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Yours Truly? Survey on Accessibility of Our Personal Data in the Connected World

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***Abstract*— Due to the advancement of embedded sensing and wireless communication technologies, in recent times, there is a sharp rise in the number of smart personal and home (multi-user) specific devices. Sensors embedded in these devices collect significant amount of personal data including raw sensor data and derived data, such as, motion, location, heart rate, oxygen saturation, step counts. This user generated data can be helpful to understand their behavior, activity, health, and quality of life and can help healthcare providers (if shared with users' consent), to get a better insight about patients and their everyday life. The lack of control over these personal data and their flow makes the user vulnerable to external attacks and data abuse. Also, most of the devices do not allow the users to access and share their self-produced raw sensor data. In this study, we investigate the accessibility of the user generated data for a wide range of currently available devices. We also present an overview of the type of data that popular home and wearable devices collect from their users. Finally, we propose a more accessible data platform where users can store and manage their data with other stakeholders in an access-controlled manner.**

Keywords—Data accessibility, API, Survey, Smart home devices, Wearable devices, Internet-of-Things

I. Introduction

With the proliferation and the pervasive use of smart devices, which contain numerous embedded sensors, we (our devices) collect an abundant quantity of data every day. These devices range from smartphones to smart clothing, and they are embedded with accelerometers to various vital sign sensors collecting different types of data. Once collected, the flow and control of the data vary for different devices. If the owner/user does not have the full control over the data and its flow, then there is an increased risk of the data being abused. Also, having the full control over own data will allow users to share it with their subject of interest, for example, physician or caregivers. In this research, we investigate currently available devices to find the answer to the following questions: (1) what data are being collected, (2) where exactly the data is being stored, (3) who owns the data, and (4) who has the control over the flow of the data.

In this paper, we have surveyed more than 80 most recent smart devices and listed them in Table I. The devices are categorized depending on their nature, activity or usage, such as, smart watches, smart glasses, smart clothing, smart jewelry, etc. While some of the devices are wearable devices measuring the geo-tagged vital signs of the users, rest of them are smart home devices recording ambient information.

Fig. 1 shows a category-wise distribution of devices we have studied. One company can have multiple smart devices as products which are usually capable of interacting with each other and sometimes with products from other manufacturers. E.g., Amazon has a smart home assistant product line up named *Echo* [7], which has several variations, like Echo, Echo Show, Echo Dot, Echo Plus, and Echo Spot. Similarly, *Awair* [36][37] is a Smart Air Quality Monitor with the same product name as the Company name and it can interact with devices like Nest [30][31][32][33], Amazon Echo [7] and Google Home [8][9] to keep the user updated about the indoor air quality. The company Eve [28][29] has different products for smart energy management and for smart air quality monitoring.

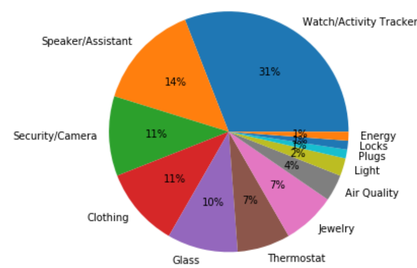

Fig. 1. Categories of Examined Devices [See Table I for a list]

In summary, we make the following contributions.

- An extensive survey of more than 80 smart home-related and wearable devices regarding the type of their embedded sensors and the nature of their data collected.
- Investigating the accessibility of the data (collected by the surveyed smart devices) through APIs and Companion applications. This will benefit users as well as future developers.
- Finally, we proposed a data storage and sharing model which is controlled by the user and shared through a access-control strategy.

