Applying digital early warning systems to healthcare

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The number of people aged over 60 will exceed 20 million by 2030 in the UK, exacerbating pressure on health and social care, carers and families. Methods such as the National Early Warning Score (NEWS) can predict a heart attack within 24 hours, but require users' vital signs to be regularly monitored, implying labour-intensive manual checks, and connecting medical equipment or wearable devices, acceptable in the hospital setting, but inconvenient and uncomfortable for older users at home. Furthermore, conventional home-based alarms can only raise an alert after a user has either pushed a button or remained immobile for some time, often too late to receive a life-saving intervention. Xim is prototyping and trialling preventive monitoring technology combining computer vision with data analytics to address the challenge of providing early warning for older patients at low cost. Using only a standard camera, the system can detect a user's vital signs by observing tiny changes in skin colour. If there is a high health risk within the next 24 hours, nursing staff and carers will be alerted while there is still time to intervene. This will allow patients who are currently rarely monitored to be constantly checked for signs of deterioration. Over time, users will be encouraged to review their own data, using this technology as part of their self-care management; initially the system will be targeted to support GPs with patients in care homes.

1. The Problem

The number of people aged 60+ in the United Kingdom will pass 20 million by 2030,[1] exacerbating pressure on healthcare services and social care provision, in addition to the voluntary sector, informal carers and families. Added to this, the trend for older people to live alone and often remotely from busy younger families has led to many studies and innovations around home monitoring, covering a spectrum of applications from telecare services such as

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[1] *National Population Projections* (2012-based). Office for National Statistics, 2013.

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movement detection through panic alarms to more condition-specific telehealth services designed for long-term health monitoring.

For home monitoring to lead to improved safety and health outcomes for a service user, a full service is required with:

- sufficient frequency of monitoring the service user in order to detect relevant changes;
- ease of adherence to the monitoring programme and minimal requirement to remember to perform any required actions (especially in the case of those with Alzheimer's disease);
- sufficient reliability of data gathered;
- timely alarms based on deterioration or other risk indicators;
- timely assessment by appropriately trained on-call staff in the event of an alarm;
- relevant, effective and timely clinical and/or social service interventions referred to by the assessment team.

It is therefore important to note that the efficacy of the monitoring system relies on people (the "service wrapper") to close the loop and respond to alerts in a meaningful and relevant manner. For the people in the loop, *timing* is critical, especially in cases of physiological deterioration requiring clinical intervention.

However, conventional home-based monitoring methods can only raise an alert after a user has either pushed a pendant button or remained immobile for a period of time, often too late to receive an intervention that could prolong a life. The challenge for digital technology is to play a role in predicting deterioration before the service user's condition is exacerbated to the point of requiring emergency intervention.

2. Early warning

Methods such as the National Early Warning Score (NEWS)[2] have been developed to improve patient safety in the acute hospital domain by prioritizing the allocation of scarce clinical resources to patients on the basis of severity. Developed from empirical data, NEWS/MEWS (modified early warning score) and other variants can predict an exacerbation such as a heart attack within the next 24 hours and ensure that a patient who may previously have been considered low-risk but whose condition has deteriorated can be appropriately highlighted and re-assessed, and a new intervention determined.

These early warning scores, although effective, require that service users' vital signs are regularly checked in order to build and track a weighted risk model.

In the hospital context, this means labour-intensive manual checks, connecting medical equipment or wearable devices. While suited to the hospital setting with trained ward staff on hand, for older users in a self-care context this would be complex, inconvenient and uncomfortable, and especially challenging for dementia sufferers. Therefore, before early warning systems can be successfully transferred to the self-care environment, new models of monitoring need to be considered.

[2] *National Early Warning Score (NEWS)—Standardising the Assessment of Acute-Illness Severity in the NHS* (Report of a working party). Royal College of Physicians (2012).

3. A new model for the self-care environment

Xim is prototyping and trialling preventive monitoring technology, "Lifelight™", combining computer vision with data analytics to address the challenge of providing early warning for older patients at low cost.[3] Using only a standard camera such as that built into a smartphone or tablet device, the system can detect a user's vital signs by observing tiny changes in skin colour. From these changes in skin colour we are able to detect, firstly, cardiac pulse and respiration by using signal processing techniques on the colour channels from the camera.[4] Through further analysis of the video signal we can, secondly, detect blood oxygen saturation level (SpO_2) and also derive blood pressure.

