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A Novel Algorithm for Extraction of Respiratory Frequency Based on ECG Applied to Artificial Respirator

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Abstract— *This paper presents a new algorithm for the estimate of respiratory frequency based on an electrocardiogram (ECG) signal of a person. It is based on the estimate of the number of R waves of an ECG signal constituting a respiratory cycle. First of all, the proposed algorithm consists to detect and locate the R peaks, then as from the number of R peaks necessary for a breath, finally to consider the respiratory frequency starting from the number of breathes equal to the sum of the R peaks which reaches a suggested condition. Our algorithm was applied and validated on real signals extracted from MIT (Apnea-ECG) and Fantasia Databases. The performance evaluation based on the rate of recognition of the rate of respiration and the precision of the computed values had satisfactory results. The average rate of recognition of the rate of respiration is 96.828%. These satisfactory results were used to control an artificial respirator designed around an Arduino Mega card and ECG AD8232 sensor. The experimental results obtained from the designed artificial respirator present an average error of 0.013% of the respiratory period for a minimum rate of recognition of 99.973%.*

Keywords— *Electrocardiogram, Aespiratory Frequency, MIT Database(Apnea-ECG), Fantasia Database, Artificial Respirator.*

I. Introduction

Electrocardiogram (ECG) represents the recording of the electric potential of the heart. It is a tool to diagnose cardiac diseases [1]. However, in certain cases, emergency for instance, it is often very essential to measure the patient breath. For example, a patient in coma, in reanimation or with insufficient respiration. The normal ECG is characterized by 3 main waves: P, QRS, and T (Figure 1). Thus, a technique able to exploit only the ECG signal of a patient to extract his respiratory frequency from it was thought in order to control an artificial respirator for real time assistance of the aforementioned patient. To this end, we propose a simple technique exploiting the digital signal processing method. This technique is particularly useful for the systems where only the ECG is available as source of information.

Several methods for extraction of a respiratory signal from the ECG signal were developed in the literature; we can classify these methods in five group base on their principles:

a) in the first group, methods are based on the principle of variations of the electrical axis angle: breathing induces a rotation of the average electrical axis of the heart [2,3,4];

b) in the second group, methods compute the amplitude difference of the R wave of the QRS complex [5,6,7];

c) in the third group, methods are based on the wavelet discrete transform and band pass filtering [8,9,10];

d) in the fourth group, methods are based on the variations of the average electric shaft angle [11,12].

e) in the fifth group, we have methods combining two principles and others mixed methods as in [13,14]. However, the implementation of these methods are more complex and requires huge computer's resources. In addition, they were not used to control an artificial respirator in real time. In this paper, we proposed a simple algorithm which produces satisfactory results to estimate de respiratory frequency and to control an artificial respirator.

The rest of this paper is organized around three sections. In section 2, we will present the methodology and research tools for the design of the proposed algorithm. Then in section 3, we will present the results and discussions of virtual simulations and the experimental tests of the artificial respirator carried out. Finally, section 4 is the conclusion of our paper.

II. Methodology and Research Tools

Fig.1 presents the signal of a normal ECG. It is characterized by three waves: P wave, complex QRS, and T wave [15]. This signal reveals that only the R wave reaches the greatest amplitudes and will be used as principal peak. In addition, the knowledge of times of appearance of two waves R makes it possible to determine the heart rate [16].

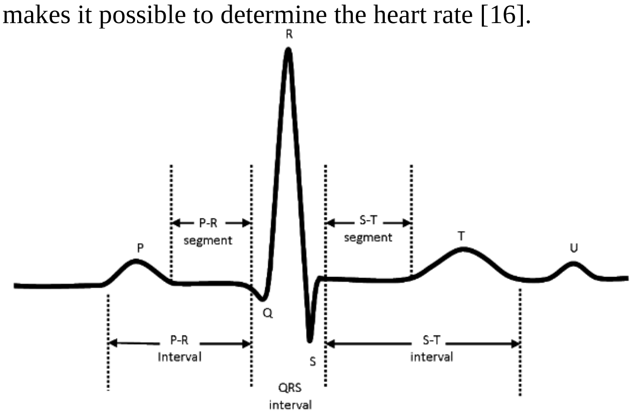

Fig.1. ECG signal [15]

The acquisition of the ECG is sullied by noises caused by the respiratory movements, the bad contacts of the electrodes with the skin and the supply frequency of 50Hz [17]. Thus before extracting the heart rate from it, it should initially be treated. The flow chart proposed for our algorithm is given on fig. 2.