II. Sensor Data Collected by Devices

In this section, we look deeper into what kind of sensors are embedded (and hence the type of data collected) into the devices we study in Table I. We have excluded sensors which are rather rare and only included the most common and important sensors that many devices contain. Some devices may have special type of sensors; e.g., Google Glass have MPL gravity sensor. Normally, gravity is measured by a combination of accelerator,

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TABLE I: LIST OF SMART DEVICES INVESTIGATED

Smart Device Type	Smart Device Instances
Watch/Activity Trackers	[Fitbit] Charge 2, Flex 2, Versa, Ionic, Alta HR, Surge; [Xiaomi] Band 3; [Huami] Amazfit Bip, [Apple] Watch 4; [Samsung] Galaxy Watch, Gear Sport, Gear Fit; [Garmin] Fenix 5 Plus, Forerunner 235, Vivosport, Vivofit 4; [Polar] M430; [Moov] now; [Misfit] Vapor, Ray, Shine; [Phillips] Health Watch; [Huawei] Talkband B5, Fit; [Mobvoi] Ticwatch Pro; [LG] Watch
Glasses	[Samsung] SSG; [Vuzix] M100, Blade AR, M300; [Google] Glass; [Everysight] Raptor; [Epson] Moverio; [Sony] Smart Eyeglass
Clothing	[Polar] Team Pro Shirt; [Google] Jacquard; [Supa] Powered Sports bra; [Owlet] Sock 2; [Komodotec] AIO sleeve; [Hexoskin]; [Athos] Clothes; [Samsung] Body Compass, NFC suit
Jewelry	[Bellabeat] Leaf Urban; [Misfit] Swarovski Activity Crystal; [Michael Kors] Access Bracelet, Access Thompson; [Motiv] Ring; [Oura] Ring
Speaker	[Apple] Home Pod; [Amazon] Echo, Echo Show, Echo Dot, Echo Plus, Echo Spot; [Google] Home, Home Mini; [Ultimate Ears] Megablast, Blast; [Sonos] One; [JBL] Link 300
Security Camera	[Netgear] Arlo Pro 2, Arlo Go; [Hive] View, Camera; [Nest] Cam IQ, Cam Outdoor; [Netatmo] Presence; [Canary] Security System; [Honeywell] Wireless Home Alarm Kit with Camera
Thermostat	[Nest] Learning Thermostat, Thermostat E; [Hive] Active Heating 2; [Honeywell] Evohome; [Ecobee] Thermostat; [Netatmo] Thermostat
Air Quality Monitor	[Netatmo] Smart Indoor Air Quality Monitor; [Awair]; [Eve] Room
Light	[Phillips] Hue color Ambience, [Hive] Active Light
Plug	[Eve] Energy
Lock	[Nest] x [Yale] Smart Lock
Energy Monitor	[Neurio] Energy Monitor
UV Patch	[L'oréal] UV Sense

TABLE IV: SMART DEVICES, THEIR APIS AND COMPANION APPS

Product Group	Data API	API Cost	Companion App	Product Group	Data API	API Cost	Companion App
Apple Watch [88]	Apple Health Kit	0	Health App	Kate Spade Activity Tracker			Kate Spade New York Connected
Tic Watch			Mobvoi	Supa Powered Sport Bra			Supa.AI
LG Watch			Google Fit	Owlet Smart Socks			Owlet Baby Care
Fitbit [89]	Fitbit API	0	Fitbit	AIO Smart Sleeve			AIO Sleeve
Misfit [90]	Misfit Cloud API	0	Misfit App	Hexoskin Smart [98]	Hexoskin Web API	0	Hexoskin
Samsung [91]	S_Health	0	Samsung Health	Athos			Athos
Garmin [92][93]	Garmin Health/ Garmin Connect	N/A/$500 0	Garmin Connect Mobile	Apple Home			Home
Phillips Health Watch [94]	Phillips Health API	0	Phillips Healthsuite Health App	Amazon Echo			Amazon Alexa
Moov Now			Moov Now App	Google Home			Google Home
Huawei			Huawei Wear	Ultimate Ears			Blast & Megablast/ Boom & Megaboom
Amazfit Bip [95]	Huami Web API	0	Mi Fit	Sonos One			Sonos Controller
Polar M430 [96]	Polar Open Access Link	0	Polar Beat	Phillips Hue [99]	Phillips Hue API	0	Phillips Hue
Xiaomi Band			Mi Fit	Hive			Hive
Vuzix				Netgear			Arlo
Google Glass				Netatmo [100]	Netatmo Weather API/ Security API/ Energy API	0	Netatmo Weather/ Security/ Energy
Epson Moverio				Honeywell Evohome [101]	Honeywell Evohome API	0	Total Connect Comfort
Sony Smart Eyeglasses				Ecobee [102]	Ecobee API	0	Ecobee
Everysight Raptor				Eve			Eve-You.Home.Connected
Bellabeat Leaf Urban			Bellabeat	Nest [103]	Nest API	0	Nest
Michael Kors Access Bracelet			Michael Kors Access	Canary Smart Security System			Canary
Motiv Ring			Motiv Ring Fitness Tracker	Neurio [104]	Neurio API	0	Neurio Home
Oura Ring [97]	Oura Cloud API	0	Oura	Awair [105]	Awair API	0	Awair

