Beats-Per-Minute (BPM): A Microservice-based Platform for the Monitoring of Health Related Data via Activity Trackers

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***Abstract*—Beats-Per-Minute (BPM) is a microservice-based platform that provides a monitoring solution for the continuous acquisition, analysis and visualisation of health related data. BPM combines Commercial Off-The-Self (COTS) Activity Trackers and a scalable cloud-based infrastructure. This paper demonstrates the efficacy, reliability and integrity of BPM when utilised as a monitoring solution for health conditions, such as Cardiovascular Disease. The results are indicative of the suitability of a microservice-based architecture for such a platform.**

I. Introduction

An activity tracker (AT) is one of a wide range of wearable devices that can record an individual's daily activity, including information relating to their health and fitness. These devices record data such as steps taken per day, daily exercise, calories burned, sleep patterns, and heart rate (HR). Typically, the trackers are worn on the wrist and are small so as not to interfere with day to day activities.

ATs provide a rich source of health based information on an individual. As such, ATs have the potential to be used as a preventative monitoring tool (assuming the data required to diagnose a condition is accessible). There are a number of conditions that would benefit from preventative monitoring, one of which is Cardiovascular Disease (CVD). CVD relates to a variety of conditions that affect the heart such as narrowed or blocked blood vessels, blood vessel disease, heart rhythm problems (arrhythmia) or heart defects from birth (congenital heart defects) that can lead to a heart attack, chest pain (angina) and stroke. CVD is contributed to by a number of factors, including high blood pressure, raised cholesterol, obesity and physical inactivity [1].

CVD effects a large percentage of Irish people with the Irish Heart Foundation stating that CVD is "the cause of one-third of all deaths" in Ireland, with approximately 10,000 deaths a year attributed to it [2]. The number of patients suffering from CVD in Ireland is a huge financial burden on the Health Service Executive (HSE) with the annual direct and indirect costs of Heart Failure in Ireland estimated to be €656m in 2012 [2].

The cardiovascular health of an individual can be assessed by monitoring heart rate (HR), HR being the rate at which your heart beats per minute (bpm) [3]. A normal resting HR for adults ranges from 60 to 100 beats per minute. A lower HR at rest signifies good cardiovascular fitness while a higher HR at rest is indicative of poor cardiovascular health that could result in CVD in the long term [4].

Due to the significant impact on the Irish population, the cost associated with the treatment of CVD and the need for monitoring to assess it, CVD is considered an appropriate condition to demonstrate the benefits of the proposed platform.

As previously mentioned, accessibility to data is one of the key requirements in the provisioning of a monitoring solution. Fortunately modern ATs have both the sensor technology and infrastructure to address this. Most ATs use a photoplethysmography (PPG) sensor to calculate HR [1]. These sensors can be placed anywhere on the body, typically over a finger or the wrist. The sensor consists of a light source on one side of the tissue bed and a light detector on the other. Every time your heart beats, your capillaries expand and contract based on the changing blood volume. LEDs are used to illuminate the skin and monitor the blood pulsating variation [5] thereby enabling ATs to measure HR automatically and continuously.

ATs are not limited to HR data, they make a number of physiological metrics available for monitoring. For instance, ATs use a 3-axis accelerometer to track user motions. An accelerometer is a device that turns movement into digital measurements when attached to the body [1]. These digital measurements are processed, providing more detailed information about the frequency, duration, intensity and patterns of a movement. This can be used to determine steps taken, distance travelled, calories burned and sleep quality [6]. Most ATs store the HR, and movement, data on the AT until it is connected to a smartphone via Bluetooth. This connection enables the AT to sync data with an online repository via a web service provided by the manufacturer [7]. Data collected is typically made available through a web based interface for acquisition and visualisataion.

Sensor technology has seen significant advancements in the last number of years with the creation of multiple devices that can provide real-time monitoring of a user's physiology. Wearable sensors are available that can acquire HR, respiration, blood oxygen saturation, blood pressure, electrocardiography (ECG) and skin temperature [8].

The costs of manufacturing sensors and actuators is decreasing, as is their physical size and as a consequence they have become less obtrusive for use in daily activities [9].