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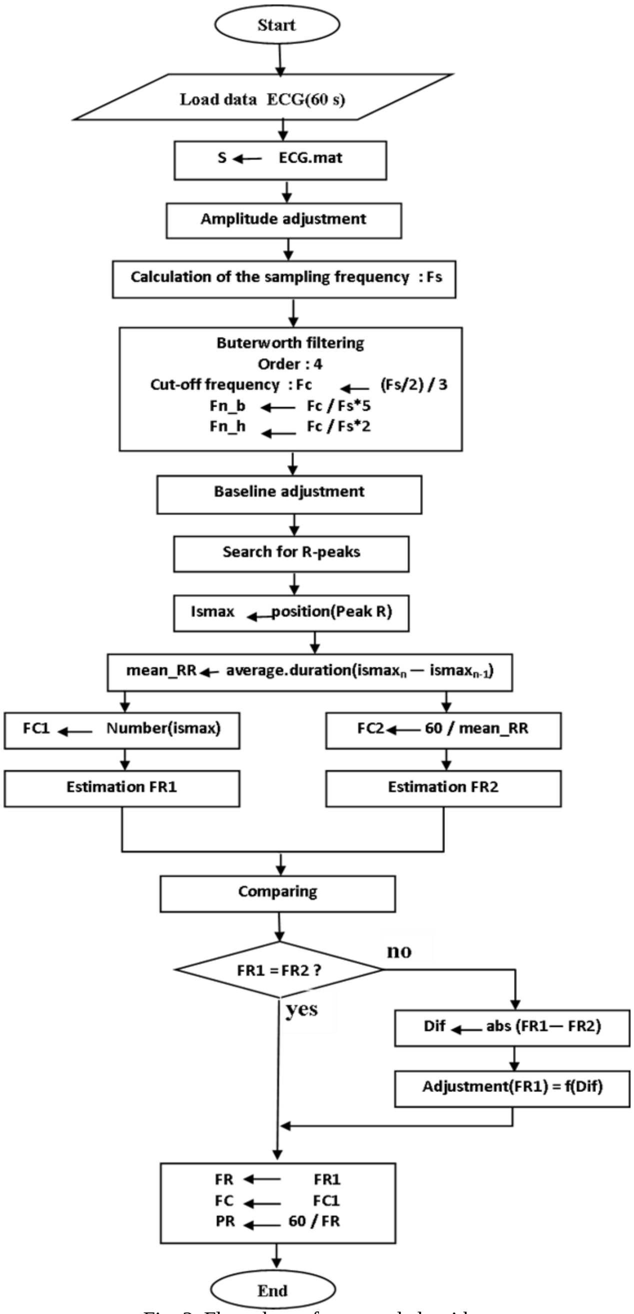

Fig. 2. Flow chart of proposed algorithm

A. ECG Treatment

The first stage consists in filtering ECG signal. Fig. 3 presents the spectrum of an ECG [18]. It shows that the great spectral power of an ECG signal lies between 2Hz and 40Hz. That shows that one can do without all the filters used in general in the processing of the ECG for the use of a single Butterworth band pass filter of 2Hz-40Hz to treat our signals. Fig. 4 presents the effect of the filter on a noisy ECG signal in Matlab R2020a taken in the MIT Apnea-ECG Database.

After filtering, one notices irregular amplitudes of various R waves. the detection of the peaks can be made by taking 0.5mV as threshold of the waves. The time of appearance of each peak is simultaneously recorded in a table to determine the heart rate.

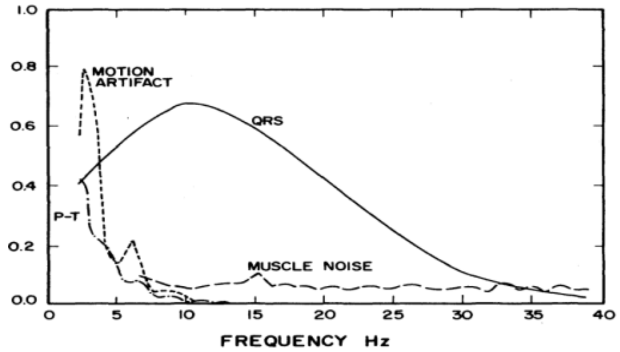

Fig. 3. Signal spectral of ECG [18]