magnetometer and gyroscope. Another distinction to note is that motion sensor in home devices is different from motion sensors typically found in wearables devices. Motion sensors in home devices can use infrared, ultrasonic, even microwave to detect motion. Some companies have produced separate sensors to work with their product. E.g., Phillips Hue have produced a line of motion sensor of their own to support their smart lights. Although the motion sensor is not part of their smart lightbulbs, in this paper, we consider that Phillips Hue's smart lights have the motion sensor embedded.

TABLE II. AMBIENT SENSORS CONTAINED IN THE MARKET AVAILABLE SMART HOME DEVICES

Device / Product Lines	1	2	3	4	5	6
Apple Home Pod [6], Amazon Echo [7], Google Home [8][9], Ultimate Ears [10][11], Sonos One [12], JBL Link 300 [13]				✓		
Phillips Hue [14]	✓					
Hive [15][16][17], Netgear [18][19]	✓		✓	✓		
Netatmo [20][21][22][23]		✓	✓	✓		✓
Honeywell Evohome [24][25]		✓	✓			
Ecobee [26][27]		✓		✓		
Eve [28][29]	✓	✓				✓
Nest [30][31][32][33]	✓	✓	✓	✓		✓
Canary Security System [34]		✓	✓	✓		
Neurio [35]					✓	
Awair [36][37]						✓
1-IR Motion sensor, 2-Temperature, 3-Camera, 4-Microphone, 5- Energy Monitor, 6- Air quality						

Table II lists the Smart Home product lines from different companies listed in Table I and records the sensors embedded in their products. We have grouped together devices that have the same type of sensors. We found that the most common types of sensors used are the Infrared Motion Sensors [used to detect presence], temperature sensors, camera, microphone [for capturing/ listening to commands], energy monitor and air quality monitor. Among them, the temperature sensor and the microphones are used by majority of the investigated smart home devices. However, some other smart home devices (not investigated by us) are found to use GPS receivers and ambient light sensors.

Table III lists the wearable devices covered in the Table I and identifies the sensors used by them. We can see that majority of the wearable devices use accelerometer which is closely followed by heart rate sensor and GPS sensor. This shows that geo-tagged mobility/acceleration and physical activity detection is vogue due to the presence of many activity trackers. On the other hand, Barometer, Altimeter, Camera and Pulse-Oxygen saturation sensors (SPO2) are hardly used. Among the devices we surveyed, we did not find any which actively measures Galvanic Skin Response (GSR) which is an important measure for stress detection. We found that a new trend in activity tracker development is blending them with accessories, jewelries and clothing, such as, Bellabeat Leaf Urban [76] and Michael Kors Access Bracelet [77]. Moreover, AIO Smart Sleeve [84] developed a new way to measure heart rate through user arms instead of wrists used by other traditional devices.

III. API AND DATA AVAILABILITY

Many devices/wearables come with companion apps, in which users can use to see their data or control and set up the devices. Sometimes a device may not have its own companion app, but syncs with popular data warehouse such as Google Fit or Apple Health Kit (discussed more later). Not all of them have a data API. We define a data API as an API that allows users or researchers to access their data, often through a REST interface. In Table IV, we list the devices, and whether they have a data API available, and the cost to access such API. If such API or companion apps are not available, we leave the cell blank.

