

# AART-BC: a sensor system for monitoring Assistive Technology use beyond the clinic \*

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**Abstract**— A wide range of assistive and rehabilitative technologies (ART) are available to assist with mobility and upper limb function. However, anecdotal evidence suggests many of the devices prescribed, or purchased, are either poorly used, or rejected entirely. This situation is costly, both for the healthcare provider and the user, and may be leading to secondary consequences, such as falls and/or social isolation. This paper reports on the development and initial feasibility testing of a system for monitoring when and how assistive devices are used outside of the clinic setting, and feeding this information to the device user themselves and/or prescribing clinician (where appropriate). Illustrative data from multiple time-synchronized device and body worn sensors are presented on a wheelchair user and a user of a “rollator” walking frame, moving along a walkway. Observation of the sensor data in both cases showed characteristic signatures corresponding to individual “pushes”. In parallel with this work, other project partners are exploring clinician and patient data requirements, as well we sensor set acceptability. The initial results highlight the potential for the approach and demonstrate the need for further work to reduce and optimize the sensor set.

## I. INTRODUCTION

Assistive and rehabilitative technology (ART) is a broad category for devices that are typically prescribed to a patient to assist with managing or rehabilitating a physical problem. In the UK mobility issues affect 6% of 16–44 year olds and up to 55% of 75+ year olds; upper limb functional limitations are also highly prevalent in, for example, populations with stroke or Rheumatoid Arthritis. Thus a large proportion of the population will require ART. There are many different types of ART such as walking frames [1], wheelchairs [2] and prosthetic limbs [3]. These devices are typically prescribed to the patient by a clinician who will then perform follow-up checks in regular, but relatively infrequent, clinics. These clinics serve as an opportunity to assess how the patient is using their ART and to provide any further assistance the patient may need.

However, there is little objective, quantified knowledge of the way that the patient uses ART outside of what can be gleaned in a clinic appointment. Further, observing a person using the ART in a standard clinical setting, such as a hospital corridor, provides only limited information on how well they manage with their ART when at home, or outdoors.

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Significant research effort has been expended attempting to fill this knowledge gap, but to date has largely been reliant on patient surveys and qualitative information. This can be subject to a number of biases and is only able to answer the most general of questions about when the ART is used. By their nature, questionnaires and qualitative methods are not able to answer the questions related to the mechanics of how the ART is being used ‘in the wild’.

This limitation notwithstanding, the research that has been undertaken has shown that a significant proportion of ART devices are not used properly [4], not used regularly, or simply discarded after a period of time [5]–[7]. For instance, more than half of wheelchairs that are prescribed in the UK are discarded [2]. There is a significant cost associated with the prescription of ART, with ARTs varying in price from a few tens of pounds to tens of thousands of pounds (in the case of advanced prostheses). Associated health and social care costs associated with reduced mobility and/or functionality may very significantly amplify the cost of non-use or incorrect use of the device. For example, there is evidence that hospitalized patients who fell were more likely to be users of walking aids [8], and a meta-analysis associated walking aid use with a 2–3 fold risk of falling [9].

The Adaptive, Assistive and Rehabilitative Technology - Beyond the Clinic (AART-BC) project is aiming to fill this knowledge gap using a technology driven solution. Specifically, as we get a better understanding of the biomechanics of device use [10]–[12] we are able to interpret data from wearable sensors on the person and/or device, not only in terms of whether or not the device is being used, but also how it is being used. In addition with recent advances in mobile sensing technology and the miniaturisation of powerful data processing hardware into platforms such as smart-phones, the principal hypotheses of the AART-BC project is that it should be possible to utilise sensing technology and computationally intelligent data analysis to provide an objective assessment of a patient’s use of ART outside of the clinic environment.

To meet this goal the AART-BC project will use a number of sensors to monitor both the prescribed ART and the patient, and couple the data from these sensors with intelligent analysis to determine so-called individual condition signatures (ICS) for a patient and their ART and provide meaningful parameters as feedback to both patients and carers/clinicians. The ICS will be device-dependent and may include, for example, when a device is used, how well it is used and where it is used. As a first step towards achieving this goal, some preliminary work has been undertaken aimed at investigating a range of sensors for the feasibility of including them in an ART assessment system. This paper

