A MULTI-SENSORY APPROACH TO ACQUIRE AND PROCESS HEALTH AND LIFESTLYE INFORMATION

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ABSTRACT: Starting around 2010, the Internet of Things has grown rapidly and now also embraces the field of healthcare. Subsequently, sensor-based technologies and infrastructure to support specific aspects of health and quality of life gain significant social acceptance and are ready to be put into practice. To address this process, a modular and reusable multi-sensor monitoring system to acquire and process health and lifestyle related sensor data was designed and implemented. The proposed system consists of a set of wireless ambient sensors and a collection unit which are all placed in the monitoring environment. The sensor components of the monitoring unit can be arranged and selected individually and were designed as a plug-and-play module to ensure a straightforward integration in the environment. The collected raw data is securely transmitted to the backend server which consists of a data storage and a data processing unit. In the data processing unit, the collected raw data is linked with individual context information and is then processed in consecutive algorithmic levels, depending on the criteria of the respective use case. The processed data of each evaluation step is separately stored and can either be forwarded to a third party (e.g. for providing results to the users) or be re-used in further evaluation. Through the implementation of interfaces, it is also possible to integrate data from external sources (e.g. wearables, health monitoring devices, etc.) at each level of data processing. The implemented and adapted system, including five non-invasive sensors which allow the monitoring of 10 different actions related to an active lifestyle, was installed and tested in 100 households in the framework of the Smart VitAALity project. First results show that the integrated sensor system was well accepted by the participants and worked in a stable and reliable manner over the test duration of one year.

1 INTRODUCTION

The usage of smart sensor networks and cloud-based applications has evolved rapidly and now also embraces the field of healthcare. Subsequently, such IoT technologies and infrastructure to support specific aspects of health and quality of life gain significant social acceptance and are ready to be put into practice. The concept of Internet of Things (IoT) describes the Internet as an interaction platform for Things to share information. Such Things are objects, able to interact with each other e.g. sensors, actuators, tags. etc. The basis definition of an IoT application describes it as a set of three different layers [1] [2]. The lowest level is represented by a set of smart sensing technologies/devices, usually combined in sensor networks, that collect information about the environment and transmit them via standard communication protocols to the middleware. The middleware is a complex software layer, which is dedicated to join all the collected data, process it, store it and provide it to the users. The crucial task of the middleware is to facilitate the docking process for new services and sensors and hide individual specifications behind an easy-to-use input and output interface. The middleware is the heart of an IoT application and contains again a set of different levels necessary to process information out of the gathered data. The last layer in the IoT architecture is the presentation layer, which is responsible for adapting collected data to viewing requirements and for presenting it to the user. During the last decades, this base concept is constantly evolving and already applied in a variety of fields, e.g. manufacturing, transport and mobility and healthcare. Also in the field of Active and Assisted Living (AAL) using IoT technologies to increase safety and wellbeing is already a common case. The usage of passive and active sensors to facilitate an independent living at home is already part of many projects and solutions. The concrete paper is focusing on the conceptualization and implementation of a reusable IoT middleware layer for the application in research projects in the field of AAL.

2 METHODS

In the proposed approach, the collected sensor data is securely transmitted to the IoT middleware layer. This layer consists of a data storage and a data processing unit. In the data processing unit, the collected raw data is linked with individual context information and is then processed in consecutive algorithmic levels, depending on the criteria of the respective use case. Every level of the classification process can be feedbacked to the user. It is possible to connect every type of sensor network to the middleware layer, as long as it supports a RESTful communication. The whole approach is visualized in Figure 1. It shows the concept of the middleware layer implemented in the pilot region Smart VitAALity[1].

The implemented IoT middleware layer is based on modules of the FIWARE platform, which has its origin in an initiative of the European commission: the Future Internet Public Private Partnership (FI-PPP) [3]. FIWARE is an open source cloud platform and ecosystem, which offers standard modules for the development and conception of IoT-applications. The platform is dedicated to the implementation of smart applications and the setup and possible combination of various open source modules enables its utilization in multiple sectors. FIWARE has already obtained a constantly growing community, which ensures a continuous development of the included modules [4].

