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Wireless Pilot Monitoring System for Extreme Race Conditions

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Abstract— **This paper presents the design and implementation of an assistive device to monitor car drivers under extreme conditions. In particular, this system is designed in preparation for the 2012 Atacama Solar Challenge to be held in the Chilean desert. Actual preliminary results show the feasibility of such a project including physiological and ambient sensors, real-time processing algorithms, wireless data transmission and a remote monitoring station. Implementation details and field results are shown along with a discussion of the main problems found in real–life telemetry monitoring.**

I. INTRODUCTION

Car drivers' fatigue and stress have been studied by several researchers [1], [2]. Race car pilots' physiological data have been monitored during competitions such as Formula One [3] and Kart Racing [4]. Compared these "normal" situations, solar car racing presents additional stresses on the driver and special considerations are necessary to ensure the pilots' well-being during the race.

Solar car prototypes focus on performance and energy efficiency but usually the pilot's comfort and safety are not a priority. During car races, drivers must endure long hours in extreme environmental conditions. Heat exposure produces fatigue, affecting human performance on task vigilance and sustained attention [5]. Inside the car, a small cockpit, poor ventilation and high temperatures generated by the sun and electrical and mechanical sources produce heat stress compromising drivers' health and driving performance [6].

Car race organizers are concerned about fatigue and dehydration in pilots. Most solar car race regulations explicitly request all participant teams to have a safety plan [7], [8]. To this end, it is usual to have an escort car with technicians, engineers and a healthcare professional to support the solar vehicle in case of emergency. To facilitate medical supervision from the escort car, it is desirable to have a telemetry system to monitor the pilot's health condition at all times during the race. The same telemetry system can also be used to monitor key variables in the car such as temperature, solar panel charging level and battery voltage and current [9], [10].

There are few reports on pilot monitoring in these competitions. In 1990, during the World Solar Challenge in Australia, health information was collected through health self-perception questionnaires and medical diagnosis [11]. It is now clear that stress and ambient conditions have a detrimental effect on the pilots. Knowing how long a pilot can drive safely given the actual conditions and when to use a relief pilot is very important. This allows a better race plan and ensures pilot safety.

This paper proposes a physiological and ambient monitoring system as an assistive device for a race pilot in extreme conditions. We present the implemented system and preliminary experimental results in a non-race condition. This work is part of the preparations at the Universidad de Concepción to participate in the Atacama Solar Challenge 2012, in Chile. The goal is to monitor the health status of the drivers during the race and check on their medical condition.

II. SYSTEM DESCRIPTION

A. Sensor Selection

Variable selection is restricted to minimally-invasive physiological data. Vital sign information is augmented with ambient monitoring to provide a comprehensive view of the pilot's condition. The following set of sensors is implemented:

- Heart Rate (HR): HR is one of the main vital signs used to evaluate cardiovascular function. It also provides information related to stress, fatigue and drowsiness by analyzing Heart Rate Variability (HRV) [12], [13].
- Respiration Rate (RR): RR is an indicator of breath depth, which is directly related to relaxation, emotional excitement and physical activity. Both high and low values are deviations from a calm, focused state [14].
- Temperature (T_a) and Relative Humidity (RH): Cockpit RH and high temperatures may lead to heat stroke, fainting or accelerated dehydration. High humidity retards evaporation, reducing the capacity of the body to cool down and worsening the effects of high cockpit temperature, which can rise above 30°C in solar car races. The Heat Index (HI) or 'apparent temperature' represents this combination. From HI table information, an alarm can be generated for the monitoring team [15], [16] to warn of dangerous conditions.

An overview of the monitoring system is presented in Fig. 1. Physiological and ambient sensors capture data from the pilot and the solar car cockpit. Then, a wireless link transmits that data, as well as other relevant information, to an escort car. In the escort car, a Graphical User Interface (GUI) displays current values and trends, and saves all collected data to a database for historical review.

B. Physiological Sensors

1) Electrocardiogram (ECG) signal: The ECG signal is acquired via three surface electrodes on the pilot's chest.

