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A Transparent home Sensors/Actuators layer for Health & Well-being services

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Abstract

Risks factor leading to type 2 diabetes and cardiovascular diseases can be reduced by a preventive care infrastructure able to modify the habits toward healthier lifestyles, including more exercise, a better diet and a reduced stress. Accessing the home space is important not only to monitor indoor environment quality (IEQ) but also to provide relevant user's feedback and engage users towards a healthy life style. This paper present a new preventive care infrastructure composed of a distributed infrastructure for heterogeneous devices in the home local area network (named xAAL) in conjunction with a machine to machine protocol (MQTT) to external health & well-being services. Finally, end-user tests were performed in the Experiment'HAAL living lab in order to test sensors and feedbacks.

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1. Introduction

Noncommunicable diseases (NCD), for instance diabetes, cardiovascular or respiratory are the leading cause of mortality in the world, representing 60% of all deaths according to the program chronic diseases and health promotion of the World Health Organization [1]. Modifying the habits toward healthier lifestyles, including more exercise, a better diet and reduced stress is associated with the reduced risk of diseases such as type 2 diabetes and cardiovascular diseases. In this context, the PREventive Care Infrastructure based On Ubiquitous Sensing (PRECIOUS [2]) project targets to develop a preventive care system to promote healthy lifestyles with specific focus on the following risk factors: environmental, socio-psychological and physiological. The PRECIOUS system proposes services to end users: monitoring of the home environment factors (e.g., air quality), gathering data from "health & well-being" devices (e.g., body weight scale) and sending feedbacks through multimodal interfaces. In this paper, we focus on the user context related to environmental factors and how we can gather long-term data in the home user space. Particularly, we discuss an infrastructure and a new protocol to seamlessly integrate home automation devices and data in a health & well-being care system. Moreover, we also address user feedbacks in the home environment to support health & well-being recommendation on different user interfaces. Finally, we conducted end users tests in the Experiment'HAAL living lab to assess the acceptance of the PRECIOUS system and better understand the motivations of the futur users.

2. Related works

The indoor environment quality (IEQ) is most of the time studied from an occupant comfort perspective and/or to reduce energy consumption of buildings [3, 4]. Nevertheless, Kim *et al.* in [5] proposed a system to measure, visualize and learn about indoor air quality. The study showed that the *inAir* system motivates user to improve their indoor air quality. This means that visualization of data related to home comfort needs to be considered in order to engage user change habits. Then, Kim *et al.* in [6, 7], presented a sensor network infrastructure for real time monitoring of several gases. The contribution is focused on data acquisition and sensor network infrastructure. The authors show that real-time monitoring is necessary as

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well as the use of pre-processing algorithm on data to reduce temporary errors. Interoperability issues related to different protocols using by sensors is not addressed. Furthermore, the integration in a smart home and health infrastructure is not considered.

Different vertical domains are present in the home environment: personal health devices, home automation devices, entertainment devices, etc. Recent works about IoT domain architecture proposed horizontal interoperability between vertical silos: eHealth, home automation, agriculture, etc. One can cite the HYDRA [8], IOT-A [9] or BUTLER [10] European projects. There is also a recent effort to standardize machine to machine (M2M) communication with the OneM2M initiative. Gateways between constrained network, e.g. BAN/PAN, HAN and WAN are still needed. Even if protocols like CoAP or MQTT are dedicated to small devices, there is still a gap because of device: power consumption, memory foot print, etc.

3. System description

The user context awareness (UCA) at home should be a key objective of a system trying to assist user in its daily life. We defined the following environmental variables: thermal comfort (temperature and humidity), noise quality and light quality. To achieve the UCA, a transparent sensors/actuators layer using xAAL [11] has been proposed to fight interoperability issues in the home automation domain. xAAL allows to seamlessly integrate TAN/BAN/PAN/LAN devices from different protocols. The xAAL infrastructure offers access with WAN interfaces (WAN-IF) to use MQTT M2M communication as shown Figure 1. MQTT is lightweight enough to be used on different communication links such as 3G/4G (cellular), Fiber, ADSL. Then, thanks to the selected M2M protocol, sensors data are exported and stored in a database to be used by health & well-being service. Data are processed and, according to a rules engine, user feedbacks will be sent to home. Basically, those feedbacks can take the form of messages, notifications, or devices actions at home (according to user's preferences).

