Wearable Activity Trackers Supporting Elderly Living Independently: A Standards based Approach for Data Integration to Health Information Systems

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ABSTRACT

Preserving independence is of high importance for aging adults. Information Technology based solutions in the context of "elderly living independently" and "ambient assisted living" provide support to increase factors like emotional security, physical activity and general well-being. It is expected that wearable activity trackers positively influence these factors. Hence, this work investigated the integration of wearable activity trackers into medical IT systems from the perspective of technical interoperability, as this is a key feature to improve quality and reliability of both the system itself and the health related data. Based on a previously conducted market analysis, investigating the most prominent wearable activity trackers on their communication interfaces, an medical interoperability standards based approach for data integration to medical information systems was proposed and prototypically implemented to study feasibility. The prototype was successfully validated with interoperability tests against the specification of HL7 FHIR to align with the Personal Connected Health Alliance (PCHA) guidelines. The results showed that the implementation of the interoperability standard HL7 FHIR for this purpose was possible and could be used as an approach to integrate several manufacturer independent wearable activity trackers in a common system to increase flexibility and extensibility. The quality of the data can be increased as it is syntactically and semantically structured according to the HL7 FHIR specification, which

may facilitate more reliable approaches for automated fall detection or emergency alarms as a follow-up. However, to fulfill the requirements of semantical interoperability a value-set was defined. Summarizing, without change of thinking and more effort on the manufacturers side to change proprietary communication interfaces (which still is the case to a very high degree) to standardized ones, the advantages based on using interoperability standards can't be effective.

CCS CONCEPTS

• **Software and its engineering** → **Interoperability**; *Software architectures*; • **Social and professional topics** → *Personal health records*; *Health information exchanges*;

KEYWORDS

Wearable Activity Tracker, Personal Health Devices, Elderly Living Independently, Personal Health Record, eHealth, Health Information Exchange, Interoperability

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1 INTRODUCTION

Preserving independence is of high importance for aging adults. Several requirements need to be fulfilled to provide optimal support in this context [19]. The classical measures supporting elderly living independently are the installation of physical assistance measures like bath rails, lowered shelves or elevator access. Seniors need additionally their essentials at home, which leads to the need for home delivery services as

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mobility may be reduced. The proper reaction to emergency situations, i.e. sending alarm to health care departments and family members is of crucial importance. This triggers another important point namely the fulfillment of emotional security and well-being of elderly people living alone. IT based solutions in the context of "elderly living independently" and ambient assisted living provide necessary approaches to fulfill such requirements and support daily life. An example could be camera systems for observation of important spots to detect falls or emergency cases (under consent of the persons) [5], but moreover the combination of different technical measures like sensors, wearables and IT-systems[6].

The application of wearable activity trackers to support elderly living independently is currently under rising interest. There is a huge potential for wearable activity trackers, which can be reinforced as the number of wearables are nearly to double in 2021 according to IDC [12]. The group around Mercer et. al. [17] investigated the acceptance of wearable activity trackers by adults suffering from chronic illnesses. The result showed that the usage of wearable activity trackers positively influenced the self-awareness and substantially increase the patients motivation. However, wearable activity tracker and its connected systems need to be prepared in advance to decrease the patients involvement. In another study [18] the same research group focused on the integration of behavior change techniques in wearable activity trackers. The results showed that all modern wearable activity trackers include behavior change techniques in the user interfaces to a high degree. Examples are goal setting, self-regulation and social support measures. As a summary the group could prove that the usage of wearable activity trackers increase the overall physical activity of older adults. Another group investigated specifically the user experiences of seniors using activity monitors in daily life[7]. In this study the seniors were equipped with wearable activity trackers and a tablet, which was used for analysis and diary functionality. Based on a conducted interview with the seniors, the results showed a positive effect on the physical activity. However, they stated that there are still substantial drawbacks regarding usability, reliability and content supporting effective behavior change techniques.