[1] Smart VitAALity – www.smart-vitaality.at

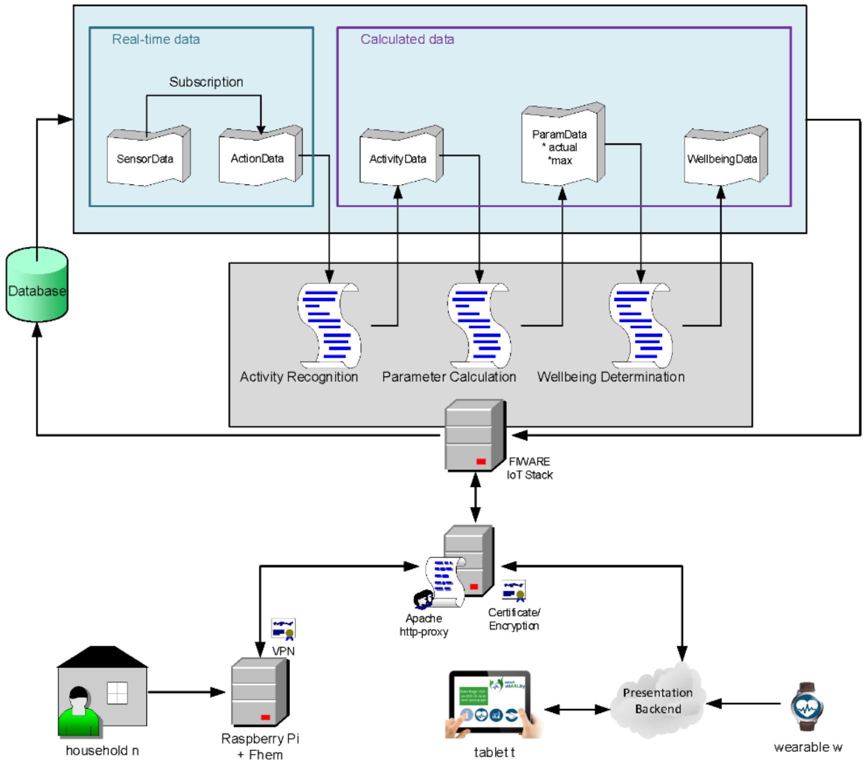

Figure 1: Overview of the Smart VitAALity Lifestyle Monitoring module, adapted from [5].

2.1 TECHNICAL IMPLEMENTATION

The following section describes the main technical components which were used to build the IoT middleware architecture. Some further minor modules and interfaces are used to connect these components but are not explained in the scope of this paper.

The first module is the FIWARE Identity Management (IDM) which is a combination of the modules Keyrock [2](user management), PEP Proxy [3](permission management) and Authzforce (RESTful API for XACML[4] requests). The IDM ensures security through authentication using the OAuth 2.0[5] architecture for registered users and devices [6]. Devices can be active and passive sensors that are permitted to write to the interfaces. A user can be any other entity that is allowed to read or update data (e.g. a presentation layer or an external data backend).

Requests from registered users and devices are forwarded to the orion context broker. The context broker keeps an eye on entities (e.g. sensors) and manages their status and adds context information if necessary. It is a REST[6] (Representational state transfer) structure based

[2] Keyrock - https://fiware-idm.readthedocs.io/en/7.4.0/
[3] PEP-Proxy – Wilma - https://fiware-pep-proxy.readthedocs.io/en/latest/user_guide/
[4] XACML - https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=xacml
[5] OAuth 2.0 - https://oauth.net/2/
[6] REST - https://restfulapi.net/

on the NGSI v2[7] model visualized in Figure 2. The included context elements are entities, attributes and metadata, which are represented by JSON[8] objects. Entities describe physical or logical objects e.g. a household or a reasoning level. Attributes are representing parameters of an entity e.g. the number of persons living in a household or the starting time of an activity. Metadata can be used to further describe attribute values e.g. the last update time of the attribute or the accuracy of a transmitted sensor value [7].