3.1. Home Area Network and External Services

Context acquisition. xAAL [11, 12] is an open-source distributed infrastructure for heterogeneous ambient devices. The communication between devices is realized by a lightweight event-based messaging protocol working on the so-called xAAL bus. Devices are described by a schema, which provides a first level of semantic. IEQ variables are then related to the following schemas: "thermometer.basic", "hygrometer.basic", "luxmeter.basic", "loudness.basic".

xAAL allows us to reuse traditional home automation devices (e.g., thermometer, luxmeter, soundmeter, Tv, etc.) to set up a pervasive health system. Data are automatically associated by the xAAL system to the location of sensors in various rooms (e.g. bedroom, living room).

From Home Area Network to Wide Area Network. xAAL and external health services are inter-connected with the MQTT protocol. It is a lightweight protocol dedicated to M2M communications and is now an open standard [13]. It is based on a publish/subscribe model and TCP/IP. The home gateway publishes relevant home data to the external health services. It allows to move the management of data storage & analytics over long term and unstructured data in the cloud. According to the MQTT architecture, a broker is needed between publisher & subscriber. This allows multiple publishers to communicate to multiple subscribers in so-called topics. However, this is an additional component to administrate. But, robust open-source implementations exist today.

The infrastructure Figure 1 is composed by the following components:

- xAAL-MQTT relay: a component of the home gateway which publishes sensor data to the cloud;
- MQTT Broker: dispatches published data to the corresponding subscribers;
- MQTT-logger: a component of the external home service that subscribes to data sent by the smart home and stores them to the health service database.

MQTT only defines a transport layer. Transported messages can be freely defined between publisher and subscriber. So, xAAL messages with sensor data are transformed to fit with the messaging protocol of the health service, and then are published to the uplink topic of the broker. It should be noticed that the user has full access to the home gateway and control/select data sent to the cloud service.

From Wide Area Network to Home Area Network. A preventive healthcare system should consider the user feedback. This offers a way to engage and motivate users toward a healthy life style. The home gateway subscribes to the downlink topic of the broker. Figure 1 is composed by the following components:

- MQTT-actuator: a component of the external home service which publishes feedback to home;
- MQTT Broker: the same broker is used to dispatches published messages to subscribers;
- MQTT-xAAL relay: a component of the home gateway that subscribes to feedback and sends xAAL commands.

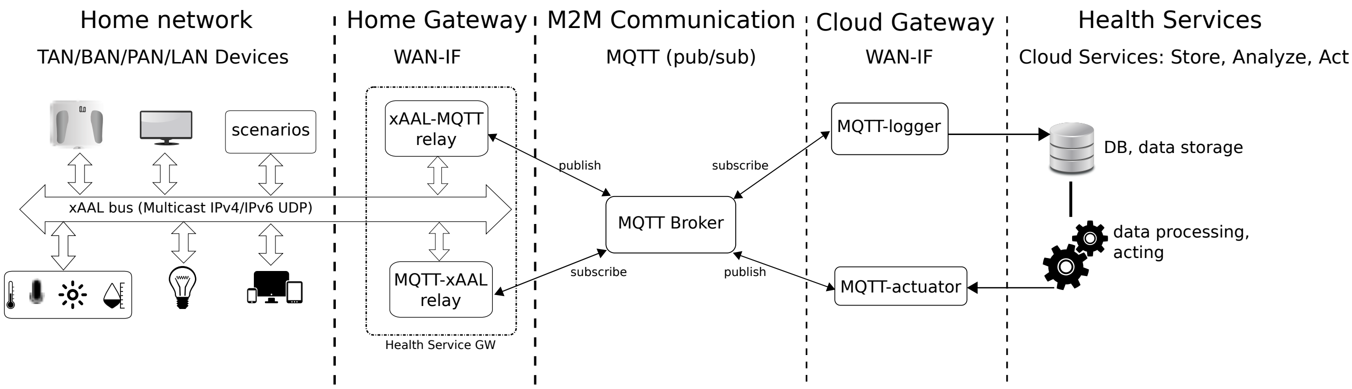

Figure 1. System overview.