TABLE III. VITAL SIGN SENSORS CONTAINED IN THE MARKET AVAILABLE WEARABLE DEVICES

Device	1	2	3	4	5	6	7	8	9	10
Apple Watch 4 [38]	✓	✓	✓			✓		✓		
Tic Watch Pro[39]	✓	✓	✓	✓		✓				
LG Watch Sport[40]	✓	✓	✓		✓	✓	✓			
Fitbit [41][42][43][44][45][46]	✓	✓		✓		✓		✓		✓
Misfit [47][48][49][50][51]	✓	✓	✓	✓		✓				
Samsung [52][53][54][55]	✓	✓	✓			✓	✓			
Garmin [56][57][58][59][60]	✓	✓				✓	✓	✓		✓
Phillips Health Watch [61], Polar [66][67][68]	✓	✓				✓				
Moov Now [62]		✓	✓	✓						
Huawei [63][64]	✓	✓	✓			✓				
Amazfit Bip [65]	✓	✓				✓	✓			
Xiaomi Band 3 [69], Motiv Ring [78]	✓	✓								
Vuzix [70][71]		✓	✓			✓			✓	
Google Glass [72], Sony Smart Eyeglasses [74]		✓	✓	✓					✓	
Epson Moverio [73]		✓	✓	✓		✓			✓	
Everysight Raptor [75]		✓	✓	✓	✓	✓				
Bellabeat Leaf Urban [76], Michael Kors Access Bracelet [77], Kate Spade Activity Tracker [80]		✓								
Oura Ring [79]		✓	✓							
Owlet Smart Socks 2 [82][83]	✓									✓
Supa Powered Sport Bra [81], AIO Smart Sleeve [84], Hexoskin Smart [85]	✓									
Athos [86][87]	✓	✓	✓							
1- Heart rate sensor, 2- Accelerometer, 3- Gyroscope, 4- Magnetometer, 5- Proximity Sensor, 6- GPS, 7- Barometer, 8- Altimeter, 9- Camera, 10- SPO2 Sensor										

From the devices we have studied, most are found to have companion apps. This makes users visualize their personal data, but they cannot access those raw sensor data in majority of the cases. Even if the users have APIs, they do not let users access the raw sensor data apart from accessing high level derived data. This fuels our concern regarding the case that the data producers are hardly having any access to their raw data and enterprises are monopolizing them and this increases security concerns. Also, this leads to various recent cases where data leaks have taken place from large enterprises, compromising user privacy.

There are several data warehouses worth mentioning. These includes Google Fit [112], Microsoft Health [113], Samsung Health (from Samsung) [114], Apple Health Kit [115], etc. They not only collect data from their own devices and applications (Apple Health Kit and Apple Watch for instance) but also from integrated devices and applications that have registered with them. We want to point out for developers that, in the case of Google Fit, the type of data received from integrated devices and third-party applications may not be normalized/standardized (for same type of data different developers might use different names, units, timestamps, etc). This means that these data might have to go through a normalization pipeline before being used.

TABLE V: TYPE OF DATA AVAILABLE THROUGH WEARABLE APIS

API name	1	2	3	4	5	6	7	Other
Apple Health Kit [88]	✓	✓	✓	✓	✓	✓	✓	✓
Fitbit API [89]		✓	✓	✓	✓	✓		
Misfit Cloud API [90]				✓	✓			
S_Health [91]		✓	✓	✓	✓	✓		✓
Garmin Health/Connect [92][93]								
Phillips Health API [94]		✓	✓		✓			✓
Huami Web API [95]	✓	✓	✓	✓	✓			
Polar Open Access Link [96]			✓	✓				✓
Oura Cloud API [97]	✓			✓	✓			
Hexoskin Web API [98]	✓	✓	✓		✓			✓
1-Characteristic Identifiers, 2- Body Measurement, 3- Vital Sign, 4-Activity, 5-Sleep, 6- Nutrition, 7-Reproductive Health								

