IoT and Smart City Services to Support Independence and Wellbeing of Older People

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Abstract— **Over the next 20 years there will be demographic shift from predominantly younger populations to older ones. Current models of care and pathways require transforming to become more citizen focused and support greater community resilience and sustainability. This will require different approaches to innovation to improve quality of life for people as they age, reduce onset of frailty as well as support those better with long term conditions around self-management and prevention strategies. Health and social care providers are looking at how they augment traditional clinical health related services with the use of IoT technologies and smart city services. This paper describes the on-going work of the Birmingham City4Age pilot, managed by the local authority, Birmingham City Council and funded by the Horizon 2020 Programme of the European Commission focused on the unobtrusive collection of data via wearable devices, outdoor sensors and other smart city systems that aims to help reduce the onset of frailty of older people. Locality and contextual data is being captured on individuals' behaviours with increased frequency that aims to help in detecting early changes in daily living - physical activity and social patterns and develop technology based interventions to help reduce the risk of frailty. The proposed systems architecture is being validated in two distinct neighbourhoods with contrasting demographics in Birmingham, UK adopting an iterative user design approach designed to support independence.**

Keywords—Frailty, MCI, Bluetooth Low Energy Beacon; Digital Log Book, Big Data, Wearables; Smart Systems; Healthy Ageing, Internt of Things

I. INTRODUCTION

City4Age is a Horizon 2020 funded project of the European Commission that aims to facilitate new smart cities technology enabled solutions to maximize independence in older people support healthy ageing particularly focused on those at risk of frailty and mild cognitive impairment [1].

It aims to validate the potential of smart systems and wearables in the early detection of (frailty) risks and subsequent interventions. The core idea is that 'smart cities' can collect personal data about individuals' behaviours enhanced through the use of technologies in an unobtrusive low cost, low power way. This data can be used in two ways:

- Early detection of risk related to frailty
- Interventions that can help the elderly population to improve their daily life and also promote positive behaviour change.

The business opportunity is to demonstrate that the City4Age solution can be delivered in healthcare systems in Europe and provide an evidence base that will accelerate adoption of smart city solutions to support healthy, active ageing to promote improved citizen wellbeing, increased efficiency and cost reduction.

To deliver this realignment the pilot considers both human factors (e.g. ethics, skills; adoption and accessibility) and technological considerations (e.g. secure sharing of datasets; privacy).

This paper provides a summary of the defined system architecture and user design for the Birmingham, UK pilot, managed by Digital Birmingham (Birmingham City Council) that exploits the opportunities of wearable technologies, smart phone devices and Internet of Things (IoT) sensors to capture personal data. It provides a description of the first phase of the pilot associated with user recruitment and data detection and management.

A. The Challenge for health care

The challenge [2] for healthcare in Europe is its ageing population. Current forecasts indicate that the population of the EU aged 65 and above will rise from 87.5 million in 2010 to 152.6 million in 2060. With greater longevity, comes an increasing demand for health and care services and increased complexity of needs due to chronic disease and multi-morbidity. Chronic diseases represent the major share of the burden of disease in Europe and are responsible for 86% of all deaths in the region. Chronic diseases affect more than 80% of people aged over 65 in Europe. It is widely acknowledged that 70% to 80% of healthcare costs are spent on chronic diseases. This corresponds to an estimated €700 billion in the European Union and this number is expected to increase in the coming years [3].

More specifically the UK population is ageing. In mid-2014, the average age exceeded 40 for the first time. By 2040, nearly one in seven people is projected to be aged over 75. These trends, partially mitigated by migration rates, will have a major effect on the UK. By 2037 there are projected to be 1.42 million more households headed by someone aged 85 or over –

an increase of 161% over 25 years. The 'oldest old', who have a substantial risk of requiring long-term care, are the fastest growing age group in the UK. As a result, there has been an increasing prevalence of age-related conditions, including mental health conditions such as dementia. Between a quarter and a half of people over 85 are estimated to be frail, which is associated with disability and crisis admissions to hospitals. Although age-specific dementia incidence rates have decreased since 1991, projections are for a substantial increase in the overall number of cases from 822,000 to 940,000 by 2021 and more than 1.7million by 2051. Chronic conditions affecting the heart, musculoskeletal and circulatory systems are also more prevalent in older age [4].

In Birmingham, people experience, on average, 19 years of ill health, which has a significant impact on health and social care expenditure. The hypothesis is that by targeting interventions in line with the needs of people with frailty, this would lead to earlier intervention and/or prevention through crisis recognition and management, and self-care; which could potentially contribute to a lessened burden on the Health and Social budget.

