A multi sensing method for robust measurement of physiological parameters in wearable devices.

R. Logier, A. Dassonneville, P. Chaud, J. De Jonckheere

Abstract — **The monitoring of physiological parameters such as heart rate, ventilatory rate, or oxygen saturation is a commonly used practice in the medical field. Many clinical solutions exist, based on the use of specific sensors, dedicated for bedside patient's vital functions monitoring at hospital. But the implementation of such sensors in ambulatory situations is rendered extremely difficult because of many artifacts induced by the movements of the subject that make the measures unusable. We have designed an original method for robust measurement of physiological parameters dedicated for wearable devices. The method is based on a multi sensing technique using, at least, two sensors of different nature or placed at different sites, for each parameter. In order to illustrate this method, we have developed a headset device including two heart rate (HR) sensors and two ventilatory rate (VR) sensors. This device has been evaluated on 6 healthy volunteers during exercises. This test showed the physiological values of HR and VR from the headset device stability and efficiency.**

I. INTRODUCTION

The measurement of physiological parameters, such as heart rate, ventilatory rate or oxygen saturation, is a commonly used procedure in clinical situations in order to monitor the patient's vital functions. Even if this practice, based on the use of specific non-invasive sensors, is simple and efficient in the case of a bedside solution, it is of serious difficulty when used in ambulatory situations. Indeed, the implementation of such sensors, when the subject is in physical exercise for example, leads to erroneous and unusable measures because of many artifacts induced by the movements of the subject [1, 2]. Nowadays, ambulatory monitoring devices integrate multi-sensing technologies in order to increase measurements efficiency [3, 4]. So it's quite interesting to consider the development of an original method for "robust" measurement of physiological parameters that would provide reliable and exploitable information when used on a wearable solution as, for example, a headset, a watch, a belt, an instrumented garment or the combination of such elements [5].

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II. METHODS AND MATERIALS

We have hypothesized that a multi sensing technique, using at least two sensors for the measurement of each parameter, would contribute to a significant improvement of the measures quality. The idea was to implement two sensors of different nature, or placed at different measuring sites, for each physiological parameter measurement. The information given by each sensor would be continuously analyzed in order to elaborate a score of quality of the output parameter. A decision algorithm is then used to determine, in real time, which is the best value of the parameter, taking into account the different scores of quality using a particular decision rule.

In order to evaluate these hypotheses, we developed a specific device for two physiological parameters acquisition: Heart Rate (HR) and Ventilatory Rate (VR). The device is designed as a headset including a double HR sensor placed inside an earlobe clip, and a double VR sensor placed in front of the subject's mouth as a microphone extension (figure 1). This headset is fully wireless and autonomous, the power supply is assumed using two batteries, and the parameters are continuously transmitted through a Bluetooth communication port.

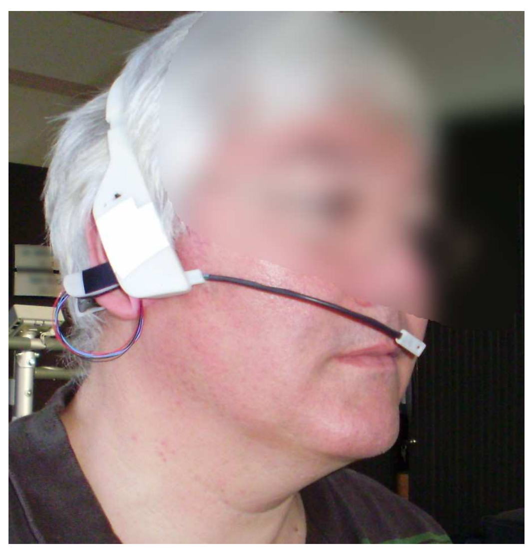

Fig. 1: Multi-sensor headset for robust heart rate and ventilatory rate measurement

A – Multi sensing main principle

The multi sensing approach is based on the use of, at least, two sensors for each parameter measurement. In addition, the sensors are, preferentially, of a different nature, or, failing that, disposed at different measurement sites. In the example of realization of the multi sensor headset, we used two optical sensors, placed inside an earlobe clip, for the heart rate measurement. Each optical sensor is composed of an infrared Light Emitting Diode (LED) and a photo detector. This couple of components, placed on each side of the earlobe, is able to deliver a plethysmographic signal, reflect of the blood flow in the capillary vessels induced by each cardiac beat. This signal can then be processed in order to carry out the beat-to-beat heart rate parameter. Regarding the measurement of ventilatory rate, we used two different sensors, both located in front of the subject's mouth, at the extremity of an extension branch. The first one is a microphone recording the noise resulting from the respiratory ventilation. The second one is a temperature sensor recording the temperature variations between expiratory and inspiratory airflow. Applying appropriate signal processing on each of these signals, it is possible to extract the corresponding ventilatory rate parameter.