The culmination of affordable, accurate sensors along with the ubiquitous nature of the technology enables broader preventative health regimes to be considered that could have a meaningful impact on society at large. A general purpose monitoring solution is considered one that enables users, such as physicians, to access, analyse and act on data in a reliable and efficient manner, the development of which is considered a worthy pursuit. As such, the research question being investigated here is "Can activity trackers be used to facilitate a general purpose monitoring solution for the continuous acquisition, analysis and visualisation of health related data".

The remainder of the paper is organised as follows: Section II presents the use cases investigated, Section III details the system design, Section IV discusses the approach taken in implementing the platform, Section V outlines the experimental setup and evaluation of the platform and Section VI discusses the conclusions arising from this research and highlights our future work.

II. Health monitoring

ATs provide an ideal means of utilising bio-signals for the detection of an undesirable state or event. A system that continually analyses HR data acquired from remotely based ATs could provide a multitude of benefits in health care. Ailments could be detected/prevented, a course of treatment/therapy could be prescribed, with early detection and diagnosis made possible. The most important element in this instance is the raw data itself as it is necessary to detect the onset/occurrence of an ailment. The availability of data to be analysed (automated or not) and a reliable means of acquiring data are crucial. A number of use cases from related work were examined and are discussed hereafter.

A. Patient Recovery

Appelboom et al [10] studied the effects of physical activity performed during patient recovery. They found that physical activity improved the neuromuscular function of patients. It is important for mental restoration and pain reduction. Tracking the physical activity performed with an AT will provide a large amount of data to be analysed. This monitoring provides physicians with unbiased patient data. It can identify if a patients treatment needs to be modified or if the patient needs an intervention.

B. Cost of Cardiovascular Disease

The HSE attempted to reduce the number of CVD patients by introducing a programme called "Heartwatch". It was set up in 2003 by the Irish College of General Practitioners (ICGP) [11]. A report released in 2006 detailed the Heartwatch programmes estimated cost of preventative drug administration at €656,473. It put the total cost of the programme at €4,169,023 including the cost of office administration and GP visits. It is estimated that 81 deaths were prevented, putting the cost per life saved at €51,469. The report stated that the cost per life saved would be considered cost-effective at €20,000 [12]. The platform proposed by this paper operates at a much larger scale and could dramatically reduce the cost per life saved.

ATs are not regulated medical devices at present as they do not make any claim to improve the risk of a disease or condition [13]. They are not considered approved medical devices and using their information to make medical decisions is at the clinicians discretion. However, one case study reported Fitbit data being used to plan a patient's treatment. The Fitbit AT recorded an increase in pulse rate, rather than a decrease, at the time of a patient's seizure. The treatment plan that followed focused on tachycardia, rather than bradycardia. The treatment for these two conditions are very different [14]. The CEO of Fitbit James Park has spoken about his vision for a wider role in health care, and even mentions similar occurrences where their trackers were used to make treatment decisions about a patient's atrial fibrillation [15]. This is a clear indication that physicians, and patients, would benefit from a system that collects patient data, enabling them to diagnose problems and per-scribe treatments based on the data collected.

The proposed platform makes data relating to the daily physical activity and cardiovascular health of an individual accessible. It enables physicians to study the recovery of patients and diagnose further treatment as necessary. An integrated threshold alert system provides benefits when monitoring by alerting physicians, nurses and/or carers if a patient's HR exceeds a certain threshold. All, in all the proposed system will assist in the monitoring of our health.

III. System Design

The decision was taken to name the platform BPM, an analogy to it's primary function as a tool to remotely monitor a user's beats per minute. The intent is to enable the recording of a user's HR in real-time thus providing the means to make this data available online for analysis and the provisioning of preventative diagnostic tools.

There are two types of users in the platform. *Clients*: patients, employees or users who are interested in having their HR monitored and shared with other individuals/parties. *Admins*: physicians, employers or users who act in an administrative/diagnostic capacity and have been permitted to utilise the platform to monitor their Client's HR data.

