desk closeness. We also employ 27 BLE beacons for room-level indoor localization.

From the collected data, a timeline was created with metrics as in Table 1. Through a fusion of proximity, localization and conversational metrics we infer interactions between study participants. This data allows us to detect communities and quantify the participants social roles. Various modalities were cross-validated: analyses based on a single signal yielded similar results. On the other hand, we can quantify the environment and the roles of specific localization in the facility. Finally, a shared timeline of all participants reveals the overall state of the analog space mission or company activities (cf. Fig. 5).

3 Deployments

We conducted our research in two very different settings. First, we conducted week-long study in two software development companies with, respectively, 20 and 60 employees, located in 3-stories villas. The convenient location of the firms allowed us to inspect the buildings and to plan positions of static devices such as beacons and the charging station onsite. The participants were introduced to the study with a presentation and all of them were instructed on how to handle and charge the device. Each participant received an informed consent form with details on collected data, study purpose and a declaration of confidentiality. Then, the deployments were inspected for conformance midweek. The main goal of the study was to find out more about the participants' preferences and analyze if the buildings properly facilitate activities of the employees.

#	Category	Metric
1	Location	The estimated XYZ location in the building.
2		The location name.
3		Whether the employee is in his/her office.
4	Conversation	Speech activity: the ratio of audio samples detected as voice.
5		Average volume of speech frames.
6		Average volume of all frames: noise level.
7	Movement and orientation	Whether the wearer is moving.
8		The variance in acceleration.
9		The azimuth the badge is facing.
10	Environmental	The temperature relative to the reference badge (in °C).
11		The atmospheric pressure relative to the reference badge (in hPa).
12		The illuminance (in lux).
13		The level in the building as inferred from the pressure difference.
14	Socio-spatial	Ids from received 868MHz beacons for each power level along with RSSI.
15		Ids from received IR beacons along with power level.

Table 1: Behavioral and environmental parameters for each time frame.

Then, after one year we were invited to quantify interactions between so-called *analog astronauts* during emulated space colonisation missions – one to the moon (Lunares) and another to Mars (ICAres), which is reported in [6]and [2]. The general purpose of such missions is to test procedures, hardware and assumptions about human nature in safe conditions. The emulation required 6 astronauts to live for two weeks in an isolated location, which mimicked a space habitat and the regolith. During the study we were not allowed to enter the spot of the experiment and direct contact with the research subjects was forbidden as well (analog astronauts communicated solely with the mission control). The participants, expected to perform all activities that are envisioned as necessary in extraterrestrial environment, were in addition asked to wear the badges in the emulated daytime for at least a week. We intended to apply sociometry to find the social structure of the group and describe its evolution, potentially influenced by more or less extreme challenges planned for the emulation. Apart from our goals, the main objective of the first mission, Lunares , was to verify endurance of the analog astronauts overloaded with scientific work, while the second, with a visually impaired astronaut, was supposed to explore the consequences of a hypothetical catastrophic event resulting in disability of an astronaut.

4 Human Nature Against Technology

While all four deployments successfully let us to collect considerable amount of data, they also posed unexpected challenges related to behaviors and attitudes of the participants. It turned out that, apparently, some of our assumptions on human nature were not entirely true in the circumstances of the study. First of all, we had imagined that people being the subjects of our research would be cooperative and, specifically, willing to follow the planned procedure. They had been also expected to handle our devices with caution and to avoid any risk of distorting the sociometric observations. Yet, just one day of our setup running in one of software houses was enough to realize that some participants were not always playing on our side.

4.1 Hardware Manipulation

What took as by surprise at monitored software houses was curiosity of their employees, who decided to take a closer look at our device and thoroughly test its durability. To begin with, when the day following the start of the study at Company A we checked on the badges, we discovered that running time of two of them is suspiciously short. Software engineers identified as temporary owners of these devices admitted they had attempted to push each and every button on the device, hoping to unlock hidden features. This way the inquisitive participants pressed (helping themselves with a sharp pencil) the reset button, which had been purposefully designed to be difficult to notice and access, and thereby zeroed the running time.

Although in further deployments we asked the research subjects explicitly to refrain from playing with the devices, a similar situation took place in Company B . This time, in the middle of the study, one of software engineers reported that their badge was blinking. Since such signal was supposed to indicate that a critical error had occurred, we found it quite perplexing: the participants had been equipped with thoroughly tested, working badges, all the devices were running the same software, but only one of them failed. While we were wondering if, perhaps, quality of hardware pieces was the source of the problem, the participant recalled that the blinking had started after an SD card had been removed from the badge (to check what was being logged, as they explained). The card had been reinserted almost immediately, but the blinking had persisted. It was due to the fact that the devices had been programmed to detect the SD card only after a reset. Later, to prevent similar situations we modified the software to repeatedly verify if the card is still missing and to reset the badge automatically in case the card is found.