B. Role of digital technologies and smart systems

Assistive technologies, home-based health monitoring equipment and smart use of big data all have the potential to change care in the home and community, reducing national health and care spending and improving wellbeing. Capitalising on these opportunities will require action to address the barriers to uptake of these technologies, and sensitivity to public concerns on privacy.

Increases in real-time data collection, driven by developments in wearable technology and other forms of telemonitoring, will enable healthcare professionals to provide more appropriate treatment and support for patients and carers [5] while the resulting large datasets could drive forward research in many areas and potentially help improve prevention and early intervention. Technology such as alarms, home monitoring systems and GPS locators can help carers locate people with dementia, although ethical issues can arise. There is evidence that carers are already using off the shelf technologies such as baby monitors and smartphone-based GPS tracking apps in supporting people living with dementia[6], but specialised technology could be more widely and effectively used.

Despite the growth in assistive living technologies, internet of things (IoT) applications and eHealth, the actual impact of ICT on supporting widespread adoption and integration of health and care is much more limited and the market has yet to reach maturity in the development of new business models that will accelerate market growth and uptake.

C. The ambition for Birmingham City4Age

The goal is to define new prevention services demonstrating that technology works and that the care receivers can use it and the city can provide a sustainable effective service. This covers two elements the detection service – that collects new personal data streams – in a unobtrusive manner that will provide the basis to interpret and apply Big Data analysis so that potential risks or decline can be identified and actioned upon to drive the intervention service.

A future Birmingham City4Age commissioned service would provide a low cost and light touch proactive solution to enable a greater number of people already being identified at risk of frailty through an electronic frailty index tool [7] to be supported at a distance focusing more on physical and mental health & wellbeing. This would then provide a means to detect those that show negative behaviour changes and in need of greater support and intervention as well as support referrals through a variety of routes from health providers linked to for example a social prescribing model. Improving mental and physical wellbeing, activity and helping to reduce social isolation has direct benefits and savings costs associated with it e.g. reducing hospitalisation from osteoporosis; fall prevention; preventing cognitive decline and reducing visits to GP.

The Birmingham pilot has adopted a user centric iterative design approach with the care-receivers actively involved in all phases of the project to validate the data detection and intervention services. Two separate pilot studies, each with 35 participants, will compare and contrast two distinct demographics taking account of aspects such as average life expectancy; wealth; ethnicity and cultural aspects that may impact on acceptance, adoption and accessibility of any technology solution. The focus is on the outdoor environment; the first pilot study participants have been recruited and the system architecture has been designed to look at how large amounts of data on individual behaviours are captured with increased frequency through the use of sensing / wearable technologies, which will help in detecting changes in daily living (physical activity and social) patterns and develop technology based interventions to help reduce the risk. Data detected through the sensing environment comprises:

- Locality data - position of user points of interest
- Motility data - data related to physical activities associated with the user e.g. steps; distance travelled; pace; rest; sleep; walking
- Ambient parameters; data regarding the environment e.g. temperature

II. System Architecture for Data Detection

The City4Age technical design for the Birmingham Pilot has taken advantage of existing Birmingham City Council (BCC) infrastructure in addition to adding a custom-built mobile app, designed and developed specifically for City4Age plus a Local Repository which serves as a database to collect, store and submit information on participants' information to the City4Age Platform. The BCC Local Repository will process the raw data to convert this to Local Elementary Actions (LEAs) and Measures agreed between Birmingham City Council and the City4Age Project.