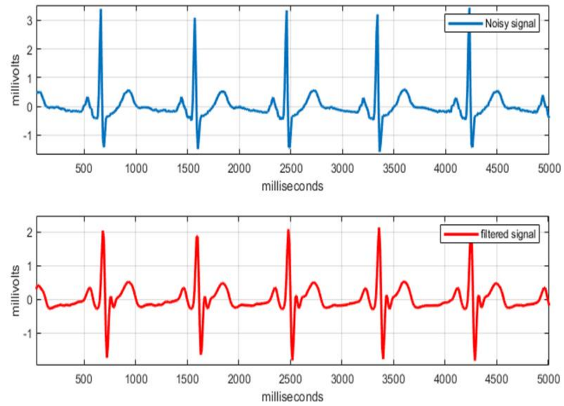

Fig. 4. Noisy ECG in blue and Filtered ECG in red

B. Estimation of Respiratory Frequency

The heart rate is estimated at rest with 60 beats per minutes for an adult in good health and varies according to breathing; the breathing cycle is 5 seconds for 12 breaths/minute [19]. Our study is based on the relationship according to which the number of breaths increases and decreases by ± 1 breath every 5 heartbeats, it corresponds to five peaks for a respiratory cycle according to fig. 5. Thus, the estimate of the respiratory frequency will consist of counting five detected peaks and to exploit times of appearance of the first and fifth peak to consider the respiratory period.

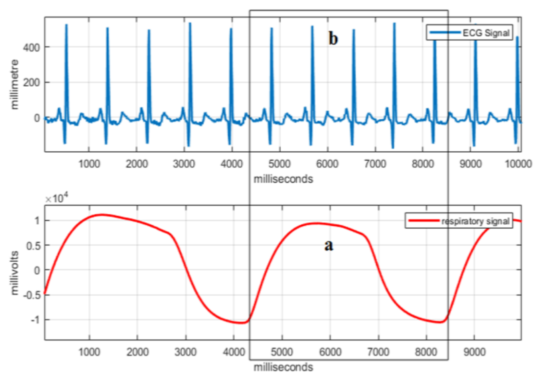

Fig. 5. Number of R peak counted in a respiration
(a) Respiratory signal; (b) ECG signal

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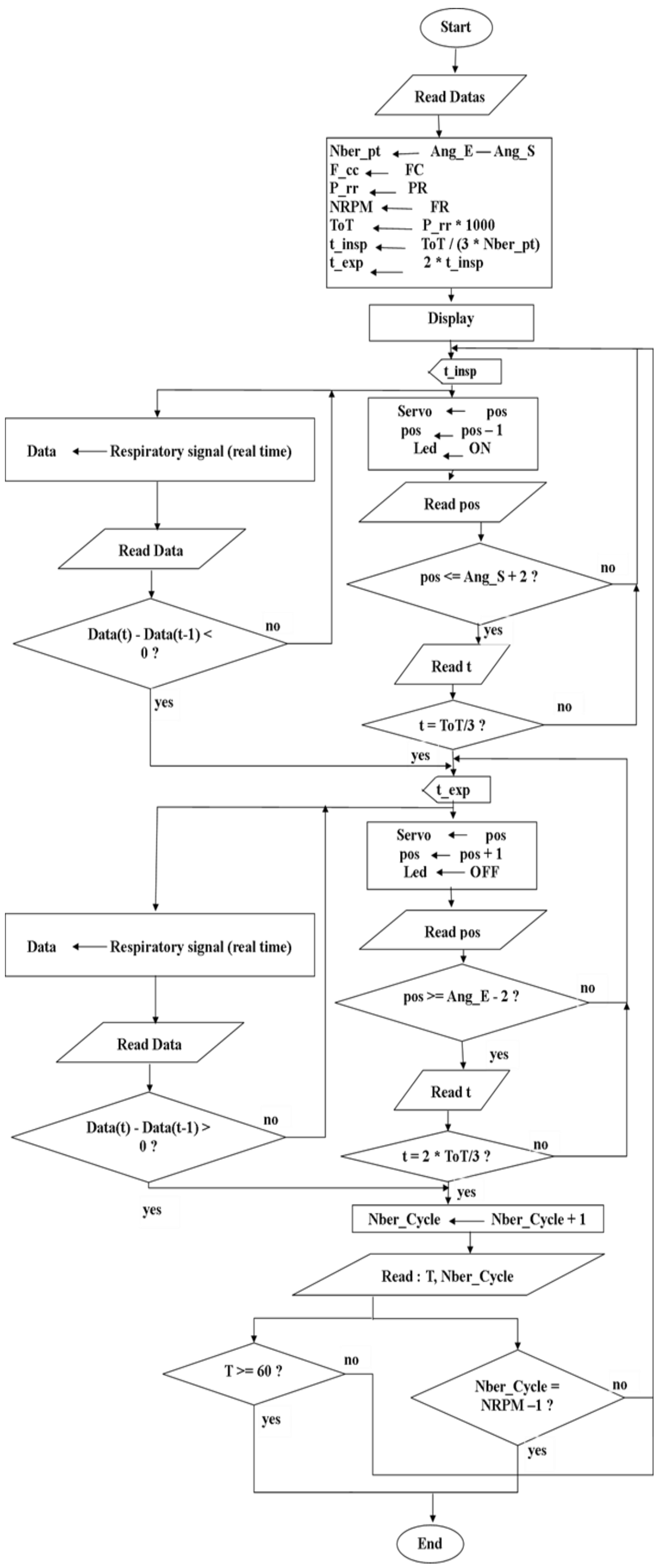