Despite triviality of these two problems, their consequences were considerable, including malformation and loss of data. A memorable example of how such a tiny human error may lead to a pressing issue is a situation, where one of the participants in Company B needed a free socket in the plug strip at the charging station. The employee, unaware of the importance of the microcontroller enumerating the badges for charging up (cf. Section 2), disconnected the enumerating device what resulted in the badges running out of battery before the end of the daily session. After this incident we decided to instruct the participants individually in the use and the maintenance of the sociometric system to make sure everyone knew that playing with the hardware was not permitted.

4.2 Bending The Rules

Precise user instructions can be, however, insufficient if the research subjects have no idea on the inner-workings of the setup and despite this fact they intend to adjust the given guidelines to their needs and wishes. For instance, some participants in Company A did not realize that wearing their badges backwards or underneath a piece of clothing (e.g. sweater) hinders an important functionality of the device: sound recording (a microphone was mounted on the front side). Consequently, our first measurements included muffled noises, the quality of which was insufficient to perform data processing typical for sociometry, e.g. detect talk structures or distinguish voices.

The microphones happened to be covered also when the research subjects put their devices front side down on the desk. Moreover, in such situations a few other sensors also took useless samples: the IR sensor was not able to detect another person, the light sensor claimed it was completely dark and, finally, the gyroscope measurements were indicating the device was not used at all (in our terminology, it was *inactive*) (cf. white regions at Fig. 5). Participants who took off their badges but kept them within a hand's reach explained that they did not realize the samples from the aforementioned sensors were important in such static circumstances like sitting at the desk when 'nothing really was happening'. They reasoned it was their location what mattered then and this parameter should have been correctly measured even by a badge laying next to the research subject. From our perspective, data collected by *inactive* devices were useless as we could not be sure of any parameters of the user: they might as well have left the badge forgotten in the office.

Another proof that even best intentions of the participants do not guarantee the procedures are followed correctly was given by the deployment in ICAres. This time one of the analog astronauts replaced their broken badge with the one that belonged to the analog astronaut who had emulated their own death and left the mission on the fourth day. While the seemingly harmless action intended to save clean badges for later it was against our assumption that each badge was assigned to a just one owner. Violation of this rule caused chaos in our scripts for automated data processing and required significant efforts to put the collected data in order. Consequently, such experiences made us realize that precise instructions are not enough: we should have provided the participants with more information on the deployed technology itself.

4.3 Carelessness

Next to curiosity that drives the research subjects to play with hardware and the tendency to bend the rules, there was one more feature of human nature that posed a threat to our venture: carelessness. We had believed that the noble idea of contributing to science would have been enough to discipline all the people involved in the study. It was not the case as regards the deployments at software houses, where enthusiasm was mainly ours. For some employees a conference held out of the office in the morning was a good reason to drop the badges for the rest of the day as well. Some subjects at Company A and Company B were frequently not meeting our requirements in general: they tended to forget to wear the device, did not complete the surveys, and even destroyed the leash. All of this happened unintentionally, due to distractions, sloppiness, and a little bit of disregard for any rules in general. Moreover, what truly surprised us as an example of a collective negligence was an enormous mess at the charging station that we saw at Company B in the middle of the study (see Fig. 2).

The chaos observed at software houses stood in contrast

Figure 2: The chaos at the charging station.

to self-discipline demonstrated by the analog astronauts during the instrumented missions. The participants of Lunares and ICAres proved to be devoted to the sociometric experiment and took great care of the hardware as well as of the quality of measurements. The striking difference between behaviors of the two groups might be understood better in the light of survey results presented in the Fig. 3 and could be an independent subject of research. As for now, we conclude that people who like their environment and their job are probably more reliable candidates for a sociometric study.

5 Technology Against Human Nature

Current design guidelines already embrace unpredictability of human nature. Fields such as user experience and accessibility have thoroughly studied the importance of antropocentrism in design. Yet, while some issues do not have a ready-to-use solution, with a limited budget it is inevitable to miss some of the latest recommendations.

5.1 Participation Rate

The first and foremost issue comes from privacy considerations. As the badge collects extensive amount of data about an individual, some people may withhold from participation in such a sociometric study. We took countermeasures to this issue: during an all-hands meeting we presented the system, reassured anonimity, promised an insight into the results, highlighted potential improvements to working conditions and answered questions. The opt-out rate in the companies was about 20% and hugely impacted our analyses. Without a way to identify everyone in the group, suddenly, being in someone's companionship was mistaken with being alone: people seemed to talk to themselves. Moreover, presence of even one non-participant at a meeting was able to jeopardize conversation analysis. Measurements of the effects of nonresponse error for various network properties show that for most properties, the absence of up to 10% of actors in the network does not cause large errors in parameter estimation. However, for some network properties, such as clustering or the mean path in the largest component, only data missing more than 30% of actors leads to significant errors [3].