1) Digital Log Book

BCC's Digital Log Book (DLB) is a web based enterprise portal tool

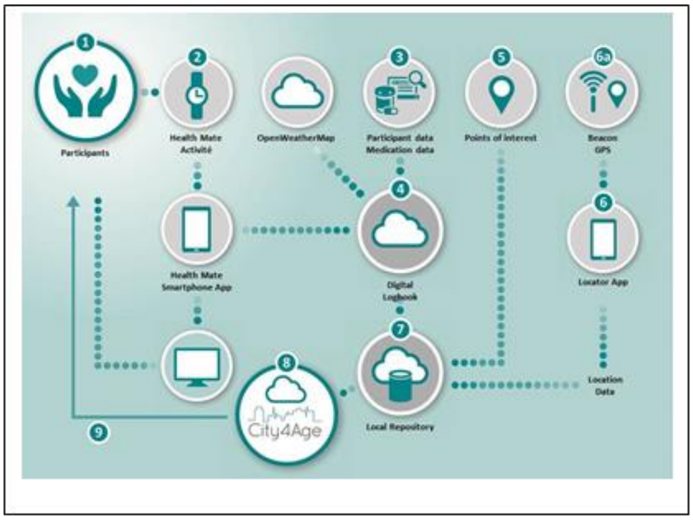

Fig. 1. Technical design for Birmingham City4Age pilot

that empowers people to interact online with local authority / government services, in line with the UK Government's Digital Service – digital by default – where all Government Services are to be delivered online. The DLB provides citizens with an easy-to-use interface enabling them to access services from any browser. For the purposes of the City4Age project it is aimed at helping them to improve their health and wellbeing and quality of life and has additional modules that can be made active around for example financial inclusion and sustainable living. The DLB users own their own data and can share relevant modules and information with their support providers which reduces duplication through a common platform. The DLB (4) has been enhanced to collect baseline participant data and other required input data. The participant owns the data in the DLB and can choose whether to share some or all of their data with selected people such as care workers or family members. For the purposes of this project, participants have signed terms and conditions which enable the sharing of their information with the City4Age project. The DLB provides a visual interface to display activity data; provide feedback from time to time, and to send data to the BCC Local Repository for submission via API to the City4Age Repository/Platform.

2) Participant data, baseline questionnaire, and medication data

Participant and medication data (3) is collected from pilot participants either directly via input to the DLB or by use of a questionnaire. The questionnaire has been designed to ensure that the required baseline data is collected for each participant. Participants are encouraged to record their medication in their DLB.

3) Caregivers, family members, participants

Those involved in the pilot, and potentially caregivers and family members (1), have access to the DLB in order to gather any further data required during the pilot or to receive feedback as the need arises. Interventions may be communicated to participants and caregivers and family members through the DLB as provided by the main project City4Age Platform Intervention Engine.

4) Points of interest and proximity beacons

Fig. 2. Proximity beacon located inside entrance of supermarket

Points of interest (5) have been selected taking into account the particular interests of pilot participants (and hence was only defined once the recruitment was concluded). A Bluetooth Low Energy proximity beacon has been placed in suitable locations (e.g. supermarkets; community centres; restaurants; pharmacists) in the local neighbourhood. BCC have determined that the pilot will use Estimote beacons due to their silicon case and ease of positioning in the various locations. Their range has been pre-set to 3.5m to optimise collection of timestamp dating providing a record of entry and exit into the points of interest.

5) Smart Watch

Fig. 3. Withings Smart watch, DLB activity dashboard and smart phone display

All pilot participants have been provided with a Withings Smart Watch (2) to track their activity and sleeping patterns. These are worn for the duration of the pilot and provide both activity and sleep data. The data will be provided via the Withings API. Both the DLB and the BCC Local Repository will use the Withings account unique identifier to access the Withings API (under explicit consent of the participant, acquired through the recruitment process via the DLB) and retrieve activity and sleep data from the API. Access to the Withings API is via a Withings Developer Account – which has been set up for the purposes of the development activities.

6) Beacon Locator App

The Android Locator app (6) has been developed to take into account simplicity of use, cost of data upload and impact on battery life due to the wide range of devices in use. The Android Locator App is configured to know the names of the beacons, it does not know the exact locations. When the app sees an appropriately named beacon, it will report proximity to the BCC Local Repository. The BCC Local Repository will check that it recognises the beacon unique identifier, acknowledge receipt to the app and store the information for later processing. The Apple app does not operate in the same way, so work is ongoing to determine the most appropriate solution.

7) BCC Local Repository

The BCC Local Repository (7) is a database that collects and stores all participant information from the DLB, the Withings activity and sleep data and beacon proximity events from the Locator app. The BCC Local Repository processes the data to create LEAs and Measures for submission to the City4Age Platform for example,

- LEAS: Entry/Exit to points of interest (beacon proximity)
- Measures: Steps and sleep data (Withings)

The BCC Local Repository requests a unique identifier for each participant from the City4Age Platform so that all data submitted via the API is anonymized. The City4Age Platform (managed through the project consortium) undertakes further complex computation to interpret and process the data in order to support assessment of participants' health and wellbeing by healthcare professionals. The API will be defined by the City4Age project. The Birmingham pilot team will work with City4Age Platform technical team to understand the requirements and set up the API.

8) Interventions

This element is to be determined in the second phase of the pilot. City4Age Platform, City4Age Intervention Engine and BCC will collaborate to define any requirements for local interventions. If necessary, some interventions in the form of generic messages may be generated via the DLB.

III. Discussion – Technical Challenges

A number of technical challenges have arisen during the first phase of validation of the data detection systems and these are described below:

1) The battery load using GPS geolocation to track someone 24x7

Using GPS is the only way to determine the position of a Care Receiver within 10m so is the only way to determine if someone is within the bounds of smaller points of interest. However constant use of GPS satellites would drain the phone battery far too quickly.

2) The inaccuracy of GPS systems indoors

The accuracy of GPS is affected by buildings. The GPS signal bounces off structures overhead which can easily cause someone to appear somewhere different. Since our points of interest are all indoors, GPS cannot be considered an adequate mechanism for locating someone inside a point of interest.

