Institution: University of Ulster

Unit of Assessment: 11: Computer Science and Informatics

Title of case study:
A new range of outdoor clothing for the active ageing based on wearable technologies

1. Summary of the impact (indicative maximum 100 words)

Two leading manufacturers of clothing for outdoor activities ([text removed for publication]) have produced a new range of functional clothing based on research at Ulster on wearable technologies for the active ageing. The new age-appropriate outdoor garments incorporate wearable technologies that enable self-monitoring of physiological parameters (heart rate, respiration rate) and activity levels (step-counts, distance walked) with optimal placement of sensors to improve signal-to-noise ratio. Additionally, [text removed for publication], a company producing [text removed for publication], have used feedback from Ulster's research evaluations to design a new range of [text removed for publication] that are incorporated into the garments, achieving increased levels of usability by elderly people.

2. Underpinning research (indicative maximum 500 words)

In modern healthcare services, a growing emphasis is being placed on self-awareness and self-management of health and wellbeing, particularly amongst the increasing number of older but active members of the population. At the centre of this paradigm is a new range of biophysical monitoring devices (e.g. heart rate monitors, step-counters). For such devices to be most effective, significant challenges exist about where and how to best locate them on the body. Sub-optimal placement of the biophysical monitoring devices leads to significant loss in accuracy of the measurements processed from the data acquired, thus rendering the devices less effective for self-monitoring.

Processing and classification of physiological signals has been a core area of research at Ulster for over 15 years. Results of our research in electrocardiology have demonstrated that appropriate combination of feature selection techniques in conjunction with bi-group classification models improves the classification of the 12-lead ECG [1]. The knowledge gained through this research has been extended through the classification of entire body surface potential maps (192 electrode arrays) (2003-2007). Electrode arrays were initially processed to reduce their dimensionality prior to classification [2]. This research stimulated the hypothesis that a reduced set of electrodes from the body surface map could be used to improve classification performance compared with both the 12-lead ECG and the full body surface map. Our research also considered the restrictive nature of connecting electrodes/cables to human subjects and the impracticalities of this for long-term monitoring [3]. Subsequently, textile-based electrodes have shown promise for the measurement of the ECG, as they do not require a gel membrane or adhesive, and are thus better suited to long-term monitoring applications. Furthermore, clothing enables textile sensors to be placed in close physical proximity to a large area of the body.

Research on optimal configuration and positioning of electrodes within a range of wearable applications has been undertaken [3] (2008-2013). Data mining approaches were shown to be capable of identifying an optimal set of 10 electrodes that yield accuracy of signal measurement similar to that achieved using the entire 192 electrode array. The results from this work formed the basis of the technology work-package in the Design for Ageing Well (DFAW) project, funded by the ESRC New Dynamics of Ageing programme.

Within DFAW (2009-2012) the effects of positioning sensors in different locations within clothing for the active ageing were investigated. The effects on the accuracy of both activity recognition and step-count measurement were considered [4, 5]. Findings from this research show the hip to be the optimal location for sensor placement, and that no significant improvement is achieved in the accuracy with which activity levels are detected by using configurations of two or more sensors [6]. User evaluations with walking groups provided insights into the manner in which the feedback on wearable devices should be provided and how the garments should be designed to incorporate the technological components to maximise ease of operation.

This work has been conducted by a team of key researchers in CSRI:

Chris Nugent	Professor of Biomedical Engineering (joined as Lecturer, 05/2000)
Dr Dewar Finlay	Research Associate/Lecturer/Senior Lecturer (06/2000-present)
Dr Paul McCullagh	Lecturer/Senior Lecturer/Reader (01/1993-present)
Sally McClean	Professor of Mathematics (joined as Research Assistant, 1971)
Bryan Scotney	Professor of Informatics (joined as Lecturer, 1984)
Dr Mark Donnelly	PhD student/Research Associate/Lecturer (10/2004-present)
Dr Ian Cleland	PhD student/Research Associate (10/2009-present)
Mr Liam Burns	Research Associate (08/2007-present)

3. References to the research (indicative maximum of six references)

* *References that best indicate the quality of the underpinning research*.

