An IoT Approach to Personalised Remote Monitoring and Management of Epilepsy

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Abstract—**Most current studies of epileptic seizure detection disclose that "Despite the design of new anti-epileptic drugs, drug resistant epilepsy still lacks an ultimate solution" [1]. The Internet of Things (IoT) provides a timely chance for a more personalised approach to the monitoring and management of epilepsy. This is by integrating smart devices deployed at home and personal patient data into a unified monitoring system. However, because the data collected from monitoring epilepsy patients in hospital is constrained and the data semantic of the devices and patient are not unified, the integration of such data into meaningful information is difficult. A personalised approach has the potential to significantly improve the patients' daily lives whose seizures cannot be controlled by either drugs or surgery. This paper, provides an overview of a proposed personalised approach to not only promote this unification between patient data and devices but also to advocate that 'not one device fits all'. This way a personalised monitoring plan (PMP) for each individual epilepsy patient can be realised.**

personalised remote monitoring; epilepsy; healthcare; internet of things; smart device; information management; wearable technology.

I. Introduction

With such a variety of epilepsy smart devices available together with the knowledge that 'seizures are a very diverse group of disorders, which are not easily managed,' [2] it is difficult for a clinician to know how to find the best device for the particular seizure patient's needs. Also; 'seizures can be different for each person; just knowing that someone has epilepsy does not tell you what their epilepsy is like, or what seizures they have' [3]. In this paper a proposed 'personalised approach' is presented which suggests that there is a more accurate and refined way of remotely monitoring the 'individual' patient at home.

Remote monitoring allows patients to use mobile medical devices to perform routine tests at home and send the test data to a doctor in real-time. A challenge in this research is to blend the devices into the web environment and make them accessible, discoverable and secure. A 'seamless' way of integrating these physical objects or things from the physical world to the cyber world is known as The Internet of Things.

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The IoT (Internet of Things) deals with this connectivity, giving these 'things' an IP address. This paper proposes an IoT approach to promote this unification between patient data and devices by employing Semantic Web Technologies. Surely the time is now to embrace connected technologies so that a quicker diagnosis and a more personalized and tailored result is provided for each patient's health. Hence shifting the power more to the patient.

Furthermore if the precise device is matched to the precise patient and continuously monitored then chances of capturing seizure data can be greater. Ultimately, such an environment could 'enhance the overall monitoring scheme of a patient usually performed by caring persons, who might occasionally miss an epileptic event' [4].

This paper is organised as follows. In Section II. the state of the art is analysed; a personalised approach to manage epilepsy together with the complexity of epilepsy and smart devices is highlighted. Also analysed in Section II. is the need to match the patient with the correct device, while a proposed method for utilizing IoT and semantic web technologies is outlined in section III. Concluding remarks are drawn in section IV.

II. STATE OF THE ART

A. *Personalised Approach*

For some patients being remotely connected to the hospital, can bring great peace of mind i.e. recently one epilepsy patient described what a more connected system might have been able to do stating: "I could have a different result if I (my device) was connected to the correct APP/Web Portal" [5]. Generic smart devices are being handed out to patients without any precision. Even though there is much hype about new healthcare smart devices on today's market; many clinicians presume they should be up to date with latest wearable technology or should be recommending them to their patients but they don't have this knowledge: "it's very rare to find a doctor so well versed in technology" [6]. Yet the impact of technology on 'future' healthcare is mammoth and if these changes hit healthcare professionals unprepared; "they will wash away the medical system we know and leave it a purely technology-based service without personal interaction" [6].

Here Mesko identifies the 'personal' element of technology; it is with this aspect in mind that the next logical step in digitalising healthcare must be embraced. This next step coming around is a more 'Personalised' approach to

Healthcare; hence current research identifies this as a “new trend in medicine focusing on patient-centered care” [7].

B. The Complexity of Epilespy and Smart Devices

With so many existing epilepsy devices, (smart and non-smart) together with associated factors (refer to sample in Table I.) and with so many eventualities in capturing a seizure at home, it is difficult to know the best device to implement. For example the patient could be in the bath, in bed, or watching the TV when the seizure occurs. For instance a Smart Watch used for monitoring shaking may not be comfortable to wear in bed, so a Smart Mattress would take its place. Likewise a Companion Monitor which monitors bed movement and sound but would not be fitting in the shower [3]. Another variant is that different types of seizures will present themselves and there are not always the solutions at the clinician’s fingertips; devices are just not suitable for all the different environments we live in.