From the Home Area Network to the Attention of the User. Feedbacks are sent to home over MQTT in the form of JSON messages. Then, they are dispatched to the right actuators according to user preferences and home capabilities. The xAAL infrastructure provides multimodal interaction between home, health systems, and the user. The scenarios addressed in our study consider different kind of users from young to elderly people, from individual to family units, with different needs/wishes/habits regarding uses of devices. The following notifications media are currently available: "Lamp blinking", "Lamp color", "Haptic / Motor vibration", "Message on smartphone" (textual & voice message), "Text message on desktop computer", "Text message on Tv". The definition of each notification depends of the home capabilities. Thanks to xAAL and its discovery mechanism, the health service gateway (at home) is aware of home capabilities. Finally, users can define the appropriate notification type according to their preferences and current home actuators.

3.2. Security & Privacy

xAAL. Firstly, xAAL is working on the local area network (LAN) and is protected by the mechanism that still exists to protect user LAN network. Secondly, with the version 0.5 a security layer has been added to the xAAL protocol [12]. Basically, it is based on a pre-shared private key, Poly1305/Chacha20 algorithm, a timestamp to avoid replay attack. The protocol version, the targets addresses and the timestamp are public. Only the payload is ciphered by the Poly-1305/Chacha20 algorithm with "targets" for additional data and a "timestamp" playing the role of nonce.

MQTT. Section 5 of the OASIS MQTT v3.1.1 standard is dedicated to security (for guidance only, non-normative). Four security levels (or profiles) are described: Level 4: Unsecured; Level 3: Base Secured; Level 2: Industry Secured (Base + Industry customizations), Level 1: Cyber Critical Secured. According to guides of the OASIS MQTT security subcommittee, we will match the level 2 security profile. Indeed, TLS provides authentication, integrity and privacy. Moreover, the TLS client authentication will be used in addition to the MQTT client authentication (username/password).

4. Implementation & Discussion

xAAL has been deployed [12] in the Experiment-'HAAL living lab. Now xAAL includes support for the following home automation technologies: KNX, Zwave, Oregon Scientific, Delta Dore. A dedicated xAAL device have been developed which embed multiple sensors: a Raspberry Pi model B with a grovepi shield, a digital light sensor, a loudness sensor and a vibration motor for notifications. For the temperature and humidity sensor, we reused a "classical" sensor dedicated to a weather station (Oregon Scientific THGR810). This use case particularly shows all the opportunity offered by xAAL to integrate and re-use "classical" home automation sensors/actuators for health application.

xAAL is enough flexible to allow several kind of users feedbacks in order to target their needs, their preferences, a handicap, the specificity of their ages and their wishes. The following xAAL notifications have been implemented: blink a lamp and/or color lamp, Tv (HTTP protocol according to HbbTV standards), laptop (Use Mac Osx or Gnome notification center), Android smartphone (text & voice), noise with a vibration motor. This offers many alternatives compared to smartphone-centric solutions.

The home gateway offers to users the control on data they accept to share: temperature, humidity, body weight, notifications, etc. The gateway is the place for processing a first level of data fusion, adding a context (*e.g.*, localisation) before to send them to the cloud service. The location information is symbolic and defined by a tag, e.g. *bedroom*. On the other side, the home gateway dispatches feedbacks to rendering devices (smartphone, Tv, lamp, etc.) according to user preferences: the time of the day, the type of device, etc. Feedbacks are predefined messages, with internationalisation (I18n) to fit user language for use cases involving text and voice messages.

In terms of ethics, security & privacy, the external services in the cloud cannot access directly the home devices. What enter at home are just informative notifications whose rendering is controlled by the user, not direct commands for home devices.

From a technical point of view, xAAL allows us to add new low level protocols and devices, such as promising EnOcean or Zwave, thanks to independent software components translating messages to xAAL. Indeed, the integration of low level protocol is done by the xAAL bus itself. Moreover, with the schema modelling, a lamp is a lamp whatever the underlaying protocol. This new lamp is transparent for the health service, developers and users.

