Impact Objectives

- Enable the detection of early symptoms of cardiovascular disease (CVD) without the need for the use of expensive equipment, thus ensuring a better prognosis for the millions of people affected by CVD
- Provide a system of regular cardiac health monitoring through a wearable system which can be used by most populations and especially for those who are remotely located
- Use data collected via the wearable sensors to better understand what combinations of indicators point to early CVD problems

Cardiac health early warning system

__Professors Ming-Yih Lee__ and __Wen-Yen Lin__ of the __Chang Gung University__ in Taiwan, describe their novel wearable continuous cardiac health monitoring system and how it can help detect and inform the user of the early warning signs of heart problems

Professor Ming-Yih Lee

Professor Wen-Yen Lin

What problems are you hoping to solve with this project?

MYL: Cardiovascular disease (CVD) is the leading cause of death worldwide, but many of these deaths could be prevented if we could detect the intermittent abnormalities and critical cardiac behaviours that lead to sudden death. Reliable, low-cost healthcare facilities are not currently available to everyone, in addition most people are only evaluated once a problem arises or when they visit the hospital for another condition. Cardiac health evaluation is usually undertaken via electrocardiogram (ECG), echocardiogram (echo), computerised tomography scans, magnetic resonance imaging and nuclear myocardial perfusion scans. However, ECG displays only electrical activity of the heart, but cannot measure the timing and rhythm of cardiac events associated with movement of heart valves, blood circulation into ventricles and contraction-relaxation of ventricle walls, therefore it's not sufficient to assess heart performance. While the echo and other medical imaging methods can measure the cardiac timing events, these methods require expensive technology and can only be used by professional experts in a hospital environment. This combination of factors suggests there is a need for an inexpensive, yet reliable cardiac health monitoring system, which measures overall cardiac mechano-electrical behaviours over time and provides an early warning of heart problems. The aim of our project is to deliver such a system via a textile-based, intelligent and wearable continuous cardiac health monitoring system.

WYL: The symptoms of some CVDs are non-classic and include shortness of breath, fatigue and weakness, swelling in lower extremities, lack of appetite and nausea. Such symptoms are not automatically associated with a heart problem, hence people with these conditions are rarely diagnosed at an early stage. Our project will help detect people with developing heart disease at an early stage and without the use of expensive equipment.

Can you describe the sensors?

WYL: Two types of sensors are used and are integrated into the smart wearable garment. The accelerometers used for mechanocardiagram measurement are tiny off-the-shelf micro-electro-mechanical sensors that are woven into textiles. The other sensors are textile-based electrodes used to make electrocardiagram measurements. These are also mounted in clothes and are barely noticeable by the wearer. So far we have incorporated both types of sensor into the smart wearable garment that can be worn comfortably and every day by the user and even while sleeping. The smart wearable garment can also be washed as per normal clothes.

Who do you envisage would wear this system?

MYL & WYL: Patients considered to be at risk of developing CVD are expected to be the main potential customers for this system and would be identified by general practitioners. However, health conscious individuals would also be able to buy the system to monitor their own cardiac data points. We aim to commercialise the system in the long term.

Do we know enough about what measurements are indicative of someone in the early stages of developing a heart problem?

MYL: We believe we have sufficient information to enable us to correlate different feature points, cardiac time intervals and physio-markers associated with cardiac timing events to identify people who are starting to experience cardiac health issues. Our smart wearable garment actively collects measurements from four valvular auscultation sites and also monitors both the electrical and mechanical responses of the heart – ECG and mechanocardiagram (MCG). We are currently undertaking a clinical assessment of the results of a large, long term study from Chang Gung Memorial Hospital here in Taiwan, to provide further clinical evidence about what combinations of feature points and values of ECG and MCG signals are reliable indicators of the early stages of a heart problem.

Monitoring heart health with wearable sensors

*Director of the **Medical Mechatronics Research Laboratory** within **Chang Gung University**, Taiwan, **Professor Ming-Yih Lee** and his colleagues are developing applied sensor technology to collect real-time cardiac health information and ultimately provide early warning of premature abnormalities from heart failure*

Wearable garment for cardiac health monitoring

According to the World Health Organization (WHO), cardiovascular diseases (CVDs) accounted for 17.7 million deaths in 2015, more than any other single disease and 31 per cent of all deaths among the global population. CVDs are a collection of conditions often associated with the build up of plaque in veins and arteries, leading to high blood pressure, arrhythmia, breathlessness, fatigue, stroke and sudden cardiac arrest. With the exception of congenital heart disease, CVDs are mostly caused by preventable lifestyle choices, such as poor diet, physical inactivity, smoking, obesity and high alcohol intake. The WHO notes that CVDs place a huge economic burden on all countries, particularly as they most often strike lower income populations who have the least access to reliable health monitoring facilities and are therefore often only detected when their disease is in the advanced stages. The earlier the risk factors for CVDs can be recognised, the more likely interventions will have successful outcomes, such that the individual can lead a normal, productive life.