3) The inaccuracy of low-power geolocation

Phones can calculate their position by identifying nearby GSM masts and wifi installations that are located around town. This is significantly less accurate than GPS but should be accurate to around 20m. Clearly, if GPS isn't accurate enough to locate someone then this isn't either but this has the advantage that it can be used all day without exhausting the battery.

4) The power requirements of tracking someone using beacons

BLE is a separate radio from the standard Bluetooth radio and is designed for low power. Nevertheless, if you scan for beacons all day using the BLE radio you will use most of the battery power of a phone.

5) The combination of low-powered geolocation and beacons

From empirical tests, low-powered geolocation uses less power than BLE scanning. Thus using coarse geolocation to give an indication that the Care Receiver is approaching beacons then turning on BLE scanning optimizes battery consumption while having 24x7 coverage of the Care Receiver.

6) The Challenge of using Apple Devices

Apple has a very clear policy on the use of power-hungry resources when an application is in the background; and that is to restrict the use of the application. Geolocation becomes very inaccurate when an app is in the background and scanning for beacons is infrequent and proximity is reported only on first contact. In the Birmingham pilot it is very possible for a user to visit three or four points of interest before a background app even notices the Care Receiver has moved. It is unreasonable for us to ask Care Receivers to keep an app in the foreground. Android smart phones are the favoured devices for research offering more reliability and as such in further recruitment this will be requested.

7) The challenge of generating LEA points of interest events from beacon proximity events

The Birmingham project is using a small number of beacons to keep costs under control and to simplify installation. A point of interest has beacons placed on every entrance/exit or above a counter in small locations. Sometimes a Care Receiver will linger within range of a beacon for a long time but usually they will walk past the beacon in a few seconds. Determining whether a user has walked into a point of interest or past it is therefore, quite tricky and geo-location cannot be relied upon to help as discussed above.


```
"id": 441,
"eventType": "lost",
"timestamp": "2017-06-20T09:31:36Z",
"rssi": -92,"parameter": -88,
"beacon": "c4a000002762",
"location": "Sainsburys, Mere Green",
"device": 2,
"poiEvent": null,
"careReceiver": 5}
```


Fig. 4. Example of data recorded by beacon locator app located in supermarket entrance

8) Configuring beacons

Beacons can be configured by the manufacturer but, thereafter, it is necessary to get within range of the beacon to reconfigure it. Birmingham beacons are configured with a range of 3.5m to ensure that, as far as possible, a Care Receiver is not in range of two beacons at once.

9) Smart Watches

Some issues with the accuracy of measures have been reported and are under investigation. This has covered misreporting due to gaps in sleep recorded and difference in measures across different makes of activity trackers, where participants have compared activity readings from the Withings device with their own personal tracker. Due to the way that different activity trackers are worn (wrist, belt clip or pocket), it is possible that they will count a different number of steps from one another. Additionally, it is important to note that the watch is calibrated so as to reduce the amount of false steps counted as a result of general arm movement, such as when brushing one's teeth as an example, and as such, it is possible that other step trackers may result in a higher step count than the watch. The Activité watch uses a 3-axis accelerometer that measures steps based on height (inserted into the Health Mate app), forward movement, stride length (which is pre-calculated based on height), and the swinging of arms. It is recognized that the data is comparative and will only be recorded across the one device.

In regards to the missing sleep data, there are reportedly only a few factors that may cause this problem. There can be a low battery issue which causes sleep data to not be stored correctly, as well as steps data. There can be a battery contact issue (which usually wouldn't be discovered unless a battery is replaced and the issue still persists). Arm movement can also cause the issue. Usually, when the watch is connected to the wrist without any interference from clothing, the improved chances sleep can be tracked. Work is ongoing to address some of the inconsistences being identified by participants as part of the data detection validation process from a user perspective.

IV. CONCLUSION

The work undertaken to date represents the proposed architecture and pilot design for data detection of proximity and locality data that will drive and support interventions to help maximise the independence of older people. This is focused on use of unobtrusive technology to collect and interpret personal data that will drive behaviour and stimulate physical and mental activity and greater social interaction to address factors associated with mild cognitive impairments and frailty in the elderly population. The system design is able to monitor continuously activity, pace of movement, sleep and also through sensors collect locality data on participants points of interest that represent places frequented by participants on a regular basis (e.g. daily; weekly). Challenges have been met in development of an app that will accurately collect proximity beacon data and while this has been securely deployed and tested with smaller no. of initial users, with Android devices, Apple devices still remain problematic for beacon data detection.

Ongoing work will focus on refining and resolving the data detection issues in preparation for supporting the phase 2 intervention service.

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