In fact there are over 40 different types of seizures [8], but even though there is this enormous variety of behaviours that may occur in different types of seizures it is also known that seizures are usually; “Stereotypic” meaning symptoms are similar whenever they occur [8]. So with this in mind an individual ‘seizure type profile’ or an individual ‘patient dataset’ can be created.

C. Matching The Patient with The Correct Device

Smart devices are becoming increasingly popular in supporting patients in their daily routines, this is due to the recent advances in “sensor development, processing and displays which have enabled devices” [9] with sensors which are wearable.[10] Depending on the patient, “some wearable devices can be placed on the almost any part of the body: wrist, ankle, waist, chest, arm, legs, etc. [10] Another factor influencing patient-device suitability is design: “A good design can also reduce mental and physical stress, reduce learning curve, improve user device operability in using the device and thus improve overall product quality.” [11]

Currently there are epilepsy devices and apps that track medication, send reminders to take medication, some are for emergency with buttons to press before losing consciousness with a seizure and some detect a seizure based on the pattern of jerks [12]. However, there is a danger that epilepsy patients and their Doctors: “faced with a bewildering range of devices” [13] may have difficulty in coming to a “balanced interpretation” of the device.

Therefore, it is vital to choose the most appropriate device, to find evidence on device reliability for a particular seizure type, and specifically to avoid “false alarms which can be disruptive for the family.” Patients with epilepsy must “discuss with their doctors the pros and cons of each device” [13].

Another problem is that some clinicians remain reluctant to adapt to smart device use in clinical practice [14]. Although medical devices and apps inarguably provide the HCP (Health Care Professional) with many advantages, they are currently being used without a ‘thorough understanding of their associated risks and benefits’ [15]. The main factor behind a device value may ultimately be “its ability to provide meaningful, accurate, and timely information” and as observed by Ventola [16] “guidance to the end user in order to serve the vital purpose of improving patient outcomes.” Therefore preparations need to be in place to realise these goals. There is still time and measures that can be taken to “guide” clinicians to choose the most precise device.

Furthermore although smart device usage is currently high by healthcare providers, “little is known about the specific patient care-related tasks performed by physicians on these devices” [17]. Yet, “the ability to obtain the right information at the right place and time is vital for hospital-based physicians” [17]. Hence medical devices and apps are already proving invaluable tools for healthcare professionals, but as their features and uses expand, there is a danger that because they are becoming even more widely incorporated into nearly every aspect of clinical practice’ [18] there may not be the knowledge or tools to match the correct device with the correct patient.

Again advocating the importance of devices; "The biggest problem in caring for people with epilepsy or doing epilepsy clinical trials is poor information," [19] "Biomedical devices that can improve the quality of information have the potential to vastly increase the efficacy of epilepsy management." As available devices grow, if clinicians could be provided with more guidance in understanding and choosing which device suits which situation then the management and monitoring of epilepsy could be improved: “Seizure detection devices are at a relatively early stage of development and, as yet, there are no large-scale studies or studies that compare the effectiveness of one device against others” [20].

TABLE I. EPILEPSY DEVICES

Epilepsy Devices: Smart and Non-Smart	**Sample factors associated with epilepsy devices**			
	Placement/ Situation	***Use at Home***	***Purpose (Detection, Alarm, Diagnostic, Monitoring)***	***Medical Training Needed***
EEG (Gold Standard)	Brain (real time hospital setting)	No	Monitoring	Yes
Smart Belt	Torso	Yes	Detection	No
Vagus Nerve Stimulation (VNS)	Nerve in Neck	No	Diagnostic/ Prevention	Yes
Brain Stethoscope	Brain	No	Monitoring	Yes
Medpage™ Model MP5	Mattress	Yes	Alarm (for Nocturnal Seizures)	No
Emfit	Mattress	Yes	Alarm Nocturnal Seizures)	No
SmartWatch™	Wrist	Yes	Monitoring/ Alarm	No
Embrace	Wrist	Yes	Monitoring/ Alarm	No
SAMi	Surveillance	Yes	Camera/Video: Monitoring/ Alarm	No