Fig. 6. Flow chart of artificial respiratory control

C. *Artificial Respirator Control*

An artificial respirator consists of a unidirectional self-filling balloon making it possible to reproduce the respiratory movements, i.e. of inspiration and expiration. The control of this balloon must exploit the respiratory frequency estimated by our algorithm of detection in order to be able to determine the periods of inspiration and expiration. A simple Arduino Mega card will generate a signal to order a servo-motor controlling the balloon. The ordering of the respirator is based on three constraints:

- A time constraint: which defines the time necessary for the inspiration and the expiration. The servo-motor is commanded in position during these times;
- A positional constraint: which defines the opening angle and thus the number of steps required for the servo to press the BAVU until the required amount of air is obtained for the patient according to his inspiratory period. The actuator moves through the defined opening angle during inspiration and expiration;
- A synchronization constraint: trigger the of the artificial respirator with a real-time movement sensor.

Fig. 6 presents the flow chart of order of the designed artificial respirator integrating above the constraints.

Fig. 7 presents the control signals in Arduino IDE generated by the microprocessor according to the respiratory signal a01erm of Apnea-ECG Database and to the flow chart proposed. One can notice indeed the synchronization between the two signals. Indeed, breathing is irregular, and the breathing period determined by our algorithm is an average over one minute. On the other hand, it can happen that the estimated control time for inspiration and expiration is not exactly the same during the control of the ventilator. It is therefore imperative to synchronize the control of the ventilator with the real time respiratory movements of the patient. This synchronization consists in detecting the maxima of inspiration in order to trigger the command of expiration and the minima of expiration in order to trigger the command of inspiration even if the first two constraints are not reached.

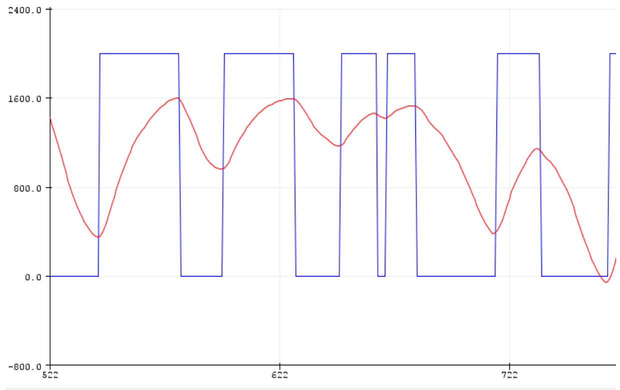

Fig. 7. Synchronization of the signals: control in blue and patient a01rem in red

III. Results and Discussions

A. *Virtual Simulation Results*

The relevant simulation tools are listed as follows:

- Matlab/Simulink R2020a;
- Apnea-ECG Database as a source of ECG signals;
- Fantasia Database as a source of ECG signals;
- PC core i7 computer, 500G and 4G of RAM;

The results obtained, following the application of our algorithm on ten ECG signals of 60 seconds duration each, are represented in Table I. This table presents the results of our algorithm applied on three groups of patients from two databases (Apnea-ECG Database and Fantasia Database):

TABLE I. Virtual results synthetization

	Subject	Real Heart rate	Estimated Heart rate	Heart Recognition rate	Real respiratory rate	Estimated respiratory rate	Respiratory recognition rate
Apnea-ECG Database	a01erm	71	71	100.000	14	14.679	95.374
	a02erm	79	79	100.000	20	16.18	80.900
	a03erm	68	68	100.000	13	14.102	92.186
	a04erm	79	79	100.000	16	15.874	99.213
	b01erm	57	57	100.000	13	11.19	86.077
Fantasia Database Young subject	f1y01m	79	79	100.000	16	15.92	99.500
	f1y02m	68	68	100.000	14	13.997	99.979
	f1y03m	70	71	98.592	15	14.826	98.840
Fantasia Database Old subject	f1o01m	57	58	98.276	13	11.957	91.977
	f1o02m	56	56	100.000	13	11.955	91.962
	f1o03m	60	61	98.361	16	12.977	81.106
	f1o04m	50	50	100.000	11	9.948	90.436
	f1o05m	55	55	100.000	11	11.008	99.927