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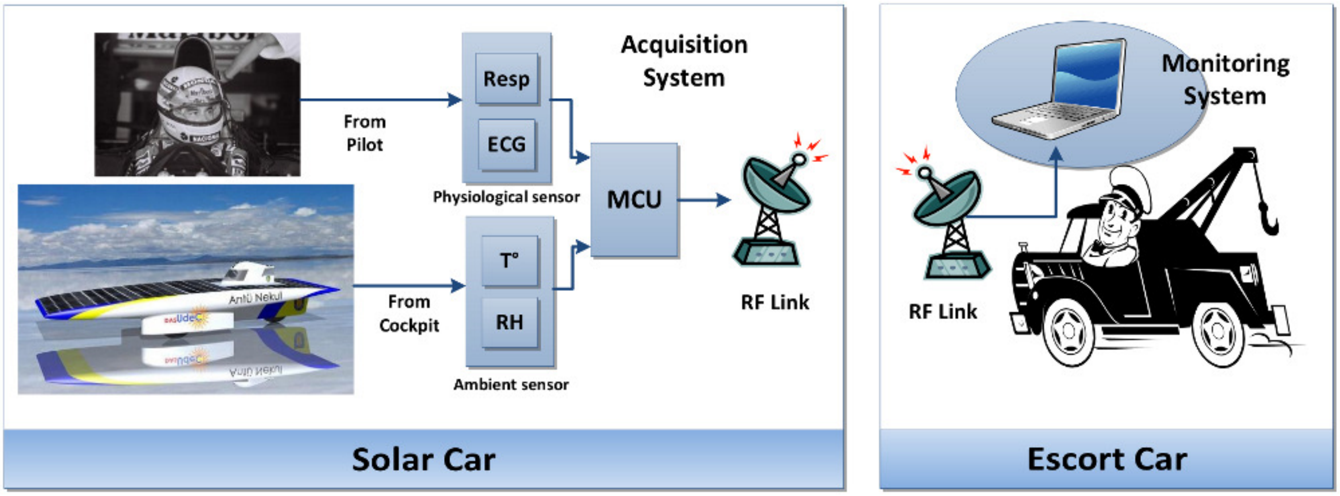

Fig. 1. System overview. Physiological and ambient sensors are processed in a microcontroller unit and sent wirelessly to an escort car.

These electrodes are connected to an instrumentation amplifier board. Signals originally in the 0.1–5.0 mV range are amplified to a 0–5 V range. The ECG board has amplifiers, low pass and notch filters and a final signal conditioning stage for Analog to Digital (A/D) conversion. The instrumentation amplifier is implemented using an INA128 chip with variable gain. A fourth-order Sallen Key low pass filter is used to attenuate high frequency noise. Filter cutoff frequency is 100 Hz. A notch filter stage, tuned at 50 Hz (Chilean mains frequency) eliminates most of the induced noise present during testing. The final stage adds an offset to the amplified signal before feeding it to the microcontroller's A/D Converter (ADC). In order to avoid damaging the ADC, a buffer is used to ensure that the input is never under 0 V or over 5 V.

2) Respiration signal: Respiration signal acquisition is based on the thoraco-abdominal movement produced by the respiratory cycle. A stretch sensor attached to the driver's chest is used to acquire this movement. This piezoresistive sensor has a nominal resistance of 1.0 KΩ per inch which rises linearly when stretched. When the length of the sensor is more than 50% of the original length, the resistance rises 2.0 KΩ per inch. The piezoresistive transducer is connected to a voltage divider to convert change in resistance to change in voltage. The signal's baseline is also removed using an offset regulator. To reduce high frequency noise and movement artifacts, a second order - 10 Hz low pass filter with Sallen Key topology is used. Finally, a buffer protects the microcontroller's ADC port.

Both physiological signals are later processed digitally in the Microcontroller Unit (MCU). Fig. 2 shows the analog ECG and respiration signals right before A/D conversion.

C. Ambient Sensors

A commercial sensor was used to measure ambient variables from the cockpit. Sensorium SHT15 integrates T_a and RH measurements in one sensor. Data is sent using a digital communication protocol to the MCU. The sensor resolution

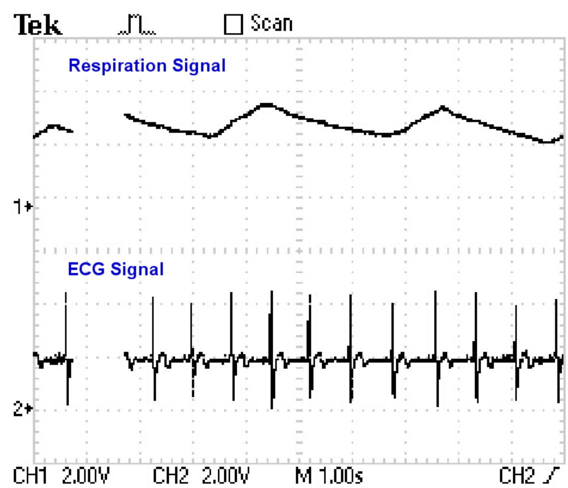

Fig. 2. Respiration (top) and ECG (bottom) analog signals from the sensors.

is 0.01°C and 0.05% RH. The measurement ranges are -40°C to 123.9°C and 0–100% RH.