In Table V, we list the APIs made available by different wearable devices we studied along with the type of the accessible data. We have used the data types as mentioned in the Apple Heatlh Kit. *Characteristic Identifiers* refer to unchangeable biological data such as blood type, biological sex, skin type, etc. *Body measure* refers to weight/height, body fat, etc. *Vital sign* includes but is not limited to heart rate, blood pressure, blood glucose level, and respiratory rate. *Activity* refers to the activity that these devices track. This may include related data at the time of the activity such as step counts, elevation, calories burnt, etc. *Sleep* refers to sleep pattern and other sleep-related data. *Nutrition* tracks diet and nutrition. Reproductive Health tracks the reproductive health of users. Other less common data such as UV exposure or GPS, etc. have not been included in the table. The table lists the *Garmin Health API* [92] as unavailable since even though it is free, it only allows enterprises to access it. *Garmin Connect API* [93], on the other hand, requires one-time $5,000 licensing fee for developers.

TABLE VI:TYPE OF DATA AVAILABLE THROUGH SMARTHOME DEVICE APIS

API name	1	2	3	4	5	6	7	8
Phillips Hue API [99]	✓							
Netatmo API [100]		✓	✓		✓	✓		✓
Honeywell Evohome API [101]		✓			✓			✓
Ecobee API [102]					✓			
Nest API [103]		✓			✓	✓		✓
Neurio API [104]				✓				
Awair API [105]		✓			✓			
1-Light 2-Air Quality 3-Weather 4-Energy Consumption 5-Temperature 6-Video/Images 7-Audio 8-Motion Log								
**L'oréal UV Sense [106] has a UV Sensor								

In the Table VI, we list the APIs made available by different smart home devices we studied along with the type of the accessible data. The data types are - *light* which refers to preferred light settings by users, such as brightness and color. Air quality includes levels of CO, humidity, dust, volatile organic compounds (VOC), PM25, PM10, etc. Weather includes rain, wind, pressure, etc. Motion log returns when the sensors detect movement (mostly for security systems) and all data associates with such event, like location, timestamp, etc. Netatmo [100], in particular, can return whether the cause of that motion is animal, vehicle, or human. For humans, they can even detect faces and determine if the person is recognized or not.

IV. OUR PROPOSED MODEL

Our extensive survey goes to prove that the users hardly have any claim on the data they produce through their daily activities. Also, the more personal healthcare related data is also stored by the smart device manufacturers and is not available to be accessed by the users (owner/developer) in the form of raw data. In order to address this problem, we propose a combined smart home and health platform (Fig.2) for data acquisition and storage. We call the system a Smart Health Management System (SmartHMS). The data acquisition in the SmartHMS system is done in a smart home environment for one or more of the inhabitants. The SmartHMS system has two component sub-systems named SmartHome IoT and SmartHealth IoT or the Health Monitoring System (HMS).

The SmartHome IoT has several interconnected smart entities (everyday objects connected with RFID or Bluetooth Low Energy (BLE) tags and/or wireless communication modules) which also collect raw data from the user's environment. The smart home data is then processed using a context management server for remote automatic control of the smart devices depending on various rule-sets. Several smart applications can also be built around the context management server depending on user requirements.

The Health Monitoring System (HMS) has at its core, several individual wearable smart devices which capture the vital signs of the user. Also, user's location in indoor as well as outdoor environment is also captured in order to geo-tag the vital signs or activities recognized. The HMS can locally detect several events related to user health and can make short or long term decisions depending on how much prior data is used for decision making. In order to facilitate more robust long-term decision making, aggregated health and home related data is periodically stored in the health cloud which is controlled by the user and shared with various stake holders in an access controlled manner. The usual stakeholders are the healthcare providers such as the caregivers, physicians, hospitals and/or ambulance persons and can also include distant family members of the elderly users living alone in homes. The health clouds can be used for large area data collection. Provided the users permit, they can detect epidemics or other common disease patterns among various age groups and can warn the users accordingly. This approach is more like symbiotic data usage and not predatory data usage common in majority of the smart devices.