[1] * CD Nugent, JAC Webb, ND Black, GTH Wright, M McIntyre (1999). An Intelligent Framework for the Classification of the 12-lead ECG, *Artificial Intelligence in Medicine*, vol. 16, no. 3, pp. 205-222.
http://www.aiimjournal.com/article/S0933-3657(99)00006-8/abstract
[***This paper was included as an output in Ulster's RAE 2001 submission for (then) UoA25, Computer Science.***]

[2] * MP Donnelly, CD Nugent, D Finlay, NF Rooney, ND Black (2006*).* Diagnosing Old MI by Searching for a Linear Boundary in the Space of Principal Components, *IEEE Transactions on Information Technology in Biomedicine*, vol. 10, no. 3, pp. 476-483.
DOI: 10.1109/TITB.2006.876033
[***This paper was included as an output in Ulster's RAE 2008 submission for (then) UoA23, Computer Science & Informatics, in which 94.9% of outputs were judged to be 2* or better.***]

[3] * DD Finlay, CD Nugent, MP Donnelly, PJ McCullagh, ND Black (2008). Optimal Electro-cardiographic Lead Systems: Practical Scenarios in Smart Clothing and Wearable Health Systems, *IEEE Transactions on Information Technology in Biomedicine*, vol. 12, no. 4, pp. 433-441
DOI: 10.1109/TITB.2007.896882
[***This paper was included (as a then internet publication) as an output in Ulster's RAE 2008 submission for (then) UoA23, Computer Science & Informatics, in which 94.9% of outputs were judged to be 2* or better.***]

[4] S Zhang, P McCullagh, CD Nugent, H Zheng, M Baumgarten (2011). Optimal Model Selection for Posture Recognition in Home-based Healthcare, *International Journal of Machine Learning and Cybernetics*, vol. 2, no. 1, pp. 1-14.
DOI: 10.1007/s13042-010-0009-5

[5] I Cleland, CD Nugent, D Finlay, W Burns, J Bougourd, R Armitage (2012). Effects of Accelerometer Coupling on Step Count Accuracy in Healthy Older Adults, *Health and Technology*, vol. 2, no. 4, pp. 259-270.
DOI: 10.1007/s12553-012-0036-1

[6] I Cleland, B Kikhia, CD Nugent, A Boytsov, J Hallberg, K Synnes, SI McClean, D Finlay (2013). Optimal Placement of Accelerometers for the Detection of Everyday Activities, *Sensors*, vol. 13, pp. 9183-9200.
DOI: 10.3390/s130709183

Key Grants

Project: Design for Ageing Well: Improving the Quality of Life for the Ageing Population using a Technology-enabled Garment System
Funder: ESRC New Dynamics of Ageing (RES-353-25-004) £193,895 (to Ulster)
Dates: 09/2008-09/2011
Ulster grant-holders: CD Nugent, D Finlay, P McCullagh, SI McClean, BW Scotney

Project: Design for Ageing Well: PhD Studentship
Funder: ESRC New Dynamics of Ageing (RES-353-25-004) £51,301 (to Ulster)
Dates: 10/2009-10/2012
Ulster grant-holders: CD Nugent, D Finlay, P McCullagh, SI McClean, BW Scotney

Project: Cross-border Centre for Intelligent Point-of-Care Sensors
Funder: NI Department of Employment and Learning £1,991,283 (to Ulster)
Dates: 11/2008-03/2011
Ulster grant-holders: CD Nugent, D Finlay, P McCullagh, SI McClean, BW Scotney

4. Details of the impact (indicative maximum 750 words)

[text removed for publication] and [text removed for publication] have both produced a new range of functional clothing for the active ageing based on research by CSRI and the DFAW project. In addition, [text removed for publication] has been guided by CSRI's research in the re-design of their [text removed for publication] product [text removed for publication] to facilitate integration within functional clothing for use by the active ageing.

Results from CSRI's research conducted within DFAW [E1] have been used by the wearable technology providers [text removed for publication] and [text removed for publication] [E2]. [text removed for publication] have improved their knowledge of electrode positioning for physiological monitoring [3, 5] (2008-2012). [text removed for publication] have used CSRI's research, and analysis of feedback from the user group of active older persons in DFAW, to reconfigure the [text removed for publication] in their [text removed for publication] product to control mobile-based applications and to redesign the switch component "to improve the size and positioning of the [text removed for publication] (to allow) for the reduced dexterity of older users" (2008-2012) [E2].

The co-design process, one of the central results from DFAW [E1] (2008-2012), was used as a methodology to produce a range of age-appropriate clothing with integrated technologies. These garments were demonstrated at [text removed for publication] in a joint exhibition with [text removed for publication] [E1]. [text removed for publication] have incorporated the research results into their current range of clothing relating to age-appropriate shape and fit, styling and fabric selection. The recommendations from DFAW have also guided [text removed for publication] in the design of the garment layering system as a basis for incorporating wearable electronics [E3]. These recommendations relate to CSRI's research findings for the most appropriate positioning of sensor and control technologies within the garments in order to both maximise usability from an active ageing perspective and to improve the accuracy of the physiological measurements processed from the data acquired by the sensors (ECG, and measurements of levels of activity) [4, 5, 6].