Interoperability of IT-Systems is a crucial factor to positively influence this stated drawbacks. This is shown in [3, 14, 25, 26], as it improves the quality and reliability of the system and the gathered data. Through syntactical and semantical structuring of the medical data, errors are reduced e.g. through reduction of duplicates and supporting machine readability. Furthermore it supports and fosters application of state-of-the-art security measures, which are necessary for secure and sustainable usage of the data and the system. In addition it provides seamless integration in medical records like personal health records or electronic health records and fosters long-term costs savings, as shown in [1, 15].

However, there are many different frameworks and standards fostering interoperability in medical IT. Most prominent standards for the personal health care domain are Integrating the Healthcare Enterprises (IHE)[13], Health Level 7

(HL7)[8], Personal Connected Health Alliance (PCHA)[22]. The IHE provides several profiles specifying processes and requirements (i.e. standards, technologies) for building standardized systems in different domains like IT infrastructure, Radiology, Laboratory etc. The PCHA provides a reference architecture for personal health device integration to IT systems in a standardized way. HL7 delivers standards for both, IHE and PCHA approaches. In December 2017, the PCHA provided a press release [20], which stated the integration of the uprising interoperability standard HL7 FHIR in their architectural approach and guidelines. This adds an additional perspective to the classical way using their device enterprise communication (DEC) profile i.e. leveraging HL7 v2.* / v3 standards. HL7 FHIR [10] is a light-weight interoperability standard specifying resources for storing and exchanging clinical data via RESTful web services, which allows a more flexible way compared to classical standards like HL7 v2.* / v3 standard.

Based on a previously accomplished market analysis investigating the most prominent wearable activity trackers on their communication interfaces, the objective was to propose a standardized approach for the integration of data from wearable activity trackers in accordance to the refreshed PCHA guidelines and building a prototype using HL7 FHIR to study feasibility.

2 MATERIALS AND METHODS

First technical conditions, which were given through existing wearable activity trackers, were collected. As the market for wearable activity tracker is very opaque and complex, a market study and investigation study on these devices technical communication interfaces [16] was carried out prior this work.

The results showed that wrist-wearable devices are in actual focus compared to other categories like headphone based-, breast strap based- or smart clothing based-approaches. Taking a closer look on this result lead to the fact that substantially wrist-based activity trackers cover the most biometric indicators. Hence, another result of the studies was that the main important biometric indicators, measured by wearable activity trackers of all categories, are heart-rate, activity-patterns and sleeping-behavior. The latter two indicators are measured generally with linear acceleration sensors to detect movement, the first is measured with optical sensors.

Therefore, table 1 provides a summarized overview about the investigated wrist-wearable activity trackers. The table shows their transmission technologies, biometric parameters, how they are mapped to the standardized format and selected devices used in the prototype. These were used as requirements in this work for the specification and design of the prototype:

Based on the requirements an IT architecture for a complete end-to-end system was defined integrating activity trackers with proprietary as well as standardized interfaces and transforming the data to HL7 FHIR format. Hence, an HL7

Table 1: An overview about the investigated and selected wrist-based activity trackers its interfaces and biometric indicators.

Manufacturer	Product	Transmission Technology	Biometric Indicators	FHIR-Mapping	Prototype?
Fitbit	Charge HR	Bluetooth	heart rate, activity-pattern, sleep-behaviour	beats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp	
Polar	A360	Bluetooth LE	heart rate, activity-pattern, sleep-behaviour	eats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp	x
Xiaomi	Mi Band 2	Bluetooth LE	heart rate, activity-pattern, sleep-behaviour	beats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp	
Garmin	vivosmart HR	Bluetooth LE	heart rate, activity-pattern, sleep-behaviour	beats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp	
Samsung	Gear Fit 2	Bluetooth	heart rate, activity-pattern, sleep-behaviour	beats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp	
Jawbone	UP3	Bluetooth	heart rate, activity-pattern, sleep-behaviour	beats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp	
Intel	Basis Peak	Bluetooth LE	heart rate, activity-pattern, sleep-behaviour, temperature	beats/minute in Obs-Comp, number/minute in Obs-Comp, number/minute in Obs-Comp, degree-celcius in Obs-Comp	