Through the collection of HR data Admins will be able to analyse and detect patterns from a corpus of data at a scale that was previously not available to them. Enabling the real-time collection of data would provide further benefits such as the ability to react to physiological events as experienced by a patient.

The elasticity and scalability of BPM is imperative as the user base grows. BPM will be required to retrieve large quantities of data from multiple data sources for multiple users simultaneously. As demand increases thousands of data

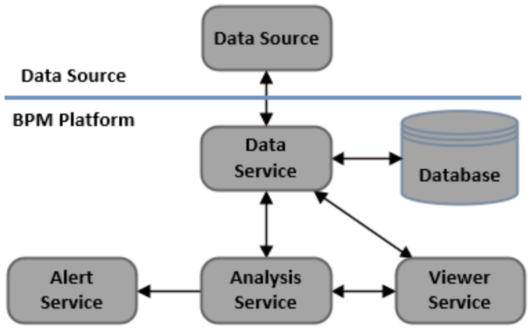

Fig. 1. BPM Platform Architecture Design

requests may be generated. It is critical that the platform can scale to handle the large volumes of data associated with these requests. Failure to do so could have detrimental effects, for instance, Clients requiring the platform to alert Admins to undesirable events, such as cardiac arrest, may not receive the help they need.

To address this issue of scale a microservice-based architecture was adopted, separating each major piece of functionality into an independent service. A microservice architecture enables single services to be scaled up and down independently during periods of high demand, thus preventing the development of an unmanageable, monolithic platform. Figure 1 depicts the architectural design of BPM and the services that constitute it.

The Data Source depicted in Figure 1 and Figure 2 refers to any third party service that makes a user's physiological data available through an Application Programming Interface (API). There are multiple companies that make their health data available. For example, Fitbit, Apple Watch, Polar, MyFitnessPal, MapMyRun, Withings, Jawbone etc. Any of the ATs manufactured by these companies could be used as a data source for BPM. BPM will initially utilise the data available from the Fitbit Web Service.

A. Requirements

The following is an overview, as opposed to an exhaustive listing, of BPM's requirements:

Real-time HR Acquisition

BPM will be designed to acquire the real-time HR of multiple users. This HR data will be made available to users via a viewer and the integrity of the data acquired will be maintained. This will enable physicians to view HR in real-time, simulating a patient visiting a GP's clinic to have their heart rate monitored.

Annotations

BPM will support the annotation of HR data. This will enable the Clients and Admins to add context to a dataset. A start and end time, a description and a set of predefined tags can be saved as part of the annotation. These annotations will be persisted in the database and displayed to any user viewing the relevant time period. It would benefit physicians, employers, personal trainers etc. to annotate the HR data. For example, a personal trainer (Admin) can view a Client's workout session and add context to the resultant HR data from that session.

Threshold Analysis

BPM will support analysis of the real-time HR data collected. This can be used to determine if an undesirable state or event has occurred. A moving average approach will be used to normalise the data. This helps to smooth out short-term fluctuations and focus on long-term patterns. If the HR exceeds a threshold for a certain length of time an alert will occur. Admins will be able to set relevant thresholds for their Clients. A graphical representation of the analysis performed will be presented through the UI. This analysis of HR data will significantly benefit BPM's users.

Alerts

To augment the threshold analysis described above, an alert system will be implemented. BPM will send an alert to the relevant users if the HR exceeds a threshold for a certain length of time. It would be useful for Admins to receive an alert if a user's HR has exceeded a predefined threshold. For example, a physician or nurse may find it helpful to be alerted when a patient's HR increases unexpectedly. An early intervention may prevent further complications.

IV. Implementation

The rationale for the adoption of a microservice-based approach for the provisioning of BPMs' services is now discussed. A microservice-based architecture enables componentisation or modularity within a system. This is achieved by breaking systems into discrete services which are independently replaceable, upgradeable and deployable. Components in a microservice architecture can interact with one another by communicating through their exposed service interfaces, i.e. over a network [16]. This restricts coupling between services and limits functionality leaking from one component to another.