The figure 2 shows the main functional diagram of the multi-sensor headset. Regarding the HR measurement, a specific driver is used in order to alternatively command the diodes of the optical sensors. The plethysmographic signals issued from the photo detectors are filtered and amplified before analog to digital conversion (ADC). Regarding the VR measurement, the audio signal, from the microphone, and the temperature signal are respectively filtered and amplified before ADC. A microcontroller PIC 24 Microchip® including a four channel ADC is used for signals acquisition and processing. The continuous transmission of the resulting parameters is completed using a Bluetooth communication module. The power supply management is assumed from two batteries.

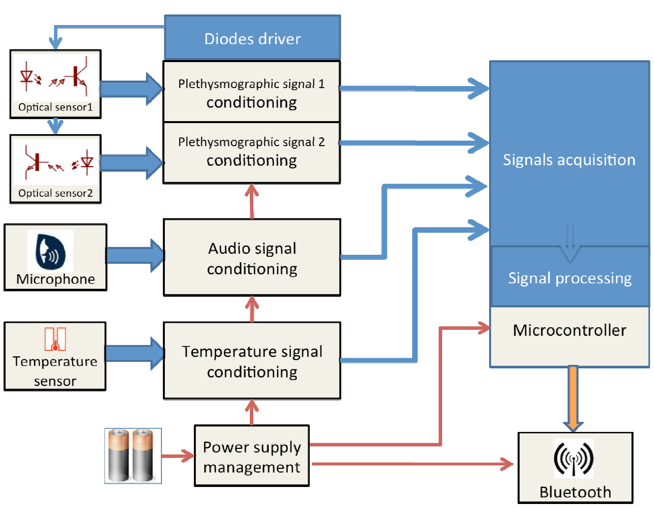

Fig. 2: Headset multi sensing main principle

B – Double sensors processing

Whatever the physiological parameter to acquire, in this case HR or VR, the method to process at least two sensors for each parameter is described on the figure 3.

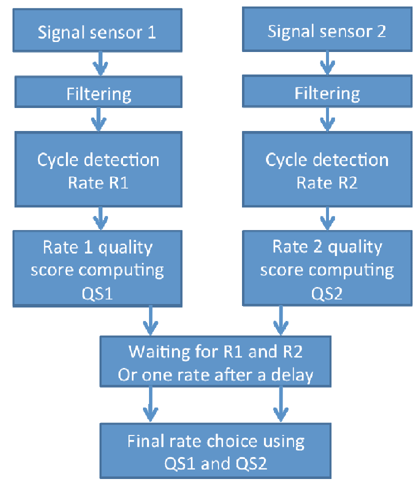

Fig. 3: Double sensors processing

Each signal issued from its respective sensor is first filtered in order to predispose the signal before the cycle detection process. The filter can be either a low-pass, high-pass or band-pass filter depending of the nature of the signal. The cycle detection algorithm is used to extract the physiological signal rate. This algorithm is particular depending of the signal characteristics. For example, in the case of the ventilatory rate, the period of the signal is calculated by counting the elapsed time between two successive zero crossing [5]. Each rate value (R1 and R2) is then analyzed in order to evaluate a score of quality (QS1 and QS2). The figure 4 shows the quality score evaluation for HR parameter.

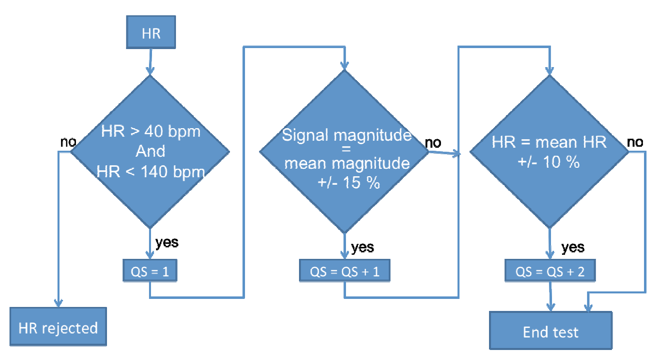

Fig. 4: Rate quality score evaluation for HR value

The score of quality of the HR value is assessed on at least three tests regarding the value range, the signal quality and the value variations. The HR value is first compared with high and low HR limits. If the HR value is in the normal range then the rate quality score value (QS) is incremented.