Finally, xAAL is an event bus and the association with a pub/sub pattern remains a good combination. The fact that messages between the house and cloud services are not standardized could be a drawback. But new health & well-being services providers are free to design their own gateway to be installed at the patient's home. They can define their own topics and message format.

5. Preliminary end-user tests

End-user tests were performed in the Experiment'HAAL living lab according to the Wizard-of-Oz principles. The objective was to collect user recommendations regarding acceptance on the overall functionalities, interfaces, data visualization & consultation, ethics & privacy. According to different researches which have shown that most of the usability issues appears with the first end-users tests (*i.e.* [14, 15]), we assumed that the results coming from our first eight end-users could highlight some important strengths, weaknesses and other preferences about their experience of the PRECIOUS system. When appropriate, we used the theoritical framework of the *Technological Acceptance Model (TAM)* [16, 17] to describe users' perceptions of the PRECIOUS system.

5.1. Description

Environmental sensors were deployed in the living lab. In the home user space they were all connected with xAAL which played the role of a transparent sensors/actuators layer.

5.2. Living lab and settings

The participants received instructions about the living lab in order to understand the whole PRECIOUS system. Sensors, dashboard and notifications have been presented together:

- Sensors: thermal comfort (*i.e.* temperature and humidity), sound, light, bath scale.
- Dashboard: a web UI presenting the raw data as graphics or gauge.
- Notifications: one or two examples of notifications has been be presented to the users in order to show the potential use of the data collected in the home user space: message texts on TV or smartphone displaying alert according to air quality, etc.

Consequently, users interacted with *sensors-HMI-notification* during the test. The experimentation supposed that all the system was well installed and working. In other words, it means that we did not evaluate the system configuration or installation and focused on the PRECIOUS system utilization.

5.3. User storyline: environmental sensors

The following scenarios of the daily life were used:

1. "After work, you come back home and when you arrived, you check your dashboard showing data related to your home environment which summarize information regarding air quality (temperature + humidity), sound level and light quality."
2. "You are in the living room and you receive a notification according to a recommendation/alert related to ambient sensors."

In the first scenario, the user was acting in the system and tried to understand its related data. In the second scenario, the user was in a passive position and the system delivered notifications related to the home environment and predefined recommendations/alerts.

5.4. User storyline: weight monitoring

The following scenarios of the daily life were presented:

1. "After a shower you want to check your current weight. During the day, you want to see on a chart your weight data with different views month/week/day. It will give you the opportunity to see your progression. It will also give you the opportunity to compare your weight with normative values."
2. "The morning you will receive a notification on your smartphone reminding your objective and your progression. "

5.5. Data collection

After having experienced the system, the users feedback were collected through questionnaires. Most of the questions required the participants to estimate their potential "intentions to use" on a Lickert scale composed of five items: 1. "Totally disagree" ; 2. "Rather disagree"; 3. "No position"; 4. "Rather agree"; 5. "Totally agre".

5.6. Results

Acceptance.

- **Thermal comfort sensors** : Every eight participants found the thermal comfort information useful (mean=4.5/5) and easy to use (mean=4.9/5). Thus it seems very acceptable. Seven of the eight participants claimed the connected thermal comfort sensors more useful than a classical one and did not think it would disturb them in the daily life.

- **Sound Level sensor** : Seven of the eight participants found the sound level sensor useful (mean=4.5/5) and easy to use (mean=4.6/5). Seven of the eight participants also found the connected sound sensor more useful than a classical one. No participant think it would disturb them in the daily life.

- **Light level sensor** : Five of the eight participants found the light level sensor useful (mean=3.4/5). One participant claimed that it is not useful at all. Thus it was not relevant to ask her for answering the next questions. Every seven left participants found the light level sensor easy to use (mean=4/5). Six of the seven participants found the connected light sensor more useful than a classical one.

- **Connected Bath Scale** : Seven of the eight participants found the light level sensor useful (mean=4.8/5) and easy to use (mean=4.7/5). Six of the eight participants found the connected light sensor more useful than a classical one.

Althought it is not relevant to perform any statistical comparison on a eight participants sample, perceived usefulness and ease of use responses lead to thing that futur users would find the thermal comfort sensor (total=9.4), the sound sensor (total=9.1) and the connected bath scale (total=9.5) more acceptable (see Figure 2) than the light (total=7.4). Moreover, almost every participants claimed that it is more useful to use connected devices than classical one's whatever the sensor.