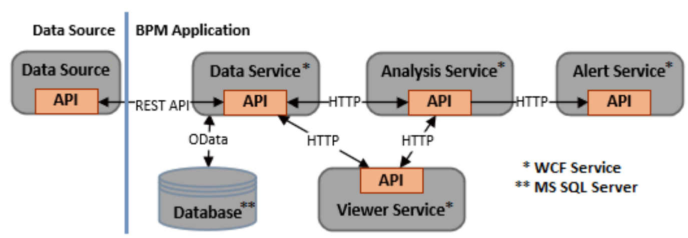

Fig. 2. BPM's architecture and data transfer protocols

A. A Service based approach

There are a number of architectural styles/protocols that are commonly used to develop an Application Programming Interface (API), e.g. Representational State Transfer (REST), Simple Object Access Protocol (SOAP), Remote Procedure

Call (RPC) and Windows Communication Foundation (WCF). WCF was chosen to handle communications between each of the BPM's services. It enables data to be sent as asynchronous messages from one endpoint to another. The service endpoint is continuously available as it is hosted by the Internet Information Services (IIS) web server as part of the service's OS. The messages can be sent using several protocols and encodings [17]. The messages sent in BPM are encoded as Simple Object Access Protocol (SOAP) messages using the HyperText Transfer Protocol (HTTP). The use of WCF in a microservice-based architecture will enable each service to maintain its independence from one another, making it more straightforward to update/alter/scale-up and scale-down services without adversely affecting one-another.

The ability to scale up and down services is made possible through the utilisation of a cloud-based infrastructure. Amazon Web Services (AWS) provide the virtual machines to which BPM was deployed. On-demand scalability of services is possible at a greater level of granularity due to the adoption of a microservice-based approach that also results in lower running-costs.

The implementation of each of the services/components in the platform are discussed under their respective headings:

Data Source

BPM is designed to be data source agnostic and as such any interaction with a potential data source will necessitate the development of an interface for that data source. To date, the primary data source operating with BPM is Fitbit. The Fitbit web service provides an API enabling the acquisition of data relating to a single user. It is invoked by the Data Service in BPM and using RESTful calls a Client's data is returned in a JSON format. Data sources are polled regularly to retrieve health data with requests being invoked on a per user basis.

Data Service

The data service is comprised of a process for polling data from Fitbit, for handling responses from Fitbit, for transforming data into a compatible format and housing the platform's database itself. The Data Service contains a WCF interface to receive communications from other services in the platform [18]. All data collated is stored in a database and is made available for processing by the alternate services constituting BPM. Services that analyse the health data for the onset detection of conditions (e.g. Atrial Fibrillation from ECG data) are currently in development and will be the subject of future work.

BPM's database is a Microsoft SQL Server instance. This was used as it integrates well with Windows and WCF Services. Only the Data Service has access to the database. The other services in the platform utilise the Data Service to access data stored on the BPM platform. Communication between the Data Service and the database are handled by Entity Framework (EF) and the LINQ query language. EF constructs the entities or models that are required to interact with the database using Object-relational mapping. The EF query returns BPM's data in the format of a list of objects. These objects are modelled on the tables in the database. These can be re-used in the platform when working with the data returned from the database.

Analysis Service

The Analysis Service is a WCF Service and is responsible for analysing data in order to detect states or events that a user is interested in. For example, a moving average calculation is performed to find data points that have exceeded a threshold for a certain amount of time. The Client and Admin can set these thresholds resulting in user specified analysis of the data.

Alert Service

The Alert Service is also a WCF Service and is responsible for informing the appropriate users that a Client's HR exceeds a threshold. The Alert Service works in conjunction with the Analysis Service to generate an e-mail and/or SMS. For example, if the Analysis Service had an threshold set to go off when a Client's HR exceeded 150bpm, the Analysis Service would communicates this with the Alert Service and provide the relevant information. Thereafter, the Alert Service would compose and send an email using the MailMessage class in the .NET Framework.