The second test concerns the magnitude of the original signal that has to be in a range of 30 % of the mean magnitude. In this case QS is one more incremented. Finally, HR value is compared with the mean HR value computed on a moving window. If HR is in the range of 20 % then QS is twice incremented. At last, if the HR value is not rejected, its QS is defined from 1, the worst quality, to 4, the best quality.

So, for each parameter, the algorithm delivers a pair of data: the rate value (R) and the rate quality score (QS). But the processing duration for each channel can be different depending of the nature of the signal. In order to process the final rate choice, it is necessary, after the calculation of one pair of data, to wait for the second one. But this waiting time is limited to a certain security delay in order to prevent any over timing system blockage. In this case, only one pair of data, the first one, is transmitted to the choice algorithm. The final rate is then determined using the quality score values. The figure 5 shows the functional diagram of the HR parameter final choice algorithm.

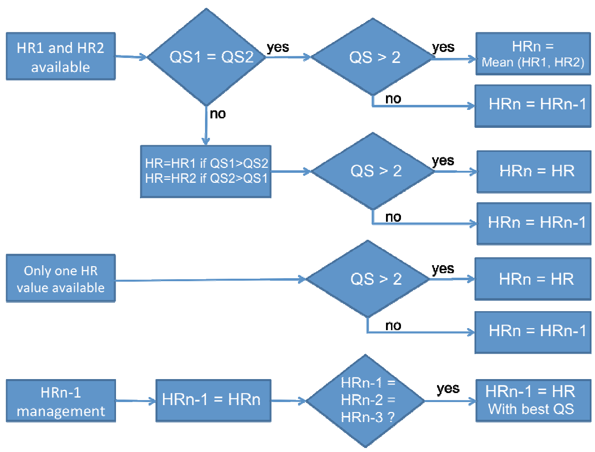

Fig. 5: Final HR value determination

If both values HR1 and HR2 are available after the security delay, a first test on the QS values is performed. If both quality scores are equivalent with a value over 2, that is to say, the two values are excellent, then the resulting value HRn can be the mean value of HR1 and HR2. If the common QS value is lower than 2, HR1 and HR2 are considered as wrong values and the last true value HRn-1 is duplicated as the resulting value HRn. If HR1 and HR2 quality scores are not equivalent then only the HR value with the best score is retained. If its score is over than 2 then this HR value become the final one. If not, the last true value HRn-1 is duplicated.

If only one HR value is available, due to the security delay timeout, the algorithm proceeds to the unique QS test. If the score is over than 2 then the HR value become the final one. If not, the last true value HRn-1 is duplicated.

Regarding the management of the HRn-1value, basically it is replaced, after each decision, by the retained value HRn. But, in order not to duplicate the same value on a long period, that could append if the quality scores are lower or equal to 2, a test is performed on the three last values HRn-1, HRn-2 and HRn-3. If these values are equivalent then HRn-1 will be replaced by the HR value with the best QS lower or equal to 2.

These algorithms for the quality score evaluation and final value determination, dedicated for the HR parameter, can be translated for VR parameter or any other physiological parameter. Only the decision rules have to be adapted.

C – Multi sensor Headset evaluation

In order to evaluate the multi sensor headset, dedicated for HR and VR parameters measurement, we compared the values issued from the headset with those issued from a classical multi parametric monitoring device Philips® IntelliVue® MP50. HR was then compared to the HR issued from the ECG signal and VR was compared to the VR issued from a pneumotachograph. A Spearman correlation test was then applied to compare series issued from each sensor. The statistical test was considered significant at a p value of 0.05. All tests were performed with SPSS 22.0.

In the same time, we compared the values issued from the headset multi-sensing algorithms with those issued from each headset independent sensors. The subjects were wearing the headset while biking on an exercise bike (figure 6). The HR and VR measurements from the headset were continuously transmitted to a PC based recorder using the headset embedded Bluetooth capabilities. Specific software was developed on the PC in order to continuously acquire the data as well as analyze, compare and plot the data files.