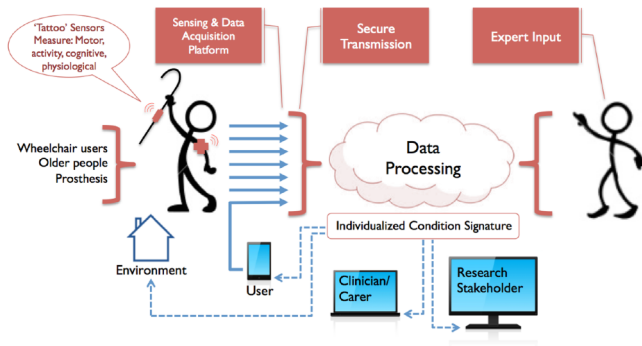


Figure 1: Overview of the AART-BC system: a suite of sensors will sense patient and RT’s alike. Data from the sensor suite are used to provide Individualised Condition Signatures, which are used to feedback to the user and their environment, the clinician/carer and the research stakeholder.

presents both the proposed system concept being put forward by the AART-BC project and some preliminary results from the sensor feasibility assessment in a few ART end-users.

## II. METHODS

### A. The Proposed System

For any ART monitoring system to be functional it must provide the ability to monitor the target device and patient both inside the home and outside of the home as well as the ability to capture, process and transfer significant volumes of data. To meet these needs, the proposed AART-BC system uses a relatively standard distributed architecture whereby sensors transmit data to a centralised database. Data from the database will be processed and then forwarded to relevant stakeholders. The proposed AART-BC system can be seen in Fig. 1 and 2, where the former indicates a stylised view of the overall system and its applications, and the latter an architecture diagram showing the sensing and data acquisition and distribution platform.

### B. The Proposed Sensor Set

Whilst the final set of sensors in the AART-BC system is still under development, at the time of writing there are four key technologies that will be employed

1. *Temporary Tattoo Sensors*: This passive skin-mounted wireless sensing technology is based on UHF RFID (Radio Frequency Identification) that operates at 860–920MHz. RFID is widely used in systems such as contactless payment and electronic door keys. However, these systems operate at 13.5MHz and are very short range. UHF RFID operates like radar and can give read ranges of a meter or more when mounted directly on-skin. One of its benefits is that no battery is required on the skin-mounted tag. These have already been shown to work over prolonged periods of time and to remain attached and functional even after activity such as running and even showering [13].

2. *SenseWheel & SmartWheel*: The SmartWheel is a commercial device which measures push-rim kinetics and has been used for several wheelchair biomechanics studies [14], [15]. Recently there has been a newly developed Sensewheel which is a lighter weight wheel which has similar functionality to the SmartWheel but with a focus on accessibility studies and the development of movement

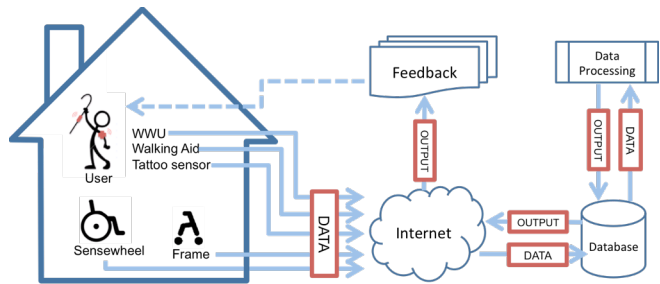


Figure 2: Architecture diagram showing the sensing and data acquisition platform – the three main technologies being assessed in this study are highlighted, namely: a wrist worn unit (WWU), a walking frame and a wheelchair.

metric to aid push style in the wild [16]. We are developing the AART-BC architecture to allow for data from both devices to maximize our potential for interfacing in clinical and in the wild studies. Both devices are wireless and data can be collected on a PC and in the case of SenseWheel on a mobile phone/tablet.

3. *Wrist-Wearable Unit*: The wrist-wearable unit (WWU) is an Android 4 smartphone in a wristwatch form factor and uses a ZGPAX S8 as the base unit with a custom app written for it. The WWU has been developed and used in previous research [17],[18] and functions as a wearable data gathering and feedback platform. The WWU is capable of gathering accelerometer data from the patient’s wrist and providing measures of physical activity, which correlate to calorific energy expenditure [19], as well as for example, whether or not a person is using a walking aid, such as a frame or stick.

4. *Inertial Sensors*: Inertial sensors, in addition to the WWU, are likely to be used to monitor specific AT in the AART-BC system, such as a walking frame or a prosthesis. Inertial sensors provide data relating to the movement of the object they are attached to, so for AART-BC will provide information on the movement of the AT. This will be combined with other data during the data processing stage. In this initial study we have focussed on using commercially available sensors. However, in future work we intend to make use of the newly developed IMUs which have been shown to be able to link both accessibility and rehabilitation metrics for wheelchair users [20].