[text removed for publication], a niche outdoor clothing manufacturer, have adapted their manufacturing procedures to support the incorporation of technology within smart garments [E4] (2012) in relation to the optimal positioning of the technology and how the technology is encapsulated within the garment during the assembly process. This change in manufacturing practice is based on [text removed for publication] involvement in DFAW, particularly the garment manufacturing methodology produced by the project and [text removed for publication] experience of working with DFAW's multidisciplinary research team in the production of prototype garments. A feature presented by [text removed for publication] during 2012 demonstrated how the manufacturing process had been adapted within [text removed for publication] and how the company was now able to incorporate wearable technologies from DFAW into their garments [E5].

Engagement with users from walking groups has resulted in a series of testimonials that report the positive experiences of active older persons who have used the new clothing for outdoor activities. A 70-year-old participant in the evaluations, who reported that she enjoyed walking as part of an active life, stated that her involvement in DFAW has resulted in her being "more inclined to go out and exercise" and that she was now "more aware of the options" available for technology-enabled age-appropriate clothing [E6]. A 67-year-old male who was a member of a walking group reported that in his opinion the use of age-appropriate clothing (as evaluated as part of DFAW) would make people "more likely to become involved in recreational activities" [E6].

The research expertise developed by CSRI in wearable technologies [3, 5, 6] is further recognised through influencing definitions of new terminology that are used in standards within the textile industry. The Textile Institute, a worldwide organisation for textiles, clothing and footwear, recognised the importance of "smart textiles". In revising their publication "Textile Terms and Definitions" (TT&D) in 2012, the Institute wished to reflect the importance of the emerging "smart

textile" sector through its inclusion in the revised version [E8]. In 2012 Prof Nugent was invited by the Textile Institute to join a committee of 12 international experts from the smart textiles community, from both academia and industry, to assist in the revision of the TT&D publication [E9]. (Nugent was one of two technology expert members on the committee.) The output from the committee is a new set of terms and definitions relating to smart textiles from design, technology and clothing perspectives that were not addressed previously in the Textile Institute's TT&D publication.

This work can be associated in part with a collaboration with Professor Jane McCann (University of South Wales, Newport), project co-ordinator of the DFAW project. CSRI were the technology co-ordinators of the DFAW consortium, and the work on incorporating wearable technologies into smart garments for the active ageing was conducted by CSRI. Subsequently ESRC has indicated that they wish to highlight the results from the DFAW project as one of their selected Impact Case Studies [E1, E9].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[E1] Publication by the NDA (New Dynamics of Ageing) Research Programme showing results from the Design for Ageing Well project.
This item provides corroborating evidence of the positive impact experienced by older persons when using the wearable technologies that have been designed for active ageing. The item contains information about the joint expo with [text removed for publication].

[E2] Factual Statement in the form of a letter from [text removed for publication].
This item provides corroborating evidence that results from the Design for Ageing Well project have been used to inform the redesign of their [text removed for publication] product for ageing users.

[E3] Factual Statement in the form of a letter from [text removed for publication].
This item provides corroborating evidence that results from the Design for Ageing Well project have influenced the range of clothing development that has already been prototyped and shown at the [text removed for publication].

[E4] Factual Statement in the form of a letter from [text removed for publication].
This item provides corroborating evidence that the Design for Ageing Well project has informed the manufacturing process of clothing lines to incorporate wearable technologies.

[E5] Feature on [text removed for publication] during March 2012.
This item provides corroborating evidence of the impact of our research on [text removed for publication], informing change that is required in the manufacturig process for wearable technologies.

[E6] End-user testimonials.
These items provide corroborating evidence of detailed feedback from users from a walking group who have evaluated the wearable technology and have had positive experiences when using it.

[E7] A letter from the Textile Institute.
This item provides corroborating evidence that the textile industry recognise the need to consider smart textiles as a new domain and the need to define new terms and definitions for Smart Garments.

[E8] Letter of invitation to Prof. Chris Nugent from the Textile Institute to join their new Committee on "Smart Textiles".
This item provides corroborating evidence of the recognition of transfer of knowledge from CSRI to production of guidelines for the Textile Institute.

[E9] Corroborating contact: Director of the New Dynamics of Ageing programme.
This person is knowledgeable about the programme of work carried out by CSRI in the ESRC-funded Design for Ageing Well project, including our engagement with the textile industry and with user groups, the overall findings of the project, and the resulting impact on development and production of new technology-enabled garments for the active ageing population.