FHIR observation for activity tracking was defined and implemented as a prototype, according the previously defined requirements to study feasibility. The following components where used in the prototype:

- Android 6.0 (Marshmallow) on a OnePlus 3T smartphone
- Polar A360 Fitness Tracker
- Open Source HAPI FHIR for the Interfaces and the Server [24]
- HL7 FHIR Validator [11]

The prototype was tested with functional tests and the conformance of the prototype to the interoperability specifications of PCHA Guidelines [23] and HL7 FHIR [9], was tested by application of no-peer interoperability tests using the HL7 FHIR Validator.

3 RESULTS AND DISCUSSION

The architectural approach shows a complete end-to-end system for the integration of proprietary wearable activity trackers to professional medical IT systems. On the left side of figure 1, n-wearable activity trackers are indicated as data sources transmitting the data via Bluetooth (BT) or via Bluetooth Low Energy (BLE) using Generic Attributes (GATT) services to the Activity Tracker Gateway (ATG). The ATG is basically a smartphone or tablet App, but could also a PC or as a black-box system. The gray blocks are indicating software modules, which are extracting the data from the different proprietary data formats of the manufacturers and

forwarding it to the general business logic of the App, which may visualize and store it on the smartphone i.e. in a SQLite database.

However, the core functionality resides in the generic definition of the FHIR Development Kit module (green, FHIR-DK), which purpose is to transform proprietary data into standardized format according to HL7 FHIR. The mapping itself is separated in domain modules i.e. Health, Social, Sports and n-other domains. These modules provide mapping routines for specific use cases, i.e. the "Wearable Activity Tracker - Use Case" as an application in this work. There can be n-domains as well as n-"use cases-submodules" inside the domain modules. On the one hand the FHIR-Library and the RESTful WS module, can be self-developed libraries for Object to XML/JSON mapping to align the format according the HL7 FHIR specification and transmission via RESTful Web Services (WS). On the other hand, third-party libraries e.g. HAPI FHIR [24] can be used, which provide full support for both or parts of these two modules.

However, the HL7 FHIR resources are then transmitted to a receiving HL7 FHIR conform server e.g. HAPI FHIR server connected to any kind of Health Information System (HIS). The system stores the data in form of resources or provides further processing to standardized PHR or EHR formats. An completely standardized example could be the transformation of the data into HL7 Clinical Document Architecture (CDA) format to have a longitudinal patient and subsequent integration into EHR infrastructure based on IHE

Figure 1: The proposed end-to-end standardized approach for the integration of wearable activity trackers to Health Information Systems (HIS). On the left, the different wearable activity trackers and/or standardized Personal Health Devices (PHD) are shown. In the center of this figure, the personal health gateway i.e. smartphone or tablet of the patient including the FHIR-Development Kit module for standardization is presented. On the right, the figure indicates the receiving HIS providing the necessary infrastructure i.e. Electronic Medical Record (EMR), Electronic Health Record (EHR) or Personal Health Record (PHR) or others.

Cross-Enterprise Document Sharing (XDS) for standardized exchange of medical information like CDA documents.

On the bottom of figure 1 the system indicates the possibility to have a full end-to-end standardized approach from the wearable activity tracker to the HIS as well. The FHIR-DK module can be connected to other *-DK modules, which support the full conformance to PCHA. Standardization of the communication between wearable activity tracker and a gateway, like the ATG, can be done by using IEEE 11073 group of standards (X73) via Bluetooth, which is indicated with the X73-DK module. On the same way the system could be enriched with Personal Health Devices (PHD) like blood pressure monitors or puls oximeter devices. The IHE-DK module indicates the mentioned transformation and integration of

HL7 FHIR data fragments to fit CDA (e.g. Personal Healthcare Monitoring Report (PHMR)) and XDS requirements. An X73-DK module and IHE-DK module, was proposed and developed in former work [25, 26], but can be combined with the actual approach.