- A group of 5 resting subjects suffering from sleep apnea (patient a01erm to patient b01erm);
- A group of 3 young subjects at rest watching the movie FANTASIA (patient f1y01m to patient f1y03m);
- A group of 3 elderly subjects at rest watching the film FANTASIA (patient f1o01m to patient f1o05m);

Table I shows in the case of patient f1o05m that a slow breathing corresponds to a low number of R peaks. Thus, the more the number of breathes increases, the more the rate of heartbeat also increases. Thus, heartbeat varies indeed according to breathing. In addition, the results obtained proves that the proposed algorithm in this paper, gives satisfactory results with good rates of recognition of the respiratory frequencies ranging between 80.9% and 99.979. Furthermore, a comparison with the reference [20] made in table II makes it possible to raise a clear improvement of 2.868%. Which confirms good performances of the new algorithm proposed in this paper. To have better appreciation, the performances of this algorithm are represented by the histograms in fig. 8,9, and 10.

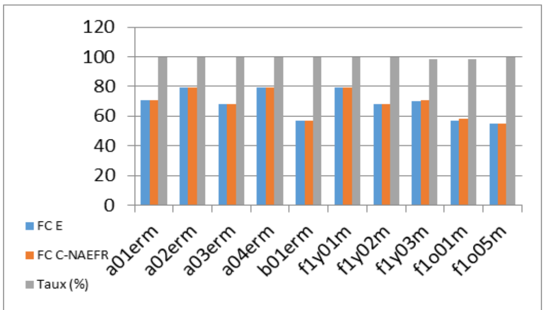

Fig. 8. Histogram of the performances of subject of Anea-ECG Database

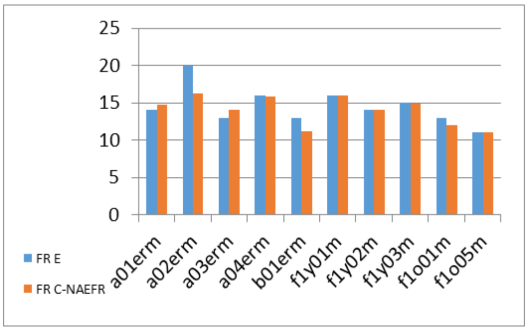

Fig. 9. Histogram of the performances of young subject of Fantasia Database

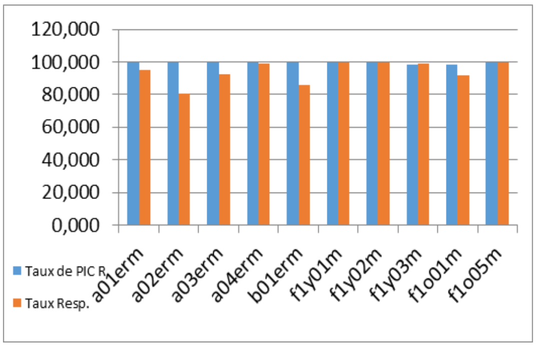

Fig. 10. Histogram of the performances of old subject of Fantasia Database

TABLE II. comparison of the proposed algorithm with [20]

	This paper	A. Zeghoudi [20]	Improvement ratio
Precision ration	94.398%	91.53%	2.868%
Error ratio	5.953%	8.47%	2.507%

Thus, the proposed algorithm gives the possibility of determining the respiratory periods, thus inspiration and expiration. These values will be used for the controlling of the experimental artificial respirator.

B. *Experimental Results*

The Proteus schematic of the experimental prototype is given in fig. 11. It is made up mainly of:

- Arduino Mega 2560 card;

- A LCD screen to plot the heart rates and respiration;
- An AD8232 ECG kit to acquire ECG signals;
- A balloon to reproduce the respiratory movements;
- A servo-motor of the type MG996R to control the balloon;

The realized prototype of artificial respiratory is given on fig. 12 with the elements cited above.

Table III presents the variations obtained between the times defined for the control and the times obtained really during the ordering of the artificial respirator. It is about the respiratory period, times of inspiration and expiration.

Table IV shows the rate of proximity between the instruction of order over the respiratory periods and the periods really obtained. One notes that the rate of minimal proximity is 99.973% and the maximum rate is 100 %, with an average of 99.987%. One finds there also the error observed over each respiratory period i.e. between the time of order wished and that obtained. One notes an average error of 0.013%.