Epilepsy Devices: Smart and Non-Smart	Sample factors associated with epilepsy devices			
	Placement/ Situation	***Use at Home***	***Purpose (Detection, Alarm, Diagnostic, Monitoring)***	***Medical Training Needed***
EpiLert	Wrist/Foot	Yes	Detection	No
Continuous Audio Visual EEG Recording	Scalp (Electrodes)	No	Diagnostic	Yes

D. *Unity for Patient at home with Device and Hospital*

This investigatory research found several further gaps: i.e. lack of communication between device, patient and the hospital, the importance of empowering the patient and how 'false alarms' from devices are wasting time highlighting again the requirement for the patient being allocated the correct device. Therefore this proposed approach will be more 'patient focused' than older approaches. It will be designed to 'empower the patient' and bring a 'new' way to manage and monitor epilepsy and henceforth will improve communication between the "patient at home and the hospital". We must unify the patient at home, with the device and the hospital; 'do the engineers and doctors really know what patients want?' It is important to ask the patients opinion and make them more central to the device suitability process. Since usually the patient is not involved in this process this could be why the patient has a low acceptance rate of devices.

III. Preliminary Methods

Initial data has been gathered and background information has been obtained based upon literature reviews and analysis from different health organisations and company reports. The preliminary findings have identified that a personalised approach to manage epilepsy is required. Since it is found that seizures are usually; "Stereotypic" [8] therefore an individual 'seizure type profile' or a 'patient profile' can be created.

A. *Semantic Web Technologies*

If Semantic Web Technologies are utilised and ontology languages are created for both a 'Patient Profile' (i.e. EPPDL; Epilepsy Patient Profile Descriptor Language) and a 'Device Profile' (i.e. EDDL; Epilepsy Device Descriptor Language) then an algorithm could be created to match the data, and specifically name it i.e. 'linked data'. This would help to form an overall snapshot of a patient with their individual strand of epilepsy and with their individual device so they could be more precisely monitored. As an example Table II. depicts an overview of some 'preliminary data' with a sample patient dataset next to suitable smart devices.

TABLE II. Preliminary Data: Patient Profile And Smart Devices

Patient Dataset	***Smart Devices***
Patient: Harry Slein	Chest Strap
Seizure Type: Nocturnal	Smart Watch
Frequency: Once a month	Seizure Bracelet
Indicator: Heart Rate Increase	

In developing a new ontology language for epilepsy smart devices; i.e. Epilepsy Device Description Language (EDDL) this knowledge can be represented in a sharable format and it is expected that this interdisciplinary knowledge could grow among multiple users. Once the ontology language is established then it will allow for future expansion by adding new patient profiles and future devices (as devices are continuously updated). Furthermore, since 'ontologies have the ability to depict the domain knowledge with a superior level of expressiveness and precision' [21] it is the favored approach compared to the creation of a conventional taxonomy because it has the scope to represent the more complex relationship which is required to match the device with the required aspects from the patient dataset.

An extract of the EDDL ontology is depicted in the XML schema in Figure.1. This captures the structure and syntax of all necessary and meaningful elements as a starting point for the planned development of the EDDL ontology.


```
<EDDL>
- <Device>
    <Device_Type>Mattress Alarm Sensor</Device_Type>
    <Model>SensorCare</Model>
    <Sensor1>Pressure</Sensor1>
    <Sensor2>N/A</Sensor2>
    <Time_of_Day>Nocturnal</Time_of_Day>
    <Seizure_Indicator>Movement</Seizure_Indicator>
    <Battery_Life>N/A</Battery_Life>
    <Operating_System>Models OS</Operating_System>
  </Device>
- <Device>
    <Device_Type>Smart Watch</Device_Type>
    <Model>Samsung Gear 2</Model>
    <Sensor1>Accelerometer</Sensor1>
    <Sensor2>Heart-Rate</Sensor2>
    <Time_of_Day>All Day</Time_of_Day>
    <Seizure_Indicator>Shaking</Seizure_Indicator>
    <Battery_Life>3 Days</Battery_Life>
    <Operating_System>Android</Operating_System>
  </Device>
- <Device>
    <Device_Type>Smart Watch</Device_Type>
    <Model>Pebble Steel</Model>
    <Sensor1>Accelerometer</Sensor1>
    <Sensor2>N/A</Sensor2>
    <Time_of_Day>All Day</Time_of_Day>
    <Seizure_Indicator>Shaking</Seizure_Indicator>
    <Battery_Life>10 Days</Battery_Life>
    <Operating_System>Android</Operating_System>
  </Device>
- <Device>
    <Device_Type>Chest Strap</Device_Type>
    <Model>Garmin HRM Tri </Model>
    <Sensor1>Accelerometer</Sensor1>
    <Sensor2>N/A</Sensor2>
    <Time_of_Day>All Day</Time_of_Day>
    <Seizure_Indicator>Pulse Increase</Seizure_Indicator>
    <Battery_Life>6 Days</Battery_Life>
    <Operating_System>920XT</Operating_System>
  </Device>
```