The purpose of the "Wearable Activity Trackers"-module in the FHIR-DK module is needed to transform the activity tracker data in HL7 FHIR conform format. In the prototype the Polar A360 wearable fitness tracker watch was used to deliver heart rate data via the use of the Generic Attribute Profile (GATT) service for Heart Rate. Therefore, the Android OS internal BluetoothAdapter-Object, which connects the App to the systems Bluetooth service previously, was used to scan for devices. Once the device was detected, the

App can connect with the BLE device and subsequently scan for its GATT services and characteristics describing the services itself. These services are generally described by the Bluetooth SIG and can be found in [4]. After selecting the proper GATT service, in this case the heart rate service, the App connects to the GATT server to provide a data sharing channel. In case the device provides measurement data, this is then handled via the implementation of a GattCallback, which first examined the correct use of the UUID for data identification. In this case the proper UUID is 180D for the "org.bluetooth.service.heart_rate" service. Subsequently, the data itself is read in a format according to the BLE specification for the service (i.e. UINT8 or UINT16). Then the data was stored locally by the App's business logic for subsequent processing by the FHIR-DK Module. Furthermore, for gathering information about the user him or herself and the movement data (usable for sleep tracking too) the appropriate services were User Data GATT service (UUID: 181C) and Running Speed and Cadence GATT service (UUID: 1814).

Supporting semantical interoperability is a very important fact in this context. This was done using terminologies and its codes (i.e. LOINC and UCUM) as defined in the HL7 FHIR specification for an observation resource. However, the lack of an appropriate code to illustrate the "number of seconds of sleep per minute" lead to the necessity of specifying a separated code and a value-set (Activity Tracking Codes (ATC)). Additionally, for the purpose of identification and categorization of the observation as an activity tracking session, lead to the fact of adding a code for this type of observation. The ATC value-set itself is shown in figure 2.

The figures 2 - 5 present an example instance of the defined HL7 FHIR observation resource for the transmission of the collected activity tracker data from the ATG to the HL7 FHIR server e.g. like the open-source HAPI FHIR server in this approach.

The first part of the HL7 FHIR observation resource includes two contained-elements for inline-definition of the performing organization providing the measurement setup and the person i.e. the patient measuring its biometric indicators with any kind of wearable activity tracker. Inside the patient-element, the gender and birth date are relevant information for combination and interpretation of the data during and after measurement. The contained-elements are referenced in the subject-element (line 32-34) and the performer-element (line 37-39) by its ids. The code-element (line 25-31) identifies and categorizes the observation as an activity tracking observation type. As previously stated, a separated code for Activity Tracking (AT) was therefore defined in the ATC value-set.

Figure 3 shows the first of three data components, containing the relevant activity tracking data measured. In this case it contains the heart rate information, which is indicated by its code-element (line 42-47) using the LOINC code 8867-4. The data is structured by using the valueSampledData-element (48-60), as this element allows to integrate multiple sample values for one transmission. This is an important requirement to provide dynamic transmission of data at any point in

```

1 <Observation xmlns="http://hl7.org/fhir">
2   <contained> <!-- Activity Tracker Gateway (ATG)-->
3     <Organization xmlns="http://hl7.org/fhir">
4       <id value="1"/>
5       <name value="ATG"/>
6     </Organization>
7   </contained>
8   <contained> <!-- Patient -->
9     <Patient xmlns="http://hl7.org/fhir">
10       <id value="2"/>
11       <identifier>
12         <system value="urn:oid:1.2.40.0.29.99.1"/>
13         <value value="1234"/>
14       </identifier>
15       <name>
16         <use value="official"/>
17         <family value="Urbauer"/>
18         <given value="Philipp"/>
19       </name>
20       <gender value="male"/>
21       <birthDate value="1984-01-26"/>
22     </Patient>
23   </contained>
24   <status value="final"/>
25   <code> <!-- type of observation: Activity Tracking -->
26     <coding>
27       <system value="urn:oid:1.2.40.0.29.99.9"/>
28       <code value="AT"/>
29       <display value="Activity Tracking"/>
30     </coding>
31   </code>
32   <subject>
33     <reference value="#2"/> <!-- ref to patient -->
34   </subject>
35   <!-- time stamp-->
36   <effectiveDateTime value="2018-02-16T10:11:47+01:00"/>
37   <performer>
38     <reference value="#1"/>
39   </performer>