Viewer Service

The Viewer Service is a web application that was implemented using a combination of technologies. These are ASP.NET MVC, JavaScript, Knockout.js, Bootstrap and D3.js. The Viewer Service is responsible for displaying HR visualisations through a browser. The Viewer Service makes a call to the Data Service to retrieve the data relating to a user for a specified time period. D3.js provides rich, interactive visualisations and can render different charts from the same data in the client's browser.

Currently, the Viewer Service provides an overview of users and their individual sessions. This is provided in the form of a dashboard displayed to the Admin users showing a list of Clients on the left and a summary of cardio sessions performed by their Clients on the right as depicted in Figure 3. The visualisation of HR data for an individual Client is provided in both a raw format and in an annotated view highlighting where a specified threshold has been exceeded as depicted in Figure 4, these views are presented for a specified date and time range along with any saved annotations.

B. Issues with the Real-Time Acquisition of Data

Once the implementation of the Data Service commenced, issues were uncovered with the real-time acquisition of the data from Fitbit. Fitbit limit the number of calls to 150 per hour for a single Fitbit user. It was envisaged that BPM would poll the Fitbit servers and acquire live HR data. However, as a call can only be made every 24 seconds the ability to provide real-time acquisition is not possible without increasing the number of API calls allowed.

A second issue uncovered related to the mechanism used by the Fitbit mobile application to sync the data from the

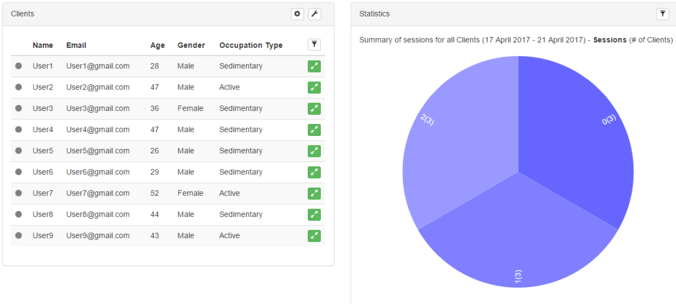

Fig. 3. Admin Dashboard for Client monitoring and analysis

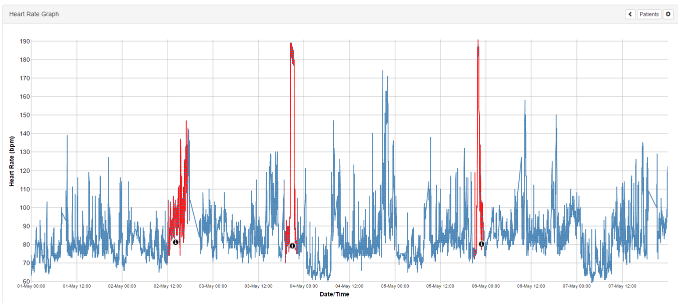

Fig. 4. D3.js rendering of HR data with saved annotations

tracker to Fitbit's own data store. This mechanism is called "*All Day Sync*" and can be turned on or off, depending on user preference. Even when this is turned on the tracker will only sync every 15-20 minutes. This means there is no real-time communication between the tracker and the Fitbit Web Service [19]. These issues did not impact BPM's implementation but they have serious implications for real-time HR monitoring resulting in a 15-20 minute delay in accessing data potentially occurring where Fitbit is acting as the data source.

V. Experimental Analysis & Review

The experimental review of the platform focused on carrying out quantitative tests relating to data integrity to evaluate ATs suitability as a data source and BPM's provisioning of services to evaluate the suitability of a microservice-based architecture.

A. Data Integrity

Data Integrity refers to the accuracy and consistency of data [20]. The integrity of data in BPM is critical as incorrect data readings could lead to unacceptable consequences in the form of false positives or false negatives. e.g. inaccurate data readings could result in a physician incorrectly identifying that a patient is at risk (false positive resulting in a waste of resources) or the more serious case where a physician may identify a patient who is at risk as healthy (false negative which could be fatal for the patient concerned). The utility of BPM is dependent on accurate data monitoring and is the foremost expectation of prospective users. As such, BPM must be able to demonstrate the integrity of its data.

Data Integrity testing is performed to ensure the real-time data acquired and stored in BPM's database is consistent with the historical data returned from a data source (Fitbit). An experiment was designed to evaluate if BPM acquired and persisted data correctly.