These vital sign signals can then be assessed using a derivative of the NEWS score adapted for the home (self-care) environment. A score will then be used to alert an appropriate assessment team of any significant deterioration. Therefore, if there is a high health risk within the next 24 hours, nursing staff and carers will be alerted while there is still time to intervene.

4. Further considerations

This technology faces a number of challenges and issues, which must be addressed before widespread adoption can be achieved.

Lighting. Clearly, operation of video-based technology is reliant on lighting conditions. Infrared operation is possible using a security-style IP-camera, but the current project aims to harness domestic smartphones and tablets, therefore sufficient room lighting or daylight is required to function. Significant work is being undertaken to ensure the software algorithms can operate reliably in varied and poor lighting. The user interface will provide suggestions to the service user to improve lighting if it is unable to determine sufficient data.

Privacy. Concerns around the use of a camera for monitoring must be considered. The software does not store or transmit any images; effectively it uses the camera as a colour sensor. Only numerical data concerning colour changes are transmitted and vital signs data received. Well-established patient consent models can be used to comply with information governance requirements, while appropriate user and carer education should help to ease fears of the advent of "Big Brother".

False positives—for an early warning system to be trusted by clinicians, it must produce a minimal level of false alarms. For the Lifelight™ project this is dependent both on the quality of vital signs data and the reliability of the NEWS-derived risk score.

Accuracy. As part of minimizing false positives, the software is being clinically validated at University Hospital Southampton in order to calibrate its accuracy against conventional vital sign measurement equipment.

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[3] Funding from Innovate UK supported this work. In order to adapt the early warning score model to the home/self-care environment, Xim has also been awarded a Knowledge Transfer Partnership with the Centre for Healthcare Modelling and Informatics (CHMI) at the University of Portsmouth. The Centre was involved in the development of NEWS.

[4] M.-Z. Poh, D.J. McDuff and R.W. Picard, Non-contact, automated cardiac pulse measurements using video imaging and blind source separation. *Optics Express* **18** (2010) 10762.