Fig.1. XML schema for EDDL Ontology.

B. *Investigating Wearable Sensors*

Recently it is found that it is the sensors, and their ‘position’ (worn by the patient) more than the actual smart devices that should be examined. During these preliminary investigations it is also found that the focus should be on how patients exhibit behavior, rather than any actual “testing” of devices. When experimenting it is therefore important to choose the most accurate sensors for monitoring epilepsy; these are found to be the accelerometer and heart-rate sensors. Numerous studies have been already conducted with these sensors for epilepsy [22], [23]. Since the ‘gold standard’ is video-EEG monitoring (which takes place within hospitals) [8] the question here is: can the patient be just as accurately monitored at home with the accelerometer and heart rate sensor? Can the individual requirements of the patient be pin-pointed? If so, is there proof that these sensors can be worn at home (a personalised approach) and be just as effective as using EEG monitoring in the hospital setting?

Keeping in mind the objective to tailor the patient’s individual needs it will be vital to experiment with ‘where’ the device is positioned for each individual patient. i.e. one patient’s indicator may be right arm therefore the sensor must be placed here. Another patient may begin shaking from right knee so therefore the sensor is placed here, refer to Figure.2.

IV. CONCLUSION

There is no doubt that smart devices for epilepsy will continue to develop quickly in upcoming years. Therefore, it is compulsory to find a robust and reliable technology to utilise essential smart devices and help clinicians, caregivers and the patients themselves manage and monitor these devices and this syndrome.

In this paper, an overview of how remote healthcare can be monitored using a personalised approach has been presented. There has been a focus on the lack of knowledge that healthcare professionals have about smart devices and evidence has been provided for the need for a more ‘personalised approach’ to monitoring long term health conditions.

In the next sections, an outline has been proposed for matching the correct patient with the correct device together with a discussion on the importance of empowering the patient.

Finally, a method for utilizing semantic web technologies has been proposed and an XML schema has been provided as a starting point for a semantic web ontology. There are promising avenues to deliver tangible outputs.

	Patient Profile 1	Patient Profile 2	Patient Profile 3	Patient Profile 4	Patient Profile 5
Type of Seizure →	Generalised Tonic Clonic	Grand Mal	Generalised Tonic Clonic	Partial Seizure	Generalised Tonic Clonic
Number of seizures Suitable for Motion Detector Accelerometer	2 per week	2 per week	5 or more per week	1 per month	2 per week
Number of seizures Suitable for Heart Rate Sensor	5 or more per week	2 per week	2 per week	5 or more per week	1 per month
Number of seizures Suitable for OTHER SENSOR	1 per month	5 or more per week	2 per week	2 per week	5 or more per week
Recommended Sensor	Accelerometer	Heart Rate	Accelerometer	Audio Sensor	Accelerometer
Recommended Position of Sensor					

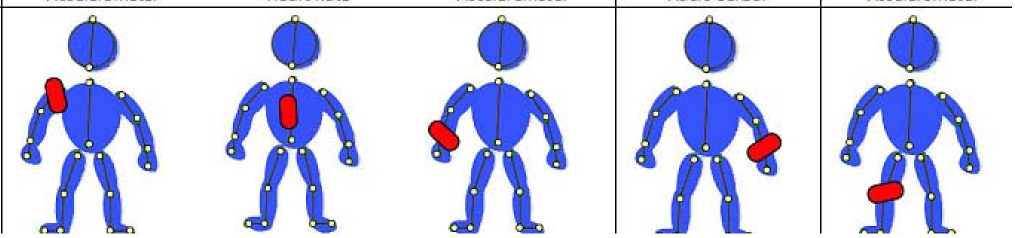

Fig.2. Position of the Sensor.

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