BPM's Data service is acquiring data on a continuous basis. For the purposes of this experiment, every four hours a single separate call is made to retrieve the previous four hours of data recorded in bulk. The historical values returned are then compared to that data that had been acquired in real-time for the same time period. The experiment was run for seven consecutive days and resulted in 99.88% of data maintaining integrity, returning identical values with 0.12% of data points returned differing in total. Upon further investigation the inconsistent data points were shown to result from a calculation error that had occurred while rounding up or down a numerical value. This is considered insignificant to the overall results and an acceptable error rate thereby demonstrating ATs suitability as a data source.

B. Database Performance

The goal of performance evaluation is to identify situations where an application suffers from an unexpectedly high response time or low throughput. The connection between the Data Service and BPM's database is a potential (and the most likely) bottleneck as all services that are required to retrieve data are reliant upon this connection. BPM's capacity to service these requests is indicative of the suitability of the microservice-based solution as an underlying architectural paradigm.

Experiments were carried out to measure the performance of the SQL Server Virtual Machine (VM) instance under varying levels of load. This enables the evaluation of BPM's performance and mimics how the platform would react to varying numbers of users. A tool was created that enabled the automated setup and running of performance based experiments. This enabled a battery of tests to be carried out to evaluate BPM's performance using permutations of the following parameters:

- VM instance: Three different types of the AWS t2.db SQL Server VMs (Micro, Small, Medium) were evaluated as part of the Data Service.
- Number of requests (Requests): The number of requests per batch to be generated to query data from BPM's database.
- Number of rounds (Rounds): The number of times a batch of requests will be dispatched.
- Wait time (WT): The wait time between rounds.
- Volume of Data: The amount of data in the time range requested.

The first performance evaluation generated 100 concurrent requests for 24 hours of data with no wait time, the results of which are depicted in Figure 5.

Table I shows the maximum response times experienced by each of the database instances in the experiment.

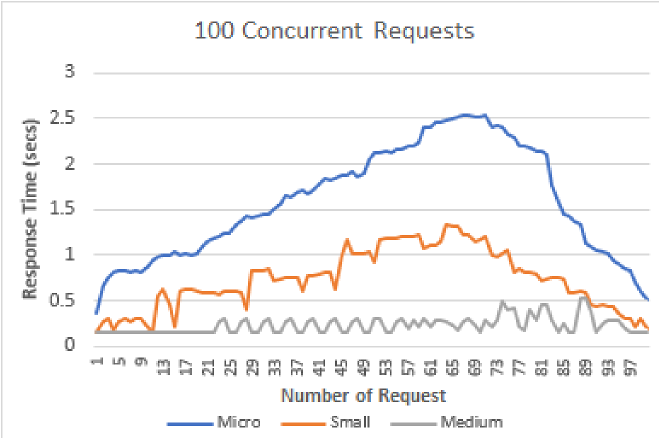

Fig. 5. Performance evaluation experiment I: 100 concurrent requests for 24hr of data.

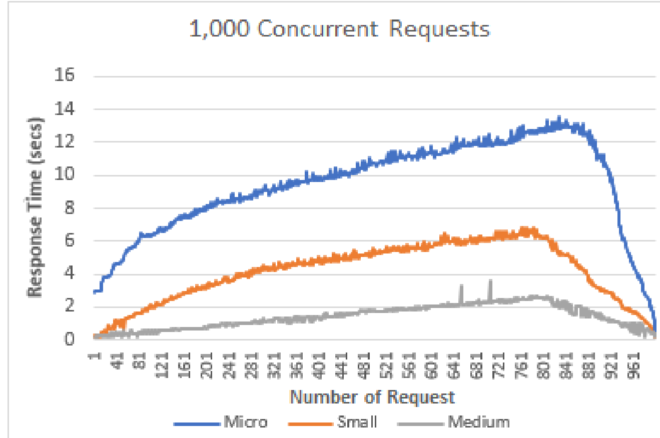

Fig. 6. Performance evaluation experiment II: 1000 concurrent requests for 24hr of data.