SMART WEARABLE GARMENT

In response to the global challenge posed by CVDs, a 15-strong research team, led by Professor Ming-Yih Lee, Director of the Medical Mechatronics Research Laboratory at Chang Gung University, Taiwan, is aiming to produce a low cost, wearable continuous cardiac health monitoring system, which can be used to continuously monitor at risk individuals and so provide an early warning of developing heart problems. As noted by Lee, traditional monitoring techniques for cardiac timing events: 'require expensive technology and can only be used by professional experts in a hospital environment.' Diagnostic tools include echocardiagram, computerised tomography scans, magnetic resonance imaging and nuclear myocardial perfusion scans. This means regular cardiac health monitoring is largely out of the reach of remotely located populations. Also, the cost of undertaking frequent heart checks on at-risk population groups is prohibitive even for wealthy nations.

The team's solution has been the development of a smart wearable garment, which can be comfortably worn by and tailored for any individual, into which are woven a number of tiny sensors which can detect electrocardiagraph and seismographic information of the heart from multiple locations. The off-the-shelf, commercially proven and reliable micro sensors are connected by conductive fibres and powered by a small incorporated power unit with a rechargeable battery. The control unit collates sensor data and communicates with a cloud-based health analytic platform, which undertakes all the necessary data processing and analysis, prior to feeding back useful information on their cardiac health to the user's smartphone. The smart wearable garment will look and feel normal on the body and can be washed as per normal clothing.

Despite the sensors already being available, the development of the 'body area network' is a major ongoing project, which has brought together many different specialists to develop a practical solution. Lee and senior colleague Professor Wen-Yen Lin are specialists in inertia-based motion sensing, body sensor networks and mechatronics system integration. Other specialisms included in the team are electrical engineering, wireless communications, textile design, software engineering, industrial design and cardiac health clinical experts. Lee's team has worked with a local textile firm and has a close collaboration with the Chang Gung Memorial Hospital in Taiwan, which has been undertaking long-term studies into the combinations of physiomarkers that indicate the early

stages of cardiovascular problems. Project management has included weekly meetings to ensure everyone is up to speed on developments and immediate actions. Co-location has assisted these face-to-face meetings and communication.

MULTICHANNEL MEASUREMENTS

The sensors woven into the smart cloth pick up both mechanical and electrical behaviour of the heart. Extensive research and clinical studies revealed that traditional single point electrocardiagram readings could miss intermittent heart abnormalities and do not reliably interpret the heart's mechanical behaviour. According to Lee: 'Echocardiography is a better modality for examining cardiac function and anatomy,' but this is expensive and often not available, even in medical institutes. By combining multiple mechanocardiagram (MCG) (also termed seismocardiogram) readings and electrocardiogram (ECG) data, the team's system can provide much greater information on heart health. Whereas previous studies have used a single accelerometer located on the sternum, Lee says the difference in this project is that: 'MCG signals are acquired at four locations in order to detect the specific motion of each heart valve and chamber, instead of just the composite vibrations of a whole heart'. Lee notes this will avoid problems such as: 'position dependency, time delay and signal attenuation experienced by single channel MCG systems'.

> *'Deaths could be prevented if we could detect the intermittent abnormalities and critical cardiac behaviours which lead to sudden death'*

According to Lin, measurements will be taken every half hour and will continue for five minutes. However, the user can customise the regularity of readings and also take manual one-off readings whenever they wish. Once the measurements are complete, data is synchronised with the user's smartphone and then transmitted to the cloud service for analysis when an internet connection is available. Analysis of the collated readings takes place on the health analysis platform and push-notifications are fed back to the user's smartphone, allowing them to act on any detected abnormalities. For this to occur, the sensor system is paired with a smartphone application, which will provide warning signals at different levels of severity, along with applicable advice to the user. For instance, as well as providing feedback on their health, the user will also be supplied with tips on how to improve their heart health by making changes to their lifestyle.

PUBLIC ACCEPTANCE

Lee's team has already made significant progress in this study. Smart wearable garments incorporating the sensors and control unit have been made and early trials have taken place. Correlation analysis has been undertaken, comparing data points from the sensors and clinically accepted indicators of heart issues. A large ongoing study from the Chang Memorial Hospital is also being assessed to determine what combinations of indicators point to there being early problems with the cardiovascular system. Conceptual and framework design of the associated smartphone applications have been developed and the graphical user interface will be designed and refined during the remainder of the project. One further challenge is ensuring the battery in the control unit is able to provide 24-hour cardiac monitoring, without becoming overly large or heavy.

A major part of the project will be assessing and designing the smart wearable garment and smartphone application to gain high user acceptance. The project team will be using the information systems theory called Technology Acceptance Model, which comprises two main features: perceived usefulness and perceived ease of use. Trials have demonstrated that the smart wearable garment is comfortable and not bulky or awkward in appearance, and trial participants will be surveyed to determine any factors that might detract from its acceptance. The team point to the increasing use of wearable monitoring devices, such as fitness trackers and sleep monitors, as evidence that their system will be welcomed by the public and medical practitioners. If the system can also be made comparatively inexpensive, it has enormous potential to limit the premature deaths and economic burden of CVD on a global front.

Project Insights

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