In each study, we noticed a drop of motivation with time.

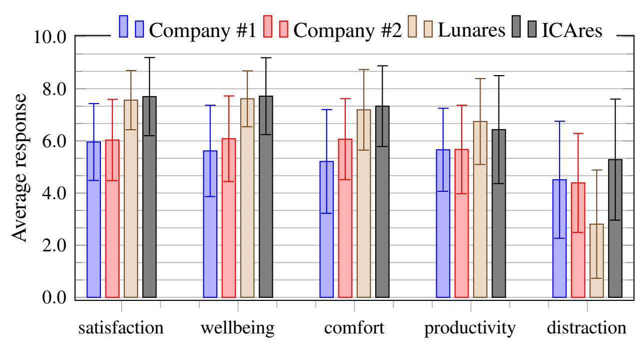

Figure 3: Differences between the two groups of research subjects: averages of grades of the selected parameters (1-9 scale) reported daily by the employees of a software company and the analog astronauts during the studies.

In the developers' studies, it was especially evident, and participants were dropping out of the study everyday, essentially becoming the haunting non-participants. The reasons were manifold. Some employees forgot to charge the device, while others, in a rush, left the device at the charging station or at their desks. The Fig. 4 depict the number of active badges each day at Company B.

5.2 User Experience

Another reason for withdrawing from the study was related to the comfort of wearing the device. While the badges were designed with a battery suitable for multi-day use and PCB secure from bending, many employees complained that the device was too heavy to be worn on a neck for a whole day. This had not been noticed during initial testing and was a headache of all the deployments. Gravity had another particular role in our struggles: the leash was always parallel to it. In principle, every time a wearer bends, the badge is leaning forward from the chest, as the relative position of the neck moves. The effect was especially noticeable during everyday acts like washing hands, eating or picking objects. We came with a hot-fix kind of a solution: velcro fasteners glued to the badge and users' clothes. While the upgrade worked for the software companies, the analog astronauts were not allowed to risk damaging their uniforms with the fasteners. Moreover, sometimes the badges had to be taken off not to hinder obligatory activities of the participants.

It turns out that it is not enough to expect some extent of sacrifice for the science from our subjects: we have to design for usability from the ground up. Otherwise, even with the greatest, state-of-the-art devices equipped with every imaginable sensor, lack of motivation would adversely impact the usefulness of collected data. If we were to design another iteration of sociometric devices, certainly those would be way lighter and designed to integrate with the garment. Yet, the question remains: how to determine that without employing bulkier prototypes at a big scale beforehand?

5.3 Accessibility

Whereas improving the interface of a device is usually just a matter of aesthetics or greater comfort for users, in some cases the goal is much more serious, namely: to make the device fully accessible for people of various skills, needs and impairments. This approach, oriented towards actual abilities of users, has been already defined as a set of principles in designing any interface of a computer system (*ability-based design* [8]). At the same time, as our sociometric setup does not require many interactions with the research subjects, we did assume the badges would be suitable for anyone who can wear them. It is the experience at ICAres that put our claims to the test and proved that using the devices may pose a bit of a challenge for a visually impaired person.

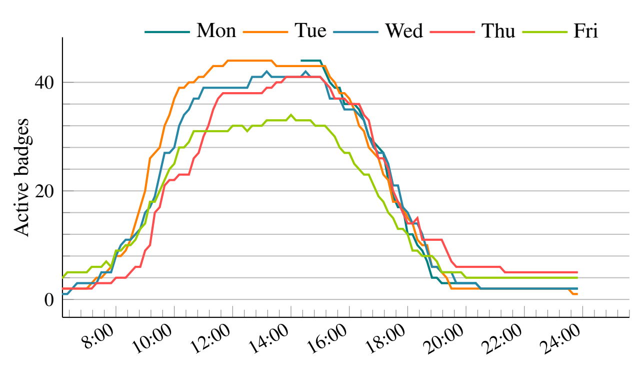

Figure 4: The number of active badges at Company B.

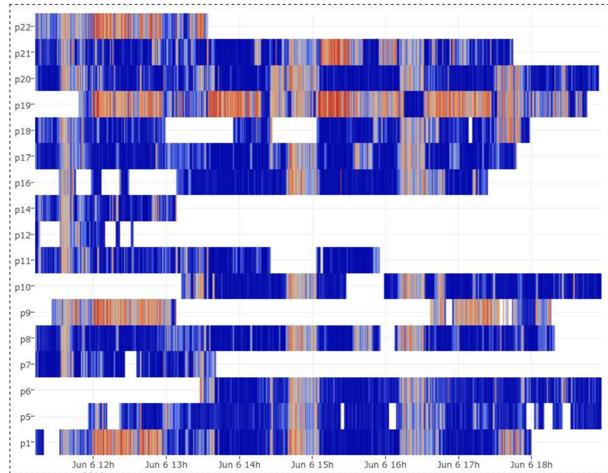

Figure 5: Microphone activity of a single day at Company A. Badges are plotted on OY, time is on OX. Meetings are clearly visible. White regions indicate *inactive* badges.