### C. Sensor feasibility Study

The aims of the sensor feasibility study were to establish if there is meaningful information in the recordings, and to examine the worth of the various sensor types. We recruited ten participants aged between 25 and 78 - seven wheelchair users, two walking frame users and one amputee. This study was approved by the University College London Research Ethics Committee. The experiments consisted of participants moving along four straight lanes, including an 8.4m flat path, an 8.4m cross-slope of 4%, a 4.8m slope of 6% and a step of 80mm, which were set up at the Pedestrian Accessibility Movement Environment Laboratory (PAMELA) at University College London.

Participants were asked to move along each lane at a self-selected speed and in way they normally moved in their everyday environment. In each lane, participants performed

one to three trials, depending on their physical capability, with a pre-experiment in which several trials were conducted to familiarise themselves with the laboratory settings.

The sensor set and placements of sensors vary between user groups (for the three groups we considered in this study). For this initial data collection the commercially available SmartWheel (ThreeRivers inc, USA) was used to collect pushrim kinetics with a sampling frequency of 240Hz, instead of the users' own wheelchairs. The Xsens IMU system (MTw, Xsens Technologies BV, NL) with a sampling frequency of 50Hz was used to capture the motion of the human body (chest, left upper arm, left forearm and left hand) and motion of the wheelchair (centre of left wheel and on the chair). The WWU was used throughout the course of the experiments. For walking frame users and amputees, only the Xsens IMU system and WWU were used. The placement of IMUs for walking frame users was on the pelvis and both feet for human body movement, and the front of the frame for the walking frame. The placement of the Xsens IMUs for the amputee was pelvis, both thighs on the human body and both shanks and feet on the pylons. The tattoo sensor was not included in this feasibility study and will be included at a later date alongside the SenseWheel (Movement Metrics, UK) and bespoke IMU sensors.

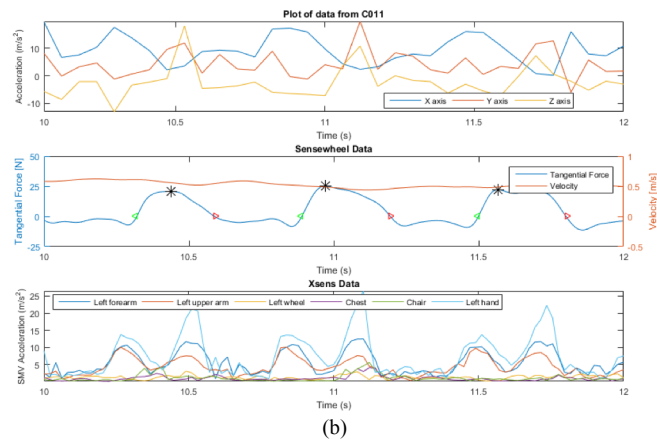
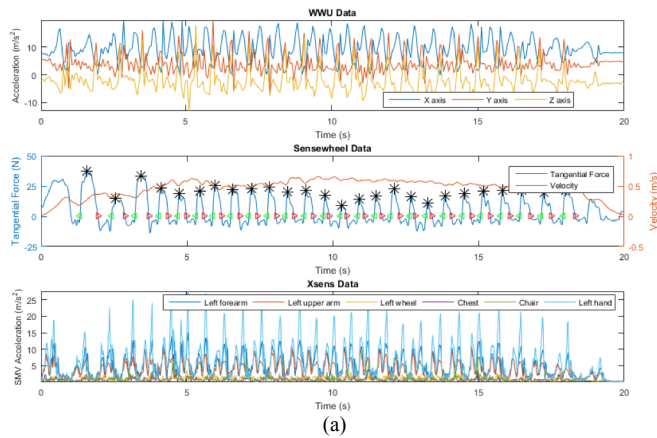


Figure 3: Wheelchair user: (a) 20s of recorded data of a wheelchair user using the WWU, SmartWheel and multiple Xsens sensors attached to the user and the wheel chair. (b) An expanded view of the 2s segment between 10-12s from part (a).

#### D. Data Analysis

For each of the three user groups, the Xsens, WWU and SmartWheel were used (in different combinations) to gather data continuously over each test run. At this preliminary stage, other than simple de-noising, very little data processing is performed on the data. Our preliminary aim was to be able to collect and align data from disparate sensors and sensor system; this was achieved and was included as a first step for the data that was processed for each user.

