A Smart Wearable Sensor Assisting in Mental Health

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Mental health - Depression

- Mental health care represents a major cost to all EU nations with a third of all GP consultations in Europe ("Mental Health in the European Region", WHO, 2003)
- European Study of the Epidemiology of Mental Disorders (ESEMeD) project, major depression and specific phobia were the most common single mental disorders in the EU.
- GPs are unable to deal with Depressive/ Anxiety disorders effectively, often prescribing drugs such as SSRI´s
- Such disorders are treatable illnesses with CBT as the treatment of choice.
- A proactive approach is required to treat before the depression has become chronic.
OPTIMI

- OPTIMI is an EU FP7 project
- OPTIMI is an acronym for
  - Online Predictive Tools for Intervention in Mental Illness
- The project runs for 3 years 2010 to 2012
- The partners are
  - EVERIS, Spain
  - University James I and University Polytechnic Valencia, Spain
  - ETH Zurich and University of Zurich, Switzerland
  - Lan Zhou University, China
  - University of Bristol, MA Systems and Ultrasis, UK
  - University of Freiburg, Germany
  - Xiwrite, Italy
OPTIMI Prime Assumptions

- Depression may result due to a large number of factors including genetic and biological factors
- OPTIMI focuses on depression that results due to the medium to long term effects of stress
- More specifically it focuses on stress in “high risk” individuals whose life context has an element of stress which cannot easily be avoided
  - E.g. A mother with a disabled child, a final year student
- The assumption is that faced with such stress, the person who is less able to cope with the stress, will eventually become depressed.
- Proactively identifying depression is achieved by identifying stress and general poor coping behaviour using a range of physiological sensors
- Having such a predictive tool, Cognitive Behavioural Therapy is applied online with adaptations resulting from sensor feedback.
OPTIMI architecture and usage 1

- **Sensors Used**
  - ECG
  - Sleep
  - Activity
  - EEG
  - Speech
  - Cortisol
- **Self reporting**
- **Supported by a Home PC and a central Server**
OPTIMI Architecture and usage 2

- Instead of streaming data from the sensors to a wearable computer, the philosophy being tested in OPTIMI is to make the sensors do the main work.
- At the end of the day the user wirelessly downloads the preprocessed and compact results to the Home PC.
- Wireless sensors that may signal process and store results while having long battery life are key.
The Heart and our emotional affective state

- The autonomous nervous system controls many aspects of our behaviour and emotional state.
- The Sympathetic NS controls our response to danger; fight or flight, it gets our heart racing.
- The Parasympathetic NS calms and soothes the body into a state of regulation, it gets our HR down.
- The result is a heart beat that varies strongly between the two states.
- A person who is “healthy” is able to demonstrate good variation capability, or heart rate variability.
Heart rate variability measures

- HRV tells us about to what extent the person physiologically is coping with stress
- Persistent High or Low heart rates indicate low HRV and a potential inability to deal with crisis
- The interval between each heart beat is timed giving the RR interval (PQRS to PQRS)
- Measures are calculated to characterise the HRV

- **Time Domain**
  - Standard Deviation
  - pNN50, a count of the number of large changes in the interval

- **Frequency Domain**
  - High frequencies
  - Low frequencies
  - High to Low frequency ratio
Heart Rate Variability Detection

- Read the Heart Beat
- Band pass filter it
- Form the derivative
- Square and integrate the derivative
- Find the peak and negative going point on the integrated signal
- Only do a peak detect when the integrated signal goes above an average/slugged threshold
Correlation and Error removal

- With the sensor placed on the chest, the pectoral muscles generate high potentials and can create artefact noise. The slugged integral threshold saturates if the noise persists and blocks any detection.
- If a valid QRS peak is detected, the QRS waveform is additionally correlated with a test signal to determine if it has a compliant shape.
- For ectopic beats (beats that are due to anomalies in the person heart muscle firing) and for signals buried in noise, the correlation method prevents false beat detection.
- Before any HRV calculations a sequence of 128 or more beats are required. Due to memory limits we use 128 beats.
- We tolerate up to 2 lost beats and linearly interpolate, after that we abort and restart the 128 sequence sampling.
FFT calculation

- For the FFT we use a 128 point decimation in time in place FFT algorithm, using 16 bit integer arithmetic.
- We are testing both triangular and Hann time window scaling to ensure the RR signal is periodic. (zero each end)
- The FFT calculation memory is aliased with the QRS detection memory and requires about 500 bytes, the FFT is performed in under 200ms.
- Below are typical results obtained.
Sleep and Depression