First, due to the fact that it is only a green light that signals whether the badge is correctly plugged in, charging the device could be more difficult for anyone with a decreased ability to see. This shortcoming turned out to be actually problematic: the badge of the visually impaired astronaut (astronaut A) run out of energy twice despite their efforts to charge it. Another issue resulted from the fact the astronaut was not able to identify his badge easily: the device's ID is shown on the e-ink display. As a consequence, the badge of astronaut A happened to be swapped with a badge of another person from the crew for a whole day. While these two situations could have been avoided without hardware updates but with some help from other astronauts instead, they are still important lessons to learn as we do not intend our solution to limit anyone's independence.

In addition, ICAres deployment made us realize that different abilities of research subjects should be carefully considered also in the context of the algorithms that run a sociometric system. For example, our software that analyzes microphone recordings to detect conversations was misled by a computer program reading out texts for astronaut A. Similarly, the algorithm would not detect a conversation in sign language. In fact, since there is a whole variety of ways to communicate between people, it might be a good idea to enable the users to report and/or confirm easily that they are talking with each other in specific cases. Such functionality would require genuine intentions of participants and mutual trust, though, the aforementioned experiences prove that these values are already indispensable to a successful study.

6 Remarks And Conclusions

Among all the issues experienced during our study two main problems stand out: the high opt/drop-out rate at software companies and unreliability of the hardware during analog missions. What could address the former one, next to improved form factor and privacy protection, we hypothesize, is employing forms of incentives, e.g. a monetary one or gamification. To counteract the latter problem, it might be worthwhile to provide the participants with a mobile app that monitors the system and reports breakdowns. Though, installation and setting up the software is a potential source of troubles leading to an even larger opt-out rate. A safer step is to develop just a status display, e.g. a one attached to the Raspberry Pi computer and informing on the charging process. Usefulness of such devices strongly depends, however, on cooperation with the subjects: again, it is people's attitude that is crucial for the success of the study.

6.1 Towards Interactive Sociometric WSNs

It is commonly believed that participants of a psychological experiment should be given no information on the verified hypotheses: awareness of the research goals may seriously impact the behavior of the subjects [5]. Similarly, in the field of IoT self-contained, almost unnoticeable devices are usually preferred over visible and obtrusive solutions. However, in case of long-time sociometric observations that (e.g. due to limited resources) are based on widely available, imperfect technology forced interactions (like charging a badge, sticking beacons on walls) between the study participants and the sensing setup are unavoidable. Then, in such circumstances, we claim, the interactions should be more than welcome: our experiences prove that deep involvement of research subjects in the sociometric procedures is a way to compensate hardware drawbacks.

We clearly noticed that the participants, who were enthusiastic about the study were also more disciplined as well as they refrained from any actions that could be harmful for the devices or could invalidate collected data. Especially the analog astronauts, already passionate about science, truly believed that the results of our study might, at least indirectly, help to improve the performance of a future space crew. This enthusiasm resulted in a spontaneously prolonged observation: the analog astronauts of Lunares decided to wear the badges twice as long as they had been asked to (for two weeks instead of one). In striking contrast, some employees of the monitored software houses, joined the experiment with a lot of reserve, complained about the devices, and neglected the rules just to drop out later. Sharing enthusiasm with the participants of the study has yet another advantage, particularly useful in case of the isolated deployments: the research subjects may supervise the system and willingly inform on any alarming situations. Undoubtedly, the positive attitude of the analog astronauts not only allowed us to collect more data, but also saved the whole experiment as they reported a serious problem with a referential badge that served to synchronize the clocks of all badges.

Instilling enthusiasm in the participants is therefore desirable, albeit not always possible. It should be much easier if the scope and the goal of the research is known to all the people involved. Most probably, in case of long-time sociometric observations that use multimodal sensing, collect lots of data and rely on artificial intelligence algorithms, even knowledge on the technical aspects of the study would not let the subjects to falsify the results significantly. Moreover, since people use to bend the guidelines in accordance with their needs and their common sense, as some of the discussed incidents prove, it is worthwhile to provide information that would help the participants to maintain the deployment.

Taking a step further, we envision a sociometric study, where the research subjects, trained and motivated, cooperate with the monitoring WSN: they provide additional input, explain ambiguities misunderstood by the algorithms and adjust the setup to own needs. They do not pretend WSN technology is invisible. Instead, they use it to its fullest.

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