D. MCU Processing

The PIC18F4580 MCU integrates data from all sensors and extracts relevant information. A 10 bit ADC is used to sample ECG and respiration signals. The sampling rate is 250 Hz for ECG and 22.5 Hz for the respiration signal. Digital filtering stages and algorithms to calculate HR and RR are implemented in the MCU. Data from the SHT15 ambient sensor is read digitally using its specified protocol. After processing, all data is sent through a serial port connected to a wireless antenna.

- HR Algorithm: A peak detection algorithm was implemented to calculate the HR. The algorithm was previously used in [17]. It uses a FIR filter and an adaptive threshold. ECG signal is processed on-line and the computed HR is updated on every beat.
- RR Algorithm: The algorithm to calculate RR was modified from [18]. First, the respiration signal is

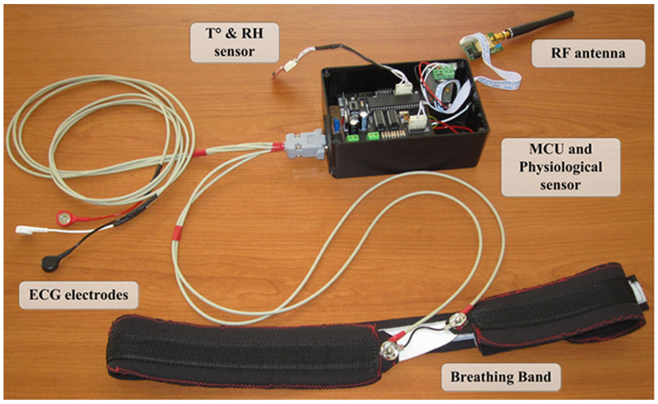

Fig. 3. Pilot Hardware consisting of the stretch sensor, ECG leads, temperature and humidity sensor board, PCB and microprocessor and antenna for wireless data transmission.

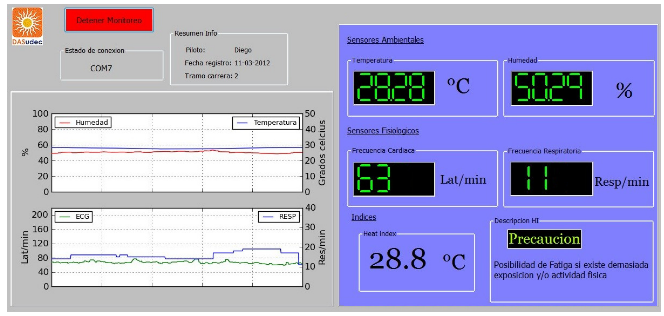

Fig. 4. GUI with current physiological and ambient data (right) and trends (left).

Fig. 5. Pilot car and gear.

Fig. 6. Escort car.

filtered using a FIR filter. The resulting signal is a constant-baseline, smoothed version of the air flow from the respiration. By detecting zero crossings, positive and negative cycles are associated with inspiration and expiration. Based on the area and width of positive and negative cycles, valid breaths are separated from noise, and then used to compute RR.

E. Wireless Transmission

A radio frequency link is used to send the acquired information to the escort car. HAC-UM96 module boards communicate at 9600 bauds over a distance of 500 meters. The transmitter module connected to the MCU serial port sends the information to the escort car. The receiver module is connected to a personal computer through a serial (RS-232) adapter and the information is displayed in a GUI.

Fig. 3 shows the pilot's final implemented system, including physiological sensors, ambient sensors, PCB and microcontroller in a containing box and wireless antenna.

F. Graphical User Interface

In the escort car, data is evaluated in real time by a medical staff through a GUI installed in a portable computer. The GUI displays current values, data trends and warnings according to the calculated HI value. Also visual alerts can be configured by the user modifying individual thresholds.