TABLE I
MAX RESPONSE TIME FOR CONCURRENT DATA REQUESTS

Instance	Requests	Rounds	WT	Vol. of Data	Max. Resp. Time
Micro	100	1	-	24 hrs	2.54 secs
Small	100	1	-	24 hrs	1.33 secs
Medium	100	1	-	24 hrs	0.55 secs
Micro	1000	1	-	24 hrs	13.49 secs
Small	1000	1	-	24 hrs	6.81 secs
Medium	1000	1	-	24 hrs	2.99 secs

This experiment evaluates how BPM handles 100 concurrent requests for a 24 hr period of data. The successful serving of these requests mimics a 100 users requesting a days worth of data at the same time. The results for the micro and small instances depict a linear relationship between the number of requests and their response times. As the number of requests increases so too does the response time. The medium instance stayed relatively flat, with most of the responses taking less than half a second to complete. While the response times of the small and medium instances are quicker, the micro instance response times are also acceptable. The micro instance experienced the longest response time at 2.54 seconds. It can be concluded that the micro instance is sufficient for a user base of 100, albeit with a degraded quality of service as the number of users increase.

The second performance evaluation saw 1,000 concurrent requests for 24 hours of data with no wait time. Table I shows the maximum response times experienced by each of the VM instances in the experiment. As can be seen in Figure 6 the results are similar to the first performance evaluation albeit with a slightly higher response time.

It is apparent from Figure 6 and the maximum response times in Table I that as the specification of the VM increased the response times decreased. While all the instances are able to handle the associated load, the response times of the Micro and Small Instances are unacceptable. The length of time a user would be waiting for a visualisation to render would degrade the user experience. The longest request using the Medium Instance took 2.99 seconds and is considered acceptable, as such the Medium Instance is to be used if BPMs' user base grows to 1,000 users.

As with any type of computing there is a balance between performance and cost. The evaluation carried out here provides metrics detailing the performance increases achieved as the specifications of the VMs increase. However it also opens a number of questions that need to be addressed, perhaps increasing the memory allocated to the database on instances with less compute could have a significant impact.

VI. CONCLUSIONS

The question asked at the beginning of this research paper was "Can activity trackers be used to facilitate a general purpose monitoring solution for the continuous acquisition, analysis and visualisation of that data". The answer to this question is yes, ATs combined with BPM constitute a general purpose monitoring solution. In that they provide the ability to access, analyse and act on data in a reliable and efficient manner.

The rationale for the adoption of a microservice-based architecture was articulated and evaluated. The performance demonstrated is indicative of the suitability of the architecture employed. Furthermore, the nature of a microservice-based architecture lends itself towards a "general purpose" monitoring solution as the ability to acquire/visualise new data formats merely requires the development of appropriate interfaces for acquiring/visualising that data which can then be readily integrated.

BPM enables a broad range of stakeholders to analyse HR data acquired from ATs. There were problems encountered with the Fitbit synchronisation mechanism that results in a 15-20 minute delay when transferring the data from the tracker to the BPM platform. The real-time collection of data would have provided huge benefits to users, such as physicians or personal trainers. These types of users would benefit from the analysis of the real-time data with the aim of detecting certain events or states. For example, a user's HR suddenly increasing or decreasing, suggesting a cardiac arrest has occurred.

However, the BPM platform developed is capable of continuous acquisition, analysis and visualisation of HR data. This HR monitoring platform will provide many benefits to the stakeholders concerned. It will aid physicians interested in monitoring the long-term health of patients.

Future work is planned to: develop analysis services for the onset detection of conditions such as Atrial Fibrillation to evaluate BPM's utility; gather qualitative data by deploying BPM for a number of practitioners interested in the monitoring of HR data and willing to take part in a case study; construct and carry out more granular performance evaluations of BPM's services; investigate how to overcome the synchronisation restriction put in place by AT manufacturers. For more information please visit http://roreilly.ie/bpm.