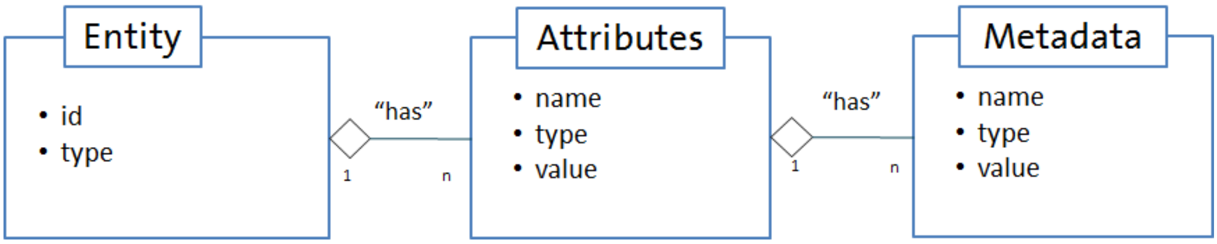

Figure 2: Visualization of the NGSIv2 data model [6].

To persist the gathered sensor data, the Cygnus module is used. It enables the historization of data by broadcasting it to connected external data storages [8]. In the implemented use case, a MySQL Database as well as a MongoDB are used to store the collected data values. The main advantage of using Cygnus is the ability to easily attach or remove new databases, depending on the given use case.

2.2 REASONING IMPLEMENTATION

The persisted raw data is used in the reasoning module where different levels of classification can be implemented. The module can be written in any language, again depending on the use case. In case of the Smart VitAALity project, the reasoning module was implemented in JAVA[9] and consists of four abstraction levels visualized in Figure 1. In order to obtain wellbeing describing parameters from the gathered sensor data, a modular approach based on [9] was implemented. The modular setting facilitates the integration of new classification algorithms and rules. Figure 3 shows the JSON representation of the implemented reasoning levels.

[7] NGSI v2 - https://fiware.github.io/specifications/ngsiv2/stable/
[8] JSON - http://www.json.org/
[9] JAVA - https://www.java.com/de/

Sensors


```
{
  "id":"household1",
  "type":"household",
  "modified_at":{
    "type":"DateTime",
    "value":"2017-04-21T10:03:33.23Z"
  },
  "s_fridge":{
    "type":"int",
    "value":0,
    "metadata":{
       "modified at":{
          "type":"DateTime",
          "value":"2017-04-21T10:03:33.23Z"
       }
    }
  },
  "s_maindoor":{
    "type":"int",
    "value":0,
    "metadata":{
       "modified_at":{
          "type":"DateTime",
          "value":"2017-04-21T08:00:00.00Z"
       }
    }
  },
  "s_bathdoor":{
    "type":"int",
    "value":0,
```


1 . Action Entity


```
{
  "id":"action household1",
  "type":"action",
  "modified at":{
    "type":"DateTime",
    "value":"2018-04-21T10:03:33.23Z"
  },
  "a_fridge_opened":{
    "type":"DateTime",
    "value":"2018-04-21T10:03:33.23Z"
  },
  "a_fridge_closed":{
    "type":"DateTime",
    "value":"2018-04-21T08:00:00.00Z"
  },
```


2. Activity Entity


```
{
  "id":"act household1",
  "type":"activity",
  "modified at":{
    "type":"DateTime",
    "value":"2018-04-22T03:00:00.28Z"
  },
  "act_eating":{
    "type":"timespan",
    "value":{
      "from":{
        "type":"DateTime",
        "value":"2018-04-21T10:03:33.23Z"
      },
      "to":{
        "type":"DateTime",
        "value":"2018-04-21T10:04:40.14Z"
      }
    },
    "metadata":{
      "modified_at":{
        "type":"DateTime",
        "value":"2018-04-22T03:00:00.28Z"
      }
    }
  },
  ...
}
```