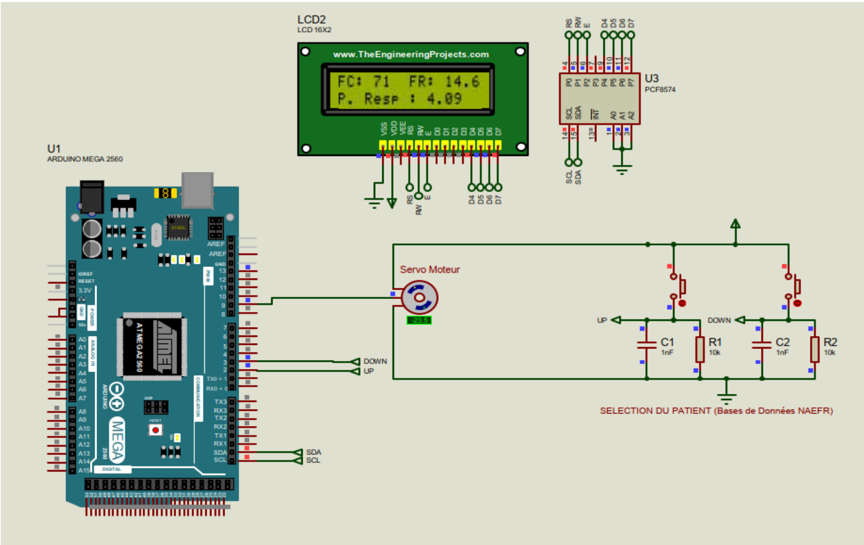

Fig. 11. Schématic diagram of artificial respiratory in Proteus

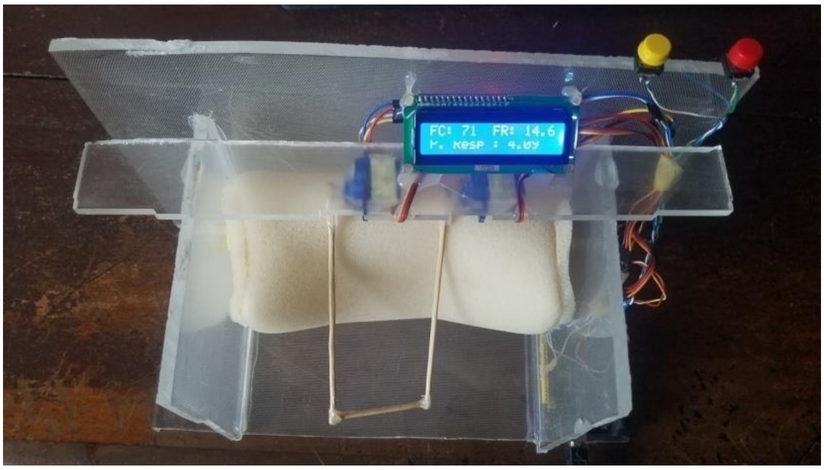
Fig. 12. Prototype of artificial respiratory

TABLE III. Experimental results synthetization

Subjects	Control respiratory period	Obtained respiratory period	Control inspiratory period	Obtained inspiratory period	Control expiratory period	Obtained expiratory period
a01erm	4.087	4.088	1.362	1.363	2.725	2.725
a02erm	3.708	3.708	1.236	1.236	2.472	2.472
a03erm	4.258	4.259	1.419	1.420	2.839	2.839
a04erm	3.780	3.780	1.260	1.260	2.520	2.520
b01erm	5.362	5.363	1.787	1.788	3.575	3.575
f1y01m	3.769	3.770	1.256	1.257	2.513	2.513
f1y02m	4.287	4.287	1.429	1.429	2.858	2.858
f1y03m	4.047	4.047	1.349	1.349	2.698	2.698
f1o01m	5.018	5.019	1.673	1.673	3.345	3.346

TABLE IV. Performances ratio of experimental results

Subjects	Respiratory period rate (%)	Respiratory period error (%)	Inspiratory period error (%)	Expiratory period error (%)
a01erm	99.976	0.024	0.049	0.012
a02erm	100.000	0.000	0.000	0.000
a03erm	99.977	0.023	0.047	0.012
a04erm	100.000	0.000	0.000	0.000
b01erm	99.981	0.019	0.037	0.009
f1y01m	99.973	0.027	0.053	0.013
f1y02m	100.000	0.000	0.000	0.000
f1y03m	100.000	0.000	0.000	0.000
f1o01m	99.980	0.020	0.020	0.020
Mean	99.983	0.017	0.033	0.008
Min	99.982	0.018	0.018	0.018
Max	99.987	0.013	0.023	0.008

For better appreciation the elements of the preceding tables, we presented them in the form of histogram in fig. 13, 14, and 15. Fig. 13 presents for each signal the periods defined by the algorithm to control artificial respiratory and the periods of real orders obtained during the operation of the respirator.