References

[1] M. Clinic, "Heart disease," 2014. [Online]. Available: http://www.mayoclinic.org/diseases-conditions/heart-disease/basics/definition/con-20034056

[2] I. H. Foundation, "Heart disease irelands no.1 killer," 2017. [Online]. Available: https://www.irishheart.ie/iopen24/facts-heart-disease-stroke-t-7_18.html

[3] WebMD, "Pulse measurement," 2016. [Online]. Available: http://www.webmd.com/heart-disease/pulse-measurement1

[4] M. C. Edward R. Laskowski, "What's a normal resting heart rate?" 2015. [Online]. Available: http://www.mayoclinic.org/healthy-lifestyle/fitness/expert-answers/heart-rate/faq-20057979

[5] K. H. S. Aymen A. Alian, "Photoplethysmography," *Best Practice Research Clinical Anaesthesiology*, pp. 395–406, December 2014.

[6] Fitbit, "How does my tracker count steps?" 2017. [Online]. Available: https://help.fitbit.com/articles/en_US/Help_article/1143

[7] ——, "What should i know about my heart rate data?" 2017. [Online]. Available: https://help.fitbit.com/articles/en_US/Help_article/1565/?l=en_USp=charge_hrfs=Searchpn=1How

[8] V. M. P. Mary M. Rodgers and R. S. Conroy, "Recent advances in wearable sensors for health monitoring," *IEEE Sensors Journal*, pp. 3119–3126, June 2015.

[9] F. Jacob Morgan, "A simple explanation of 'the internet of things'," 2014. [Online]. Available: https://www.forbes.com/sites/jacobmorgan/2014/05/13/simple-explanation-internet-things-that-anyone-can-understand/42c1a0591d09

[10] B. R. C. E. M. B. J. S. O. B. S. S. B. B. E. Z. J.-Y. R. E. S. C. J. Geoff Appelboom, Annie H. Yang, "The promise of wearable activity sensors to define patient recovery," *Journal of Clinical Neuroscience*, pp. 1089–1093, July 2014.

[11] I. C. of General Practitioners, "Heartwatch," 2016. [Online]. Available: http://www.icgp.ie/go/research/heartwatch

[12] T. I. N. D. C. The Heartwatch National Programme Centre, "Heartwatch clinical report," 2006.

[13] U. D. of Health, H. S. Food, C. f. D. Drug Administration, and R. Health, "General wellness: Policy for low risk devices guidance for industry and food and drug administration staff," 2016. [Online]. Available: https://www.fda.gov/downloads/medicaldevices/deviceregulationandguidance/guidancedocuments/ucm429674.pdf

[14] V. S. M. S. A. S. Joshua Rudner, Carol McDougall, "Interrogation of patient smartphone activity tracker to assist arrhythmia management," *Annals of Emergency Medicine*, pp. 292–294, September 2016.

[15] M. H. N. Jonah Comstock, "Fitbit ceo hints at expanding healthcare strategy," 2016. [Online]. Available: http://www.mobihealthnews.com/content/fitbit-ceo-hints-expanding-healthcare-strategy-fda-cleared-devices

[16] E. P. Alexandr Krylovskiy, Marco Jahn, "Designing a smart city internet of things platform with microservice architecture," *2015 3rd International Conference on Future Internet of Things and Cloud*, pp. 25–30, August 2015. [Online]. Available: http://ieeexplore.ieee.org/document/7300793/

[17] Microsoft, "What is windows communication foundation," 2017. [Online]. Available: https://msdn.microsoft.com/en-us/library/ms731082(v=vs.110).aspx

[18] Withings, "Tracking my heart rate," 2017. [Online]. Available: https://help.withings.com/hc/en-us/articles/227731067-Tracking-my-heart-rate

[19] M. A. M. W. A. E. K. P. B. L. Daniel J. Plews, Ben Scott, "Comparison of heart rate variability recording with smart phone photoplethysmographic, polar h7 chest strap and electrocardiogram methods," *International Journal of Sports Physiology and Performance*, pp. 1–17, March 2017.

[20] J. E. Boritz, "Is practitioners' views on core concepts of information integrity," *International Journal of Accounting Information Systems*, pp. 260–279, December 2005.