- Sleep quality is almost always negatively affected by stress in daily life.
- Acute stress, in particular of a kind that cannot be resolved during the daytime, results in a reduction of sleep quality and poor coping.
- Insomnia is independently associated with depressive disorders.
- The evidence clearly indicates that insomnia is a predictor for depression.
Sleep quality Estimation

- Complex polysomnographic instruments may be used to measure sleep quality, however this leads to high costs and inconvenience.
- Sleep detection, using movement sensing of the sleeping person, has a relatively long history involving scoring algorithm with a precision of sleep detection of 80 + %.
- ECG may also be used as a low cost sensor since Heart rate is reduced in NREM sleep and higher during REM phases and in association with arousal events during sleep. Recent studies [5], [6] in our paper, have found clear correlations between heart-rate variability and sleep depth.
Sleep Quality as a function of motion and Heart rate

- Motion detection (ACT) is measured by integrating over time the changes in absolute values of acceleration measured by the 3 axis accelerometer combined in the ECG sensor.
- The ECG is used to measure heart rate HR and HR variability in the form of LF and HF values.
- The sleep quality will then be determined as

  \[ \text{Sleep\_quality} = a \times \log(ACT+1) + b \times \log(HR+1) + c \times \log(LF+1) + d \times \log(HF+1) + I \]

- The coefficients a, b, c, d are to be fine tuned by laboratory experiments using a parallel range of polysomnographic equipments.
ECG Sensor Hardware 1 – CPU and RF

- The sensor is based around the nRF24LE1 from Nordic
  - Based on an 8051 core
  - 2.4GHz transceiver 1 Mbps air data rate
  - 16 kB program memory (Flash)
  - 1.5 kB data memory (on-chip RAM)
  - 1.5 kB NV data memory
  - 12 bit ADC, 10 channel MUX
- Solves I/O and wireless comms
- Ultra low power, low cost, small footprint
- Low computing speed
ECG Sensor Hardware 2 – Analogue front end

- The analogue front end comprises a fairly standard circuitry employing INA321 instrumentation amplifier, OPA336 for feedback and filtering and a MAX7407 switched capacitor filter for 50 Hz removal.

- The power to the overall front end and the MAX7407 enable are controlled by the CPU to conserve power.
The sensor is to be worn around 22, 23 hours of the day, for about 2 weeks. Therefore the sensor is fully encased in a resin making it impervious to water.

Having no on off switch and no connector for charging, the sensor is non contact charged via an inductive loop.

Once off the charging unit the sensor continues to run its application until the battery reaches a threshold level, below which the sensor maintains enough charge to perform a communications session.
ECG Sensor Software – Key tasks

- **ECG**
  - Detect peaks
  - Remove errors
  - Record RR intervals
  - Compute Time and Frequency domain characteristics
  - Record with time stamp the result

- **Sleep Activity**
  - Detect standing or lying down
  - Filter Accelerometer signals
  - Integrate the accelerometer signals
  - Record results with time stamp

- **Runtime**
  - Maintain runtime power management
  - Check for RF wireless broadcasts from Home PC
  - Perform system download and update from Home PC
  - Maintain battery detection for low battery as well as charging mode
Some results

- Usability test have been conducted with 12 people, of varying ages and backgrounds, with very positive acceptance of the sensor, worn as a necklace.
- Further tests are underway testing the electrode placement robustness for 23 Hour usage.
- Test are underway to ensure robustness with artefacts. The main noise being EMG from the pectoral muscles.
- How HRV varies with life style and context will be tested
  - Heavy Smoker vs Non Smokers
    - We expect to see much lower HRV for heavy smokers
  - Roller Coaster Rides vs Quiet Activities
    - We expect to see higher HRV for the Roller Coaster
Home PC application

- Communication between the Home PC software and the sensors is via an RF Dongle
- The RF Dongle has a special driver as well as a DLL written to allow the HOME PC application a simple interface
- The DLL performs all the RF Protocol including data downloads and sensor re-initialization with new time and date and if necessary calibration parameters.
CONCLUSION

- A very small unobtrusive wearable has been developed that stores HRV and activity related data over 24 hours, such that it may be downloaded to a PC each day.
- Unlike systems that stream data to another wearable, this approach minimizes the cost and avoids power hungry wireless transmission.
- The wearable, though small, is able to perform the necessary computing required.
- Much more testing is needed to characterize its performance as well as make the sensor robust and foolproof.