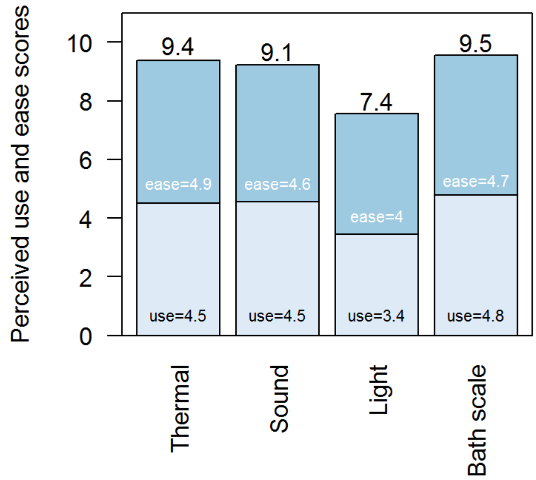

Figure 2. Means scores of perceived usefulness & ease of use depending on the sensor types

Notifications. First of all, every participants wanted to be able to set up notifications about environmental event (*e.g.* out of range temperature, long unusual noise, etc.). We noticed that they also want to be able to block notifications whenever they want.

After experiencing each environmental sensor, the end users were required to choose on which devices/supports they would like to receive notifications. Every responses taken together, participants claimed they expect to set up the system to receive the notifications "on the mobile phone" mainly (13 times). TV (6) and computer (7) were well represented too, but wishes of notifications on other devices remained really rare (see Figure 3).

Sensors locations.

- Every eight participants would install the **thermal comfort sensors** in the living room and in the bedroom while only half of them would like to install it in the kitchen and in the bathroom.

- Seven of the eight participants would put the **sound level sensors** in the living room, six would put it in the kitchen and 6 in the bedroom.

- Six of the seven participants would put the **light level sensors** in the living room, five would put it in the kitchen and three in the bedroom.

In brief, participants claimed they would like to locate sensors in the living room and in the bedroom (see Figure 4).

Sharing data with general practitioner. Among the participants, most of them would like to share the data

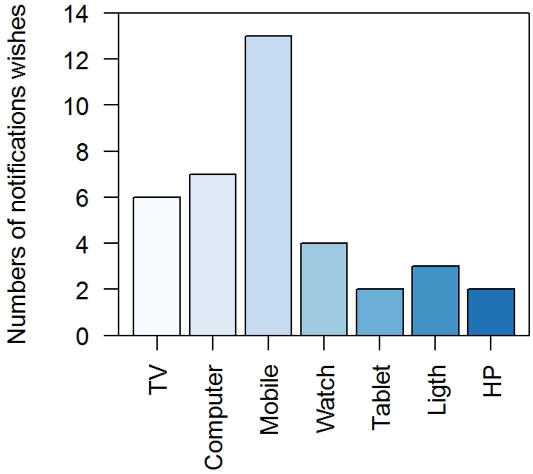

Figure 3. Numbers of participants wishes per support to be notified about environmental events

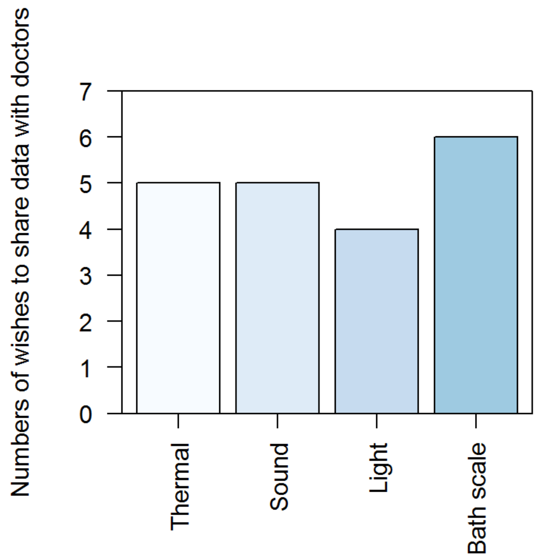

Figure 5. Numbers of end users intentions to share data with their general practitioner