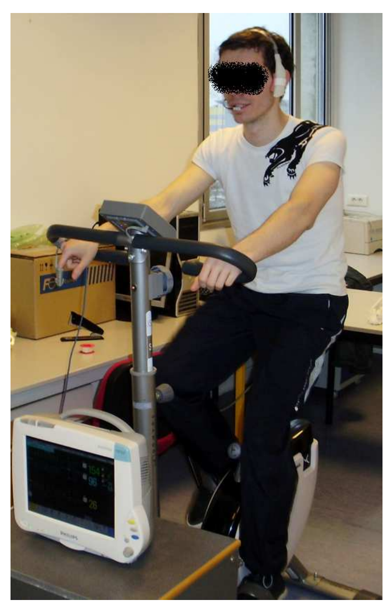

Fig. 6: Multi sensor headset evaluation

III. Results

We investigated 6 adult participants. In order not to affect the participant's attention, he was blind of the recorder display. The bicycle was equipped with a variable magnetic resistance of the pedals. In order to perform measurements under different effort conditions, the protocol included 5 recording periods of 3 minutes each. The period 1 was recorded as a reference one, without any effort. The period 2 was recorded while biking at the first resistance level. The period 3, at the second resistance level, the period 4, at the first resistance level again, and the period 5, without any effort.

The figure 7 shows one of the resulting Heart Rate curves from the headset. Global heart rate clearly increases during periods of activity 2 and 3, and decreases during periods of lesser activity 4 and 5. HR headset is clearly reliable, demonstrating the quality of the measurement from the headset against the measure coming from each sensor.

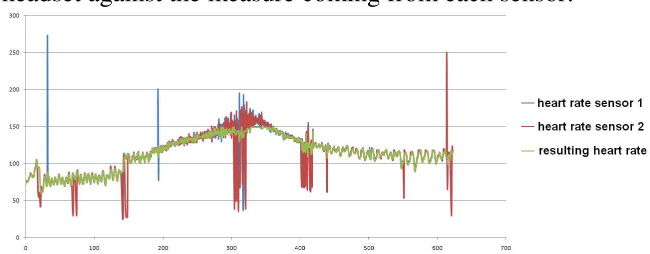

Fig. 7: Heart Rate curves

The figure 8 shows one of the resulting Ventilatory Rate curves. Like for the HR, VR increases during periods 2 and 3, and decreases during periods 4 and 5. VR headset is clearly reliable, demonstrating the quality of the measurement from the headset against the measure coming from each sensor.

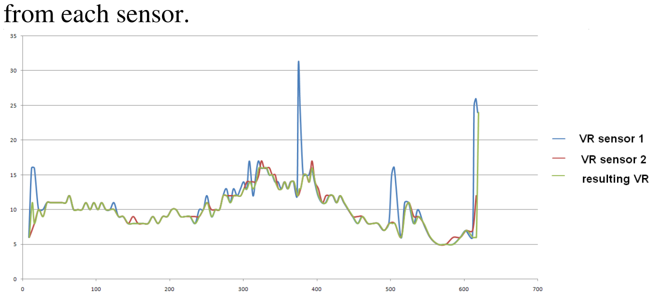

Fig. 8: Ventilatory Rate curves

Table 1 shows the results of the comparison tests for both HR and VR. For all participants, correlations between computed VR and HR and gold standard values were higher than 90 % ($p<0.0001$) showing the system ability to obtain reliable VR and HR values. We observed than lower correlation records were subject to HR or VR artifacts both on our system and the gold standard. We hypothesized that the use of an efficient HR and VR filtering algorithm would increase this correlation [6].

Table 1 : Correlation test for VR and HR.

	VR		HR	
participant	Correlation	p	Correlation	p
1	0.90	<0.0001	0.9	<0.0001
2	0.98	<0.0001	0.95	<0.0001
3	0.96	<0.0001	0.89	<0.0001
4	0.99	<0.0001	0.96	<0.0001
5	0.98	<0.0001	0.97	<0.0001
6	0.98	<0.0001	0.98	<0.0001

IV. Conclusion

This first trial has been successful, demonstrating that the multi-sensor headset, as it is described, is able to continuously produce HR and VR physiological parameters. Testing during activity conditions was necessary to evaluate the robustness of the measurement. Following this study, the system has been patented [7]. This patent will be used in special applications as, for example, stress or pain measurement using heart rate variability analysis [8, 9] for ambulatory or home care solutions. Finally, other trials have to be held in order to evaluate the ability of the multi sensing solution to be more robust than the classical measurement in any situation.

V. References

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