V. RELATED WORKS

Although there are many papers devoted to study sensors in Internet-of-Things (IoT) devices, Sanozov and Newman [1] explored the inner-working of various types of sensors in their book. Seneviratne, et al. [2] have carried out a comprehensive survey and categorization of commercial and prototype wearables. They have also studied the communication security and power efficiency of those wearable devices. Motti, et al. [3] delves into the privacy issue inherent with wearables. Their

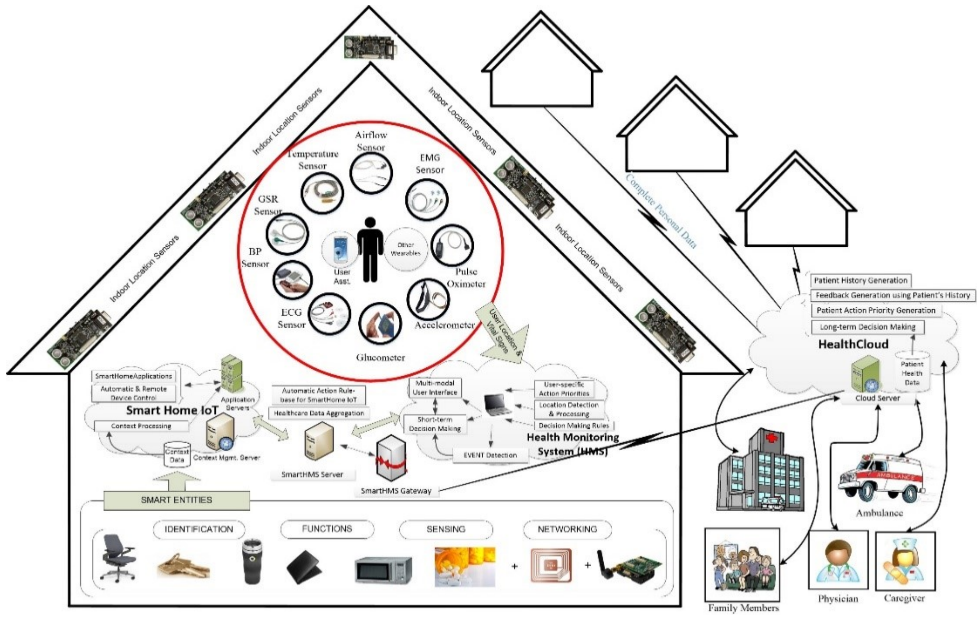

Fig. 2. Proposed Model for Data Acquisition and Sharing in Combined Smart Health Management System

experiments show that not all sensors are equal. Users actually consider microphones and cameras more invasive than sensors such as heart rate or accelerometer. F. Perez, et al. [4] studies the interoperability challenges related to the collection and processing of data from wearable devices from different vendors and proposes several ways to solve it. Patel et al. [5] conducted a survey of several wearable devices with respect to different application domains, such as, health and wellness, safety, home rehabilitation, assessment of treatment efficacy, and early detection of disorders. However, existing works have not studied the availability of user data through the APIs and/or the companion applications.

VI. Conclusion and Future Works

Nowadays, we use numerous smart devices and they collect an enormous amount of data. This continuous collection of personal data is being stored and accessed differently for different devices. The storage, accessibility, and flow of this data need to be carefully reviewed and controlled to minimize the risk of abuse and external attacks. In this study, we investigated more than 80 most recent smart devices to find the available sensors, and the type and accessibility of the collected data. We found that most of the devices provide their own companion applications which present an overview of the data but do not let the user access the raw sensor data. Based on our findings, we proposed a model to store and share user generated data in an access-controlled manner. In future, we want to extend our survey by including more devices and further study the privacy and security aspects of the user data managed in the data warehouses maintained by the existing vendors.

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