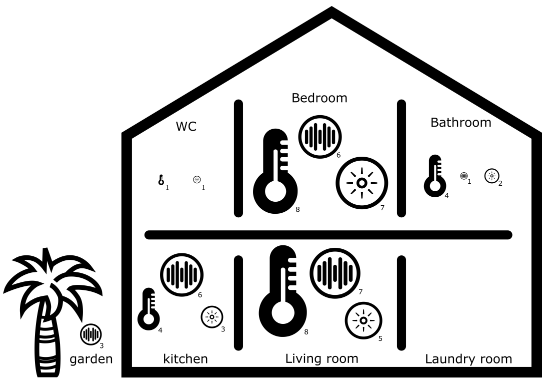

Figure 4. End users sensors locations preferences

from the home sensors with their general practitioner. The greater score was about the data from the connected bath scale. More precisely, six of the eight participants would accept to send their weight monitoring data to their general practitioner. Then five end users claimed they would share thermal comfort and sound data to obtain a medical advice. Eventually four participants would send their data about the light (see Figure 5).

Behaviour changes expectations. In order to take into account the end users intentions to change, we asked the following question: *"Do you think using this sensor will change your daily behaviour?"*. On a scale from 1 to 5 (*op.cit.*), participants answered revealed a mean score of 4.6 for the thermal comfort sensors, 3.2 for the sound level sensor, 2.7 for the light level sensor and 3.7 for the connected bath scale (see Figure 6).

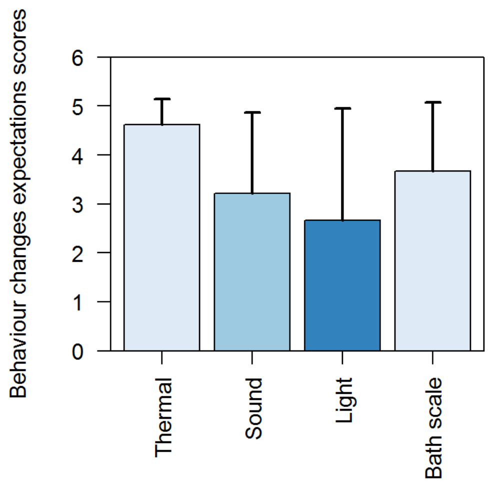

Figure 6. End users behaviour change expectations means scores

5.7. End users tests discussion

We expected to be able to understand whether the PRECIOUS system was acceptable to provide users with context awarness, why and how. According to the TAM (*op. cit.*), these first results lead to deem that connected environmental sensors would be well accepted by the end users since perceived usefulness and perceived ease of use scores are very high.

The end users seemed particularly interested in locating environmental sensors in the rooms where they live the most often: the living room and the bedroom.

It was also clearly shown that participants wanted to use connected sensors to receive notifications. Indeed, this would not be not possible with classical sensors. Moreover, end users pretended they would like to share health information with their general practitioner. These results corroborate the main idea that more accessible information could contribute to increase healthcare's behaviours and thus would empower people to improve their health.

Eventually, discussions with participants revealed that the motivations to use such a system aimed for improving the well being and the quality of the living environment in general. These claims were consistent with the strong expectations to change their behaviours thanks to the connected devices (especially thermal comfort and bath scale). However it was important to take into account the main fear of the end users: they want to control the system (*i.e.* set thresholds, block notifications, etc.) and not to be control by the system (untimely notifications, intrusive warnings, etc.).

6. Conclusions & Future Work

This paper proposed an infrastructure using xAAL and MQTT in order to offer the possibility to use home automation sensors/actuators in future health and well-being services. It offers access to home environment data in order to have a better understanding of the user context, *i.e* environmental factors such as thermal comfort, noise and luminosity levels. But, it also gives capabilities to developer of health applications to integrate feedbacks in order to engage users and help them to change their behaviour [18]. Finally, the infrastructure allows to build persuasive technology.

The subjection of the system to the end-users during tests in the Experiment'HAAL living lab allowed to expect a good acceptance of the system. However to get deeper into usability investigation, it would be interesting to set up the system in participants house to provide them with a true long experience of the PRECIOUS system.

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