Designing and optimizing a healthcare kiosk for the community

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ABSTRACT

Investigating new ways to deliver care, such as the use of self-service kiosks to collect and monitor signs of wellness, supports healthcare efficiency and inclusivity. Self-service kiosks offer this potential, but there is a need for solutions to meet acceptable standards, e.g. provision of accurate measurements. This study investigates the design and optimization of a prototype healthcare kiosk to collect vital signs measures. The design problem was decomposed, formalized, focused and used to generate multiple solutions. Systematic implementation and evaluation allowed for the optimization of measurement accuracy, first for individuals and then for a population. The optimized solution was tested independently to check the suitability of the methods, and quality of the solution. The process resulted in a reduction of measurement noise and an optimal fit, in terms of the positioning of measurement devices. This guaranteed the accuracy of the solution and provides a general methodology for similar design problems.

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1. Introduction

Worldwide, there are both immediate and far-reaching challenges to the provision of healthcare. For many countries, changes in demographic, growth in Long Term Conditions (LTCs) and changes in the ratio of caregivers to cared for is forcing a rethink in the way that healthcare is provided. Recently, a new kind of healthcare technology has emerged, based upon the use of self-service kiosks (PK, 2013; SoloHealth, 2013). These systems can be used to take physiological measures such as blood pressure, in order to provide healthcare advice.

When it comes to the design of such technology, the Human Factors and Ergonomics literature provides many classic and applicable design rules, relating to the physical characteristics of technology. Designers can also apply data relating to the statistical characteristics of the target population in order to fit a proposed solution to the characteristics of the user population (Yang and Chang, 2012; Vincent and Blandford, 2014). There are also guidelines relating to design methods (AAMI, 2009; Maguire, 2001; Salvendy, 1997; Vincent et al., 2013), and user interfaces (Borchers et al., 1995; Johnson et al., 2005; Maguire, 1999). All of the above can help match the design of healthcare kiosks with the

properties of both users and environment, but doesn't necessarily guarantee accuracy of measurement.

1.1. The need for measurement accuracy

Given the potential use of physiological measures in healthcare diagnosis, monitoring, and clinical decision-making, there is a need for accuracy. Measures need to be in compliance with clinical standards. This imposes challenges upon the design of the kiosk, because there is rarely a one size fits all solution. In addressing these challenges, it helps to break down the problem, consider the factors that impact on measurement accuracy, and control them The kiosk measurement process can be considered as an interaction between human and machine, of which there are multiple components (e.g. physical, sensorimotor and psychological). They include traditional physical capabilities, as characterized by anthropometry and biomechanics. These factors contribute to the measurement accuracy and include aspects such as body posture, measuring device height, spatial arrangement of the equipment, etc. For instance, different postures can cause a variation of more than 20% in the measured systolic/diastolic blood pressure (MacWilliam, 1933). Another component relates to the psychological or mental state of the individual. This can result in a variation of more than 20% on cardiovascular measurements (Madden and Savard, 1995).

Getting an accurate measure is important, as almost two-thirds of hypertensive individuals would be denied morbidity preventing

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treatment if the diastolic blood pressure is underestimated by 5 mmHg. Conversely, the number of people diagnosed with hypertension would more than double if systolic pressure is overestimated by 5 mmHg (Campbell and McKay, 1999). Therefore, the design of an interactive self-service kiosk for the reading of vital signs needs careful consideration, including theoretical modelling of measurement accuracy and optimization across a number of factors.

1.2. Optimizing device interactivity

When it comes to the user interface, although, researchers have frequently studied the ergonomics standards and efficiency of using different interactive components, to control equipment; comparatively few have investigated how to optimize the properties of equipment, to support the accuracy of measurement. Studies have proposed the ergonomics standards for user interactions (Maguire, 2014; Stewart, 1995), and contrasted the efficiency of various input modalities and interface structures, for example the use of touch screens versus manual controls and tangible elements (Rogers et al., 2005; Zuckerman and Gal-Oz, 2013), multimodal interaction techniques (Bergweiler et al., 2010; Kinen et al., 2002), intelligent presentation of user interfaces (UI) (Hagen and Sandnes, 2010), and alternative structuring of task instructions (Eiriksdottir and Catrambone, 2011). There are also studies focussing on the use of formal methods to improve interactivity, such as the use of model checking to verify safety properties (Bolton et al., 2012); nonlinear programming to calibrate and tune the properties of the design prior to implementation (Eslambolchilar and Murray-Smith, 2008), and optimization though the use of parametric design problem solving (Motta and Zdrahal, 1996) (examples from outside of healthcare). In addition, there are also studies optimizing the equipment integration from the perspective of communications, data exchanges and inter-operations (Lyu et al., 2014; Marcelli et al., 2007).