The histogram of fig. 14 appreciates the rate of proximity between the respiratory periods of definite order and the periods of order really obtained during the operation of the experimental respirator.

The histogram of fig. 15 appreciates the variation observed for each patient between the time of order wished and that obtained.

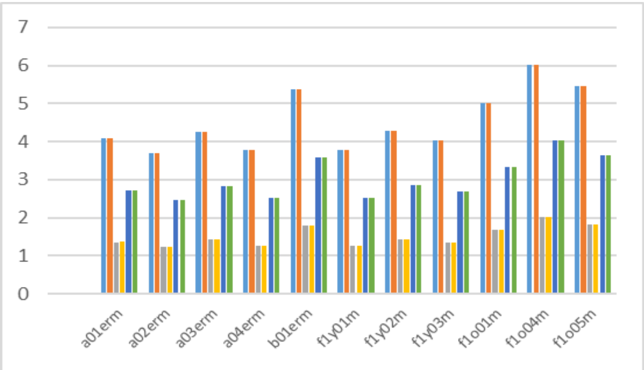

Fig. 13. Comparison between control and obtained period

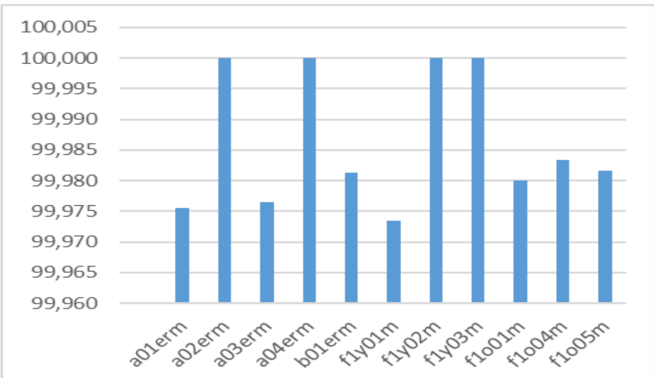

Fig. 14. Proximity rate of respiratory period

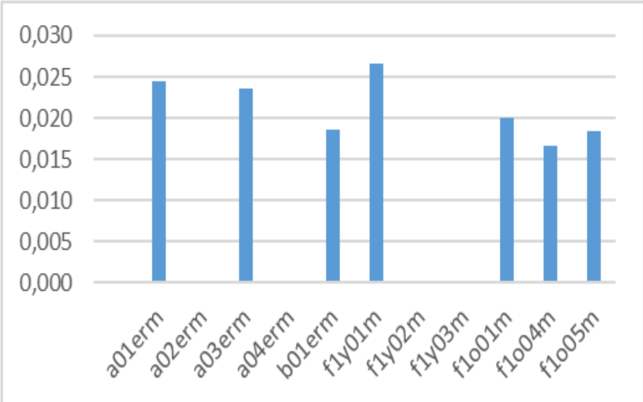

Fig. 15. Error between control and obtained period

IV. Conclusion

Ultimately, it was a question for us in this paper to design a new algorithm of extraction of the respiratory frequency from only ECG signal and apply it to control an artificial respirator. Thus, after processing of the acquired signal, the algorithm proposes to detect the R peaks of the QRS ECG signal complex and their time of appearance in the form of table. Thereafter, five successive peaks are retained each time for a respiratory cycle. The results of this simple new algorithm made it possible to control times of inspiration and expiration of the artificial respirator through a servo-motor. This method is particularly useful whenever the ECG is the only source of information available and could be used for real time control. The satisfactory results compared with certain references show a clear improvement. The respiratory rate is estimated by the proposed algorithm with an average precision of 94.398% for an average error of 5.602%. In addition, the control of the artificial respirator is carried out using Arduino Mega 2560 board with average rate of accuracy of 99.987% and an average error of 0.013%, which is satisfactory to admit that this control is in real time. However, these rates not being 100%, it would be significant to explore another type of processor such as the ESP32 OR FPGA to control the artificial respirator in real time with better accuracy.

References

[1] M. S. Chavan, R. A. Agarwala, M. D. Uplane, et M. S. Gaikwad, "Design of ECG instrumentation and implementation of digital filter for noise reduction ", *World Scientific and Engineering Academy and Society (WSEAS)*, vol. 1, pp. 47-50, 2004.