```

Figure 2: The first part of the HL7 FHIR observation resource defined for the integration of wearable activity tracker data in form of an Activity Tracking observation. This was successfully validated by applying the HL7 FHIR Validator.

time, in contrast to fixed transmission times which makes less sense in this measurement context. In the origin-element the zero-value as well as its physical unit derived from UCUM, is defined. The period-element defines the time span (60000 milliseconds) between the samples, the lowerLimit-element the minimal value and upperLimit-element the maximum possible value taken into account for heart rate measurement. The data-element contains the heart rate values separated by whitespace-character.

Integration of activity data was done as shown in figure 4. As stated previously, the proper coding of the activity component could be done by using an IEEE 11073-10101 (Point-of-care medical device communication – Part 10101: Nomenclature) code. The data about the steps is stored similar to the approach in the heart rate component i.e. using valueSampledData (line 70-82). The difference lies only in the upperLimit-element value.

Finally figure 5 shows the last observation component focusing on sleep-related activity tracker data. For this activity component, a separated code "Number of seconds of sleep per minutes measured" (NSSPM) was defined for the coding-element (line 86-90), as the investigation to find a proper code for the needed resolution of "amount of seconds of sleep per minute" failed. The code investigation was done by an Internet

Table 2: The developed value-set with the codes to fulfill the necessity of indicating activity tracking as an type of observation in HL7 FHIR, indicating the amount and distribution of sleep and the amount of steps, both over a small resolution i.e. per minute.

Value Set Name: ATC Value Set Root OID: 1.2.40.0.29.99.9		
Display	Code	Comment
Activity Tracking	AT	Observation Type: Activity Tracking
MDC_DIM_STEP_PER_MIN	6752	From IEEE 11073-10441-2013. Describes the "number of steps per minute measured", when observing a person with a wearable activity tracker for activity
Number of seconds of sleep per minute measured	NSSPM	Describes the "number of seconds of sleep per minute measured", when observing a person's sleep behavior
Heart Rate	8867-4	Heart Rate as defined in LOINC

```

40 <component> <!-- heart rate component -->
41 <code>
42 <coding>
43 <system value="urn:oid:1.2.40.0.29.99.9"/>
44 <code value="8867-4"/>
45 <display value="Heart rate"/>
46 </coding>
47 </code>
48 <valueSampledData>
49 <origin>
50 <value value="0"/>
51 <unit value="beats/minute"/>
52 <system value="http://unitsofmeasure.org"/>
53 <code value="{beats}/min"/>
54 </origin>
55 <period value="60000"/> <!-- one minute -->
56 <lowerLimit value="0"/> <!-- measure ranges -->
57 <upperLimit value="250"/> <!-- measure ranges -->
58 <dimensions value="1"/>
59 <data value="56 59 61 120 130 144 123 50 56"/>
60 </valueSampledData>
61 </component>

```

Figure 3: The second part of the HL7 FHIR observation resource shows the component containing the heart rate data.

```

62 <component> <!-- activity component-->
63 <code> <!-- added indicator -->
64 <coding>
65 <system value="urn:oid:1.2.40.0.29.99.9"/>
66 <code value="6752"/>
67 <display value="MDC_DIM_STEP_PER_MIN"/>
68 </coding>
69 </code>
70 <valueSampledData>
71 <origin>
72 <value value="0"/>
73 <unit value="number/minute"/>
74 <system value="http://unitsofmeasure.org"/>
75 <code value="{#}/min"/>
76 </origin>
77 <period value="60000"/> <!-- one minute -->
78 <lowerLimit value="0"/> <!-- measure range -->
79 <upperLimit value="300"/> <!-- measure range -->
80 <dimensions value="1"/>
81 <data value="7 2 3 2 45 49 39 22 30"/>
82 </valueSampledData>
83 </component>