This paper focuses on the design of the physiological kiosk from the perspective of optimizing HMI and improving measurement accuracy. The proposed kiosk integrates several medical devices and sensors for reading the physiological characteristics of participants, including the blood pressure (BP), blood oxygen (SpO_2), pulse rate (PR), electrocardiograph (ECG), blood glucose (BG), height and weight. These vital signs are useful for both ubiquitous (general) and clinical (specialist) applications. Furthermore, amongst the educated population, the origins and meanings of these terms are well known. The main contributions of this paper are:

- Structuring the design problem formally, stating the factors that might impact on the formulation and choosing an appropriate design methodology.
- Stating the design method and linking it to a proposed implementation.
- Implementation of a design to realise the methodology.
- Conducting user trials to check the accuracy of the solution.

To do this, we formulated and analysed the design problem (Section 2); generated and applied a design methodology (Section 3); tested and analysed the implementation (Section 4) and made conclusions about the success of the overall process (Section 5).

2. Formalising the problem

In formulating the HMI design problem, we proposed a series of factors that could feasibly impact on physiological measurement. We then narrowed these down to create an approximate expression of the factors that could be considered and controlled during the design.

2.1. Design goal

The value of a vital sign (y), as read from a sensor could be formulated as a combination of factors emanating from human (X_{human}) and machine (X_{machine}) as defined by the function Γ (Eq. (1)).

$$y = \Gamma(X_{\text{human}}, X_{\text{machine}}) \tag{1}$$

An example of a factor relating to the human would be the position of their arm, relative to a blood pressure monitor. An example of a factor relating to a machine would be the ability for an ECG monitor to determine the rate of the heartbeat from analysis of the input signal. One of the aims of designing the kiosk was to integrate multiple standard sensors, to obtain physiological measures. We therefore focused on the human factors (X_{human}) that had the potential to affect measurement accuracy, as the equipment we were using had already been assessed in terms of quality and performance (e.g. the effects from the machine, X_{machine}, were discarded).

So, given the vital sign set $V = \{\text{BP, SpO}_2, \text{PR, BG, ECG, Height, Weight}\}$, the design goal was to minimize the total measurement error of each vital sign i, as a result of human factors, as described in the following optimization Eq. (2):

$$\min. \quad \Phi = \sum_{i \in V} |\Gamma_i(X_{\text{human}}) - v_i| \tag{2}$$

For Eq. (2), $\Gamma_i(X_{\text{human}})$ is the measured value of vital sign i, as determined by the range of human factors (signal + noise). v_i is the reference value, believed to be the real value of the vital sign i when artifacts and noise are eliminated.

In order to decompose the range of human factors (X_{human}), we considered the range of possible influences that might impact on the vital signs. The kiosk was designed to measure vital signs, as derived from intrinsic factors (changes that occur within the body, such as cardiovascular diseases) as a result of the overall health of the user. We also needed to consider non-intrinsic inputs from either outside of the body (e.g. postural changes or environmental changes) as well as those from inside the body, but not relating to the general health of the user e.g. mood/emotions etc (Cacioppo et al., 2007; MacWilliam, 1933). The intrinsic inputs reflected the health status of the person using the kiosk. They determined the values of the vital signs, as denoted by reference value v_i. The non-intrinsic inputs determined the noise to the vital signs; they were the ones that we needed to control and optimize when designing and implementing the kiosk. We therefore defined the value of the vital sign y_i as:

$$y_i = \Gamma_i(X_i) = v_i + \delta_i(X_i) \tag{3}$$

which means that the measured value of the vital sign y_i, is composed of the intrinsic value v_i and the noise $\delta_i(X_i)$ relating to "human" factors X_i (the X_{human} in Eq. (2)). This means that Eq. (2) can be rewritten as:

$$\min. \quad \Phi = \sum_{i \in V} |v_i + \delta_i(X_i) - v_i| = \sum_{i \in V} |\delta_i(X_i)| \tag{4}$$

2.2. Considering the range of human factors

Table 1 shows a summary on the factors that could affect the vital signs, which are collected from the known physiological measurement guidelines (AAMI, 2009; Campbell and McKay, 1999; MacWilliam, 1933; Madden and Savard, 1995; Myrtek et al., 2000; Pickering et al., 2005).

Based on the summary, we developed a basic model of the range of factors that could impact on the vital sign measurements. This allowed us to decompose the optimization problem (Fig. 1). The