[2] G. B. Moody, R. G. Mark, A. Zoccola, et S. Mantero, “Derivation of respiratory signals from multi-lead ECGs”, *Computers in cardiology*, vol. 12, p. 113-116, 1985.
[3] L. Zhao, S. Reisman, et T. Findley, “Derivation of respiration from electrocardiogram during heart rate variability studies”, *IEEE*, 1994.
[4] D. Caggiano et S. Reisman, “Respiration derived from the electrocardiogram: a quantitative comparison of three different methods”, *Proceedings of the IEEE 22nd Annual Northeast Bioengineering Conference*, pp. 103-104, 1996.
[5] Z. B. Khaled et G. Farges, “First approach for respiratory monitoring by amplitude demodulation of the electrocardiogram”, *14th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, vol. 6, pp. 2535-2536.
[6] J. Felblinger et C. Boesch, “Amplitude demodulation of the electrocardiogram signal (ECG) for respiration monitoring and compensation during MR examinations”, *Magnetic Resonance in Medicine*, vol.38, no1, pp. 129-136, 1997.
[7] D. Dobromir et D. Ivan, “Two-electrode telemetric instrument for infant heart rate and apnea monitoring”, *Medical Engineering & Physics*, vol. 729–734, pp. 20, 1998.
[8] W. J. Yi et K. S. Park, “Derivation of respiration from ECG measured without subject’s awareness using wavelet transform*”, Proceedings of the Second Joint 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society, Engineering in Medicine and Biology*, vol.1, p. 130-131, 2002.
[9] J. Boyle, N. Bidargaddi, A. Sarela, et M. Karunanithi, “Automatic detection of respiration rate from ambulatory single-lead ECG”, *IEEE Transactions on Information Technology in Biomedicine*, vol. 13, no 6, pp. 890-896, 2009.
[10] R. Martinek, “Advanced Bioelectrical Signal Processing Methods: Past, Present and Future Approach—Part I: Cardiac Signals”, *Sensors*, vol. 21, no 15, pp. 5186, 2021.
[11] R. Bailón, L. Sornmo, et P. Laguna, “A robust method for ECG-based estimation of the respiratory frequency during stress testing”, *IEEE transactions on biomedical engineering*, vol. 53, no 7, pp. 1273-1285, 2006.
[12] S. Leanderson, P. Laguna, et L. Sörnmo, “Estimation of the respiratory frequency using spatial information in the VCG”, *Medical engineering & physics*, vol. 25, no 6, pp. 501-507, 2003.
[13] M. Varanini, “Adaptive filtering of ECG signal for deriving respiratory activity”, *Proceedings Computers in Cardiology*, pp. 621-624, 1990.
[14] C. Orphanidou, O. Brain, J. Feldmar, S. Khan, J. Price, et L. Tarassenko, “Spectral fusion for estimating respiratory rate from the ECG”, *9th International Conference on Information Technology and Applications in Biomedicine*, pp. 1-4, 2009.
[15] A. Bonjyotsna et S. Roy, “Correlation of drowsiness with electrocardiogram: A review”, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 3, no 5, pp. 9538-9544, 2014.
[16] Steve Ulriche Otam, E. R. Gamom Ngounou, Jean Mbihi, and Bertrand Moffo Lonla, “Design and Co-Simulation on FPGA Target of an ECG Signal Acquisition System Using Duty-Cycle Modulation and Derivative Filtering”, *International Journal of Innovation and Applied Studies*, Vol. 31 No.4, pp. 795-807, Jan. 2021.
[17] Otam stève Uriche, MOFFO LonLa Bertrand, GAMOM NGOUNOU E. R. Christian, MBIHI Jean, “A novel FPGA-Based Multi-Channel Signal Acquisition System Using Parallel Duty-Cycle Modulation and Application to Biologic Signals: Design and Simulation”. *Journal of Electrical Engineering, Electronics, Control and Computer Science*, volume 7, Issue 24, pp 13-20, 2021.
[18] Nitish v. Thakor, John g. Webster, and Willis j. Tompkins, “ Estimation of QRS Complex Power Spectra for Design of a QRS Filter”. *IEEE Transactions on Biomedical Engineering*, vol. 31, no. 11, November 1984.
[19] J.-C. Chatard, « Intérêt des mesures de fréquence cardiaque », Lutter contre le dopage en gérant la récupération physique, p. 97, 2003.
[20] A. Zeghoudi, O. Benali Medjahed, B. Saadi, et H. Zine-Eddine, “Algorithme d’extraction du rythme respiratoire (AERR) à partir des signaux ECG”, *Biomedical Engineering International Conference*, pp 1-7, October 2014.
[21] L. T. Nguefack, F. Pauné, et J. Mbihi, “Experimental study of ECG signal transmission system via a coaxial cable line using Duty-Cycle Modulation”, *Algerian Journal of Engineering and Technology*, vol. 4, pp. 1-6, 2021.

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