```

Figure 4: The third part of the HL7 FHIR observation resource shows the activity component.

based research as well as by usage of the Terminology-Server for the Austrian Healthcare System [2]. The physical unit was defined as amount/minute. The lowerLimit-elements and upperLimit-elements inside the valueSampledData-element, which was again chosen for the sleep-related data, define the range between 0 and 60 seconds. Based on this value it should be possible to indicate if a patient was in deep-sleep or weak-sleep, as this is the most prominent analytic approach which was observed during the market analysis study for wearable activity trackers. The proposed HL7 FHIR observa-

```

84 <component> <!-- sleep component-->
85 <code> <!-- added indicator -->
86 <coding>
87 <system value="urn:oid:1.2.40.0.29.99.9"/>
88 <code value="NSSPM"/>
89 <display value="Number of seconds of sleep per minute measured"/>
90 </coding>
91 </code>
92 <valueSampledData>
93 <origin>
94 <value value="0"/>
95 <unit value="number/minute"/>
96 <system value="http://unitsofmeasure.org"/>
97 <code value="{#}/min"/>
98 </origin>
99 <period value="60000"/> <!-- one minute -->
100 <lowerLimit value="0"/> <!-- measure range -->
101 <upperLimit value="60"/> <!-- measure range -->
102 <dimensions value="1"/>
103 <data value="0 0 1 2 49 55 59 58"/>
104 </valueSampledData>
105 </component>
106 </Observation>

```

Figure 5: The last part of the HL7 FHIR observation resource contains sleep-related data.

tion resource for activity tracking was successfully tested by application of the HL7 FHIR Validator tool [11] to prove its conformance against the HL7 FHIR specification.

4 CONCLUSION

The results showed that integration of wearable activity tracker data in accordance to the PCHA Guidelines and HL7 FHIR is applicable. However, there is no FHIR profile yet for integration of wearable activity tracker data. Therefore an HL7 FHIR observation was defined, implemented and successfully tested with no-peer interoperability tests using the HL7 FHIR Validator. The proposed approach is applicable

for any wearable activity tracker system, independent of the place of application on the body as the biometric indicators used are the most prominent ones which are measured by common devices.

A crucial factor was the support for semantic interoperability through the application of codes. No fitting codes for the specified data were found in most prominent medical terminologies during Internet research and usage of the Austrian Terminology server. Regarding "seconds of sleep per minute" several codes used in the context of EEG were found, but these were too specific. Nevertheless, using the resolution of minutes for all values made the most sense, taking into account the analysis made on existing activity tracker platforms, like Polar Flow. Additionally the minute resolution for steps, sleep and heart rate allows clearly defined transmission blocks, which could be transmitted dynamically at any point in time, in contrast to steps per day which would be more reasonable for long time reports. However, with the minute-resolution approach it is also possible to calculate these numbers algorithmically later by the smartphone/tablet or the HIS.

Although the approach provides a very broad integration of non-standardized as well as standardized wearable activity trackers, it has to be stated that on the one hand it is partly complex or impossible to integrate existing proprietary interfaced devices as they can not be read or even accessed. On the other hand standardized devices would be accessible, but there are no wearable activity trackers available yet, as it can be researched in the PCHA showcase database [21].

Summarizing, it can be stated that it is possible to integrate wearable activity tracker data using HL7 FHIR and PCHA Guidelines with some additional effort. As the data is made syntactically and semantically interoperable by applying this approach, it can increase data and systems quality and reliability. Nevertheless, without change of thinking and more effort on the manufacturers side these improvements based on using interoperability standards won't be effective.

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