3. Parameter Entity


```
{
  "id":"param household1",
  "type":"parameter",
  "modified at":{
    "type":"DateTime",
    "value":"2018-04-22T03:00:00.71Z"
  },
  "c_param_eating":{
    "type":"int",
    "value":5,
    "metadata":{
      "modified_at":{
        "type":"DateTime",
        "value":"2018-04-22T03:00:00.71Z"
      },
      "desc":{
        "type":"string",
        "value":"Counts per day."
      }
    }
  },
  "d_param_outside":{
    "type":"int",
    "value":120
    "metadata":{
      "modified at":{
        "type":"DateTime",
        "value":"2018-04-22T03:00:00.53Z"
      },
      "desc":{
        "type":"string",
        "value":"Duration in minutes."
      }
```


4. Wellbeing Entity


```
{
  "id":"well household1",
  "type":"wellbeing",
  "modified at":{
    "type":"DateTime",
    "value":"2018-04-22T03:00:00.89Z"
  },
  "well_movement":{
    "type":"double",
    "value":95,
    "metadata":{
      "modified_at":{
        "type":"DateTime",
        "value":"2017-04-22T03:00:00.89Z"
      },
      "desc":{
        "type":"string",
        "value":"Die heutige Aktivität entspricht
        Aktivitätszeit!"      }
    }
  },
  ...
}
```


Figure 3: JSON representation of NGSIv2 Entity objects, own implementation

Actions

The first level contains Actions, which are directly derived from raw sensor data representing state changes from the deployed sensors. These data are available in real-time based on the subscriptions implemented in the orion context broker. The generated entities can be used to e.g. visualize the status of the sensed objects and report it back to the user. As a result of the real-time availability of the data, another use case could be the implementation of an alarm system to enhance security.

Activities

In the next step, the Actions are used to derive interaction of the user with the sensed objects. This is achieved by adding context information and classification processes via e.g. rule-based algorithms. Depending on the used sensor set, more or less complex activities can be derived. In the actual use case, the following activities were classified: entering and leaving the flat, interaction with fridge, interaction with toilet, activity in the living room, sleeping (at night). In this stage, it is also possible to combine data from different types of sensors such as active and passive sensor technologies (e.g. ambient sensors, health devices and fitness tracker) to enhance the classification quality and to receive more precise results.

Wellbeing describing Parameters

The classified activities are now transferred to wellbeing describing parameters (WDP). In the current use case it was defined, that the WDP should represent a timespan of 24 hours and are created by combining different activities. Thus, classified WPD were describing the number and duration of activities performed during a whole day (24 hours) as well as the total time in and outside the flat during this timeframe. The goal was to create an overview of active and inactive periods which occur during a whole day.

Wellbeing

The last classification level abstracts the generated information to a wellbeing index. The index is calculated based on a concept suggested in [10]. The calculated result is obtained based on the current activity and the activity values of a defined past timeframe. This procedure allows a prediction of the future index values as well as an assessment of the current situation.

3 RESULTS AND OUTLOOK

The described levels of wellbeing determination were used in the Lifestyle Monitoring module in the framework of the Smart VitAALity project. An ambient sensor set composed of three energy harvesting and maintenance free reed contacts and two movement sensors was placed in the living environment. The recorded values cover the opening/closing of doors and movement/no movement in certain areas. All reasoning levels described above were implemented for research purposes. It was not intended to implement a full activity recognition module. This would also have not been possible with the given sensor set. The goal was to determine active and inactive times during the day. Users did receive feedback about their wellbeing describing parameters in form of charts visualized on the Smart VitAALity application on their tablets. Due to lack of comparison data, a complete analysis of the quality of the provided WDP was not possible, but the overall feedback regarding the calculated values was very positive. Furthermore, it was possible to receive interesting information regarding the long-term execution of such a Lifestyle Monitoring module directly in the field. Except from a few minor server downtimes, the middleware including the reasoning module was running stable over the whole test duration.

As consequence of the promising results from the field test, it is planned to reuse the proposed modular evaluation structure based on the FIWARE implementation in further research projects. Currently, the structure is extended with an interface for the integration of health measurement devices. The combination of passive and active sensor data with data from wearable devices will be subject to further investigation in upcoming research projects. The middleware is also used for student projects.

4 ACKNOWLEDGEMENTS

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