Fig. 3 depicts excerpts of recorded data of one wheelchair user during a flat path trial. Part (a) depicts 20 s of data where WWU (3 axes), SmartWheel (2 traces) and Xsens (6 traces corresponding to various locations). Bespoke Matlab (R2015a) scripts were used to define pushes, denoted by the black (\*). The green and red triangles depict the start and end of each push respectively. Part (b) depicts a close-up of a 2s segment (from 10–12s) in part (a) with the same annotations as before. Fig. 4 similarly depicts excerpts of recorded data from one walking frame user from a flat path trial where a number of Xsens were placed on the user and the walking frame itself and the user wore the WWU. Part (a) depicts 70 s worth of recordings from the WWU (3 axes), an Xsens on the walking frame and 3 Xsens mounted on the user. As before

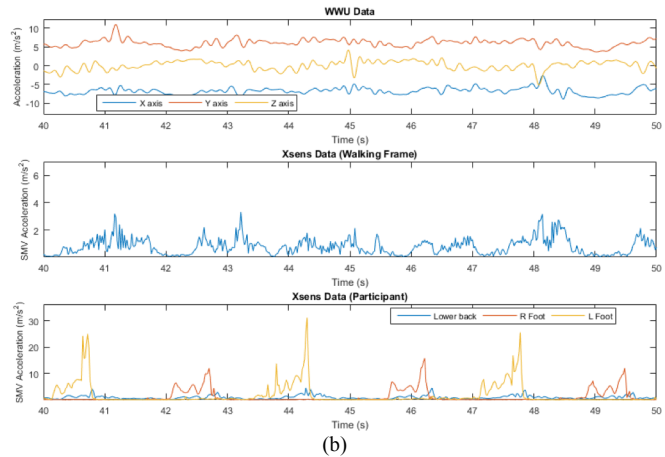
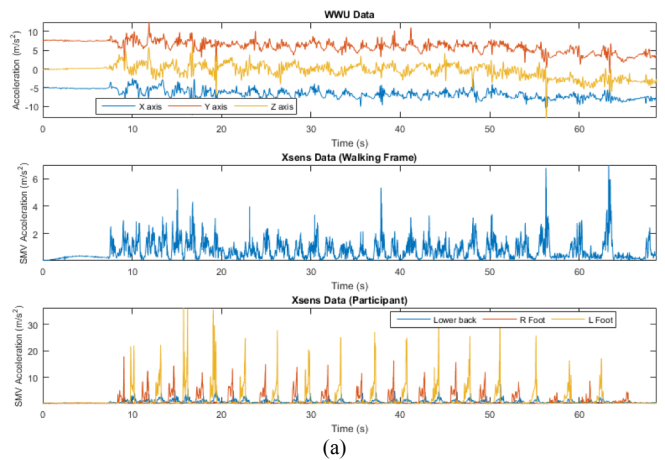


Figure 4: Walking frame user: (a) 70s of recorded data of a walking frame user using the WWU and multiple Xsens sensors attached to the user and the walking frame. (b) An expanded view of the 10s segment between 40-50s from part (a).

part (b) depicts a close up of a 10 s segment (from 40–50s) in part (a) with the same annotations as before.

### III. DISCUSSION

For the wheelchair users data from 3 sensor types needed to be collected and time-aligned; and for the walking frame and prosthetic limb users 2 sensor types were used. Initial analysis has been restricted to preliminary de-noising of the data and aligning the traces through their time-stamps.

The data shown in Fig. 3 and Fig. 4 is typical of the rest of the data, and even through simply aligning the datasets it is apparent that the information being recorded by the AT, and the sensors on the AT is quite correlated with the information obtained from the body worn technology. Clearly, where on the body sensors are worn reflects in the quality of data and the information content there-in. However, in the wheel-chair data, for example, where the SmartWheel identifies a series of “pushes” both the WWU and the Xsens on the hand and arm clearly show correlates with these pushes. Similarly the data from the walking frame, although much noisier, shows clear “pushes” as the walking frame is rolled forward. The WWU struggles to show this due to the limited hand movement on the walking frame but between the WWU and the Xsens on both the frame and the person (left and right legs) it is possible to track the forward movement of the walking frame (note especially the alternate left/right foot movements recorded by the Xsens on the body versus the general forward movement recorded by the WWU and the Xsens on the frame).

The initial data collection and analysis has demonstrated that further work is needed to identify the optimal sensor set(s). Ongoing work to inform sensor optimization is being conducted by other project partners who are exploring data requirements of both clinicians and users of ART, as well as the acceptability of different sensors and sensor locations.

### IV. CONCLUSION

We conclude that the ARRT-BC cloud-based infrastructure can support multiple, different data types and is able to synchronize across these. Further it is capable of post-processing data using a range of script types (e.g. Matlab). Future work will determine a minimum acceptable sensor set capable of measuring when and where a device is being used and distance travelled, as well as the more comprehensive set needed to extract biomechanical parameters reflective of how well a device is used. These data will be obtained for a range of devices and methods will be investigated for delivering feedback to users and clinicians.

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