The GUI was developed in Python and integrated with a MySQL database to save all the information for post-processing. The GUI is shown in Fig. 4. The last 30 minutes of data are shown in two graphs, one for ambient trends (top left) and one for physiological trends (bottom left). Also current values of T_a, RH, HR, RR, HI and warnings are displayed. Above the trend graphs there is information about the registration process and connection state.

III. RESULTS

The monitoring system was tested in non-race conditions using two conventional cars. The first car traveled with the sensor system ('race car' - Fig. 5) and the second car had the monitoring software ('escort car' - Fig. 6). A 25 year-old male driver and his cockpit conditions were monitored along 48.0 km during 47 minutes. Ambient trends obtained during the test are shown in Fig. 7. On average, the cockpit temperature and humidity were 28.2°C and 50.3%. Heat Index values were between 27°C and 30°C during about 40 minutes. According to the Heat Index classification [19], these values indicate possible fatigue with prolonged exposure, and the GUI was displaying a warning to alert the escort car team. However, the physiological trends were in a normal range. On average, during the test, HR was 66.4 beats/minute and RR was 17.1 breaths/minute. Physiological trends are shown in Fig. 8. HR was not affected significantly by artifacts, but RR was. Compared with a test done in resting conditions to check the RR algorithm where there was a standard deviation of 3.04 breaths/minute, the standard deviation on the road was 5.91 breaths/minute. A simple moving average filter reduced physiological trend variability. During the test, there was no significant loss of information due to the wireless transmission. Only RR data stream was interrupted when the RR algorithm could not detect a valid breath due to noise.

IV. DISCUSSION

A radio-frequency monitoring system was implemented to check the driver's health status in real-time during a solar car race based on physiological and ambient information. Preliminary results are presented in a non–race condition using conventional cars.

The RR data is affected by artifacts. Car vibration and driver movement produce noise in the respiration signal

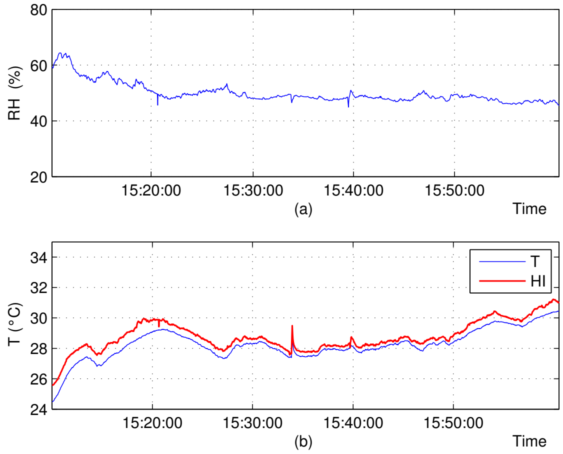

Fig. 7. Ambient trends. (a) Humidity, (b) Temperature and HI.

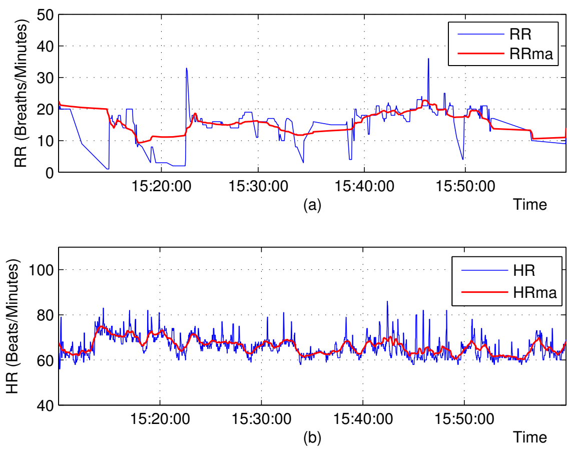

Fig. 8. Physiological trends. (a) Respiration Rate and (b) Heart Rate.

which affects the detection accuracy. However, it is possible to detect the RR trend during the test reasonably well by adding a moving average filter. Current research involves testing more robust algorithms for the challenging environment of in car monitoring.

Multiple sources of information proved useful. For instance, the system generates a warning when the Heat Index is over 27°C. However, if physiological data are normal, the pilot can keep driving. Acclimatization, pilot health and inter-person variability account for different responses to a Heat Index value.

Future work on assistive devices will focus on improving sensor design, testing noise-robust algorithms and adding more inputs such as accelerometers and CO_2 or SpO_2 data. Also, we are working on a high level processing stage to integrate all the acquired information to produce intelligent alarms.

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