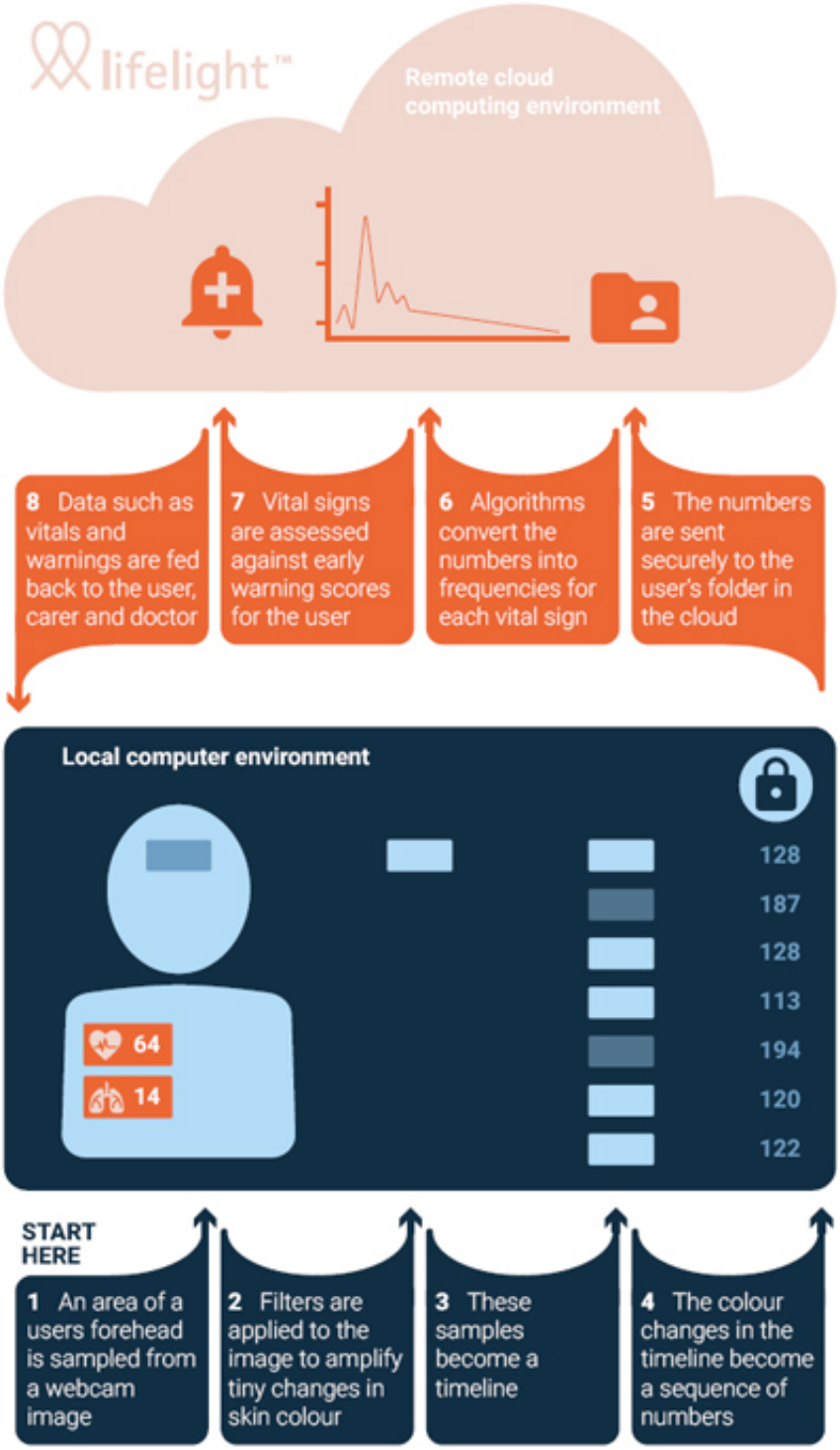

Figure 1. Lifelight™ camera-based vital signs capture, analysis and early warning.

Regulatory approval. Lifelight™ is classed as a Class IIa medical device and is in the process of gaining regulatory approval. Working towards obtaining a CE mark for a software device requires a risk-driven approach based on ISO 14971. This provides assurance that an appropriate level of rigour is applied to addressing each of the above concerns as well as many more, ensuring that risks are constantly reviewed and mitigations designed into the product, wherever possible, or covered by training or labeling otherwise.

Compatibility with current NHS software systems. A final consideration is to ensure that the technology can integrate with and, just as importantly, not overload existing NHS systems with data. Integration is becoming technically much simpler thanks to the take-up of modern application program interfaces (APIs) by many of the leading electronic health record (EHR) suppliers. However, data created by monitoring is relatively new territory, and the potential volume of this data may be very great. Further work will be necessary to explore methods of summarizing data to ensure that trends and alerts can be stored and retrieved without unnecessarily populating records with large amounts of raw data.

5. Advantages

As well as providing early warning, there are a number of further key advantages to Lifelight™ relative to "traditional" telehealth methods of monitoring.

Improved adherence. Use of a passive camera means that the service user does not need to do or even touch anything in order to be monitored. Reading an eBook, watching the news on a tablet or even watching daytime television on a webcam-equipped smart TV are all moments in the day when the system would be able to capture the user's vital signs data passively. Adherence is a challenge for telehealth services when users are required to routinely attach and set up devices in order to record and send data. By removing the need for the user to take action, the monitoring becomes frictionless, not interfering with daily routine.

Low cost. No specialist devices or custom hardware are necessary as the system has been designed to use conventional CCD-type cameras, such as those found in many modern devices.

Interoperability. As the camera is built into a network-enabled device, the data generated can be easily integrated into existing electronic health and social care records (EHRs) to reduce duplication of effort. Xim is developing a two-way link between Lifelight™ and the popular primary care EHR EMIS Web, with others to follow.

Wide applicability. Current telehealth programmes run by Care Commissioning Groups (CCGs) tend to focus on a subset of their local population, based on need and suitability. Need must be stratified due to the cost and resources needed for the telehealth programme, while suitability depends on the patient's ability to cope with the technology. By addressing both cost and usability, Xim's passive monitoring approach will therefore allow a wider group of service users, who are currently unmonitored or at best rarely monitored, to be constantly checked for signs of deterioration.

Fostering of self-care. Over time, users will be encouraged to review and learn about their own data, using the Lifelight™ technology as part of their self-care management in order to make positive lifestyle and dietary changes.

6. Next steps

The product of the project will be a system initially targeted to support GPs with patients in the care home sector but extending to home-based monitoring after further trials and validation. Outcomes should include:

- Reduced deaths and unplanned hospital admissions;
- Reduced emergency call-outs and out-of-hours visits;
- Coping with increasing demand from an aging population with more complex and severe needs than hitherto;
- Improved patient experience and quality of life.