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Respiratory Rate Estimation using a Pressure Sensor Mattress

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cose per ringraziare

Contents

Abstract

Sleep is one of the most important physiological functions. Sleep quality can affect physical and mental wellness; for this reason, it is crucial to monitor vital signs without interfering with natural sleep. The state-of-the-art to monitor physiological data during sleep is cardio-respiratory polysomnography [**?**], which involves a cannula, chest belts and electrodes for ECG.

During sleep, a person cycles between two phases Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM); this second phase is further divided into three other stages (N1-N3). Different muscle tones, brain wave patterns, eye movements, and heart and breathing rate alterations characterise every phase and stage. [**explenation of sleep stages**]. Focusing on one of the vital signs that characterise the different sleep stages is the respiratory rate which slowly becomes more stable going from the awake to the REM phase. Respiration is also central in one of the most common sleep disorders, sleep apnea, in this case, the individuals experience a collapse of the airway in deeper sleep states, causing them to experience reduced time in stage N3 and REM sleep. The ability to monitor it allows for a faster and closer intervention in severe cases.

As said before, the state-of-art is a cumbersome device that requires cables attached to the users' bodies and often interferes with natural sleep. For this reason, we decided to use an unobtrusive sensor placed over the typical mattress to allow us to study the possibility of monitoring the patient's health. The sensor involved in this project is a pressure-sensor textile from SensingTex [x], with a sensor area of 192 x 94 cm filled with 1056 sensors (sensor area density of 4 sensors for 10cm^2).

The high number of sensors leads to the necessity of an algorithm to discriminate the ones from whom it is possible to extract valuable information about the respiratory rate of the person that is on the mattress. Many of these channels are with null or stationary information; others present just interference from the mattress itself. From just a few sensors, it is possible to retrieve a respiratory pattern and extract the respiratory rate per minute (rpm). To obtain them from all the possibilities, we have defined our confidence metric to assign each sensor a percentage of confidence that it will be a suitable sensor. [**parlare del somnomat**].

Since no data and polygraphs were available from the same person on the

SensingTex was necessary to collect new data, this gives us the possibility also to understand if this kind of Instrument could work with a lab project called Somnomat. A special rocking bed [**parlare del somnomat e di come potrebbe essere integrato**]. The protocol involved 6 participants (three female /three male) between 20-30 years of age. It was divided into two phases: one with the sensor mattress over a standard bed and the second on the rocking bed while this was moving. Each participant had a fixed set of positions that had to be while lying on the mattress. We also decide to insert variability into the data since, during sleep, respiratory rate increases in different stages. In order to do that, we ask a participant to perform a set of five jumps before lying down in the first phase of the protocol; for the second part, we ask them to turn around on the bed and stay on it while it is moving without performing any activity.

the data collection also involved Cardiorespiratory polysomnography. In our case, we use the nox a1 and noxturnal app. **chennal selected and canulas**

x—x

the data coming from the data collection was cleaned in this methods, than was used this approach to smoot or filtering the singal. than was use this to asset the number of breath

Chapter 1

Introduction

Chapter 2

Methods

2.1 Protocol:First Part

- 5 jumps
- lie down on **prone** position
- 5 jumps
- lie down on **left side** position
- 5 jumps
- lie down on **supine** position
- 5 jumps
- lie down on **right side** position

2.2 Data Collection Protocol

The aim of this protocol is to collect data with the two mattresses (SensigTex under the Sensomative) of different heart rates and breath rates. During this protocol will be asked to change positions to collect the data in all four positions: supine position, lateral right position, prone position, and lateral left position. Before data collection will also record what the sensors measure in case a participant is not on the mattress whether it is stationary or moving.

2.3 Experimental Setting

The experimental setting includes a bed above which two sensors will be positioned: SensingTex and Sensomative. The Sensomative has to be placed under the SensingTex Sensor and the sensor will be used simultaneously.

2.3.1 Mattress

The Sensomative Sensor gives the best result for detecting breath rate and heart rate when placed under the chest.[**investigate possible distance from the start of the mattress**] For this reason, should be placed exactly []cm from the top part of the mattress. Above this sensor, the SensingTex Sensor should be placed above this sensor because applying even pressure will not affect the measurements.

2.3.2 Pillow and bed sheets

2.3.3 Ground truth

The ground truth value for this data collection will be collected via polysomnography and video cameras. Polysomnography allows to recording this following parameters:

- Nasal flow and nasal pressure: that will be used as the ground truth for the breath rate.
- Chest and abdomen movement: that can be also used as ground truth for the breath rate, with different types of approaches. [**can also detect the heart rate o heart movement?**]
- SPO2 and Pulse with a fingertip: that will be the ground truth data for the heart rate
- { Raimon }

Along with Polysomnography will also be involved cameras to record the position of the participant for further analysis.

2.4 Patient setting

2.4.1 what to wear

The participant should wear comfortable clothes. T-shirts are recommended in order not to have a too high layer of fabric that could interfere with the detection of data, in particular with the heart bit detection.

2.4.2 Lay down position

There are four different positions that will be asked to

- Lateral left position
- Lateral right position
- Prone
- Supine

2.4.3 Pattern Position

One of this data collection's main points is finding peaks in different positions, so each patient will be asked to lay down in a different position pattern.

- supine position, lateral right position, prone position, and lateral left position
- lateral right position, prone position, lateral left position and supine position
- prone position, lateral left position, supine position and lateral right position
- lateral left position, supine position, lateral right position and prone position

Once a position pattern is given to a specific participant, it must be repeated for each step of the protocol.

2.4.4 how long they have to lay down

2.5 Data Collection

2.5.1 Joint Data Collection

Breathing rate and Heart rate at rest in normal condition

In this part of the protocol, the aim is to collect data on the breathing rate and heart rate of the participants at rest.

Breathing rate and Heart rate at rest during mattress movement

This part of the protocol aims to collect data on the participant's breathing rate and heart rate at rest while the mattress is moving.

Breathing rate and Heart rate after an effort

In this part of the protocol, the aim is to collect data on the participant's breathing rate and heart rate after an effort, to analyze data of an accelerated breath and heart bit and gradually decelerated. The effort consisted of ten jumping jacks repeated before each position change.

2.5.2 Heart Rate Data Collection

Heart rate at rest with constrained breath rate

This part of the protocol aims to provide a known rhythm to the breath rate according to an acoustic time. The sound will indicate when they start to inhale and exhale to the participants.

Heart rate at rest with constrained breath rate during mattress movement

This part of the protocol aims to provide a known rhythm to the breath rate according to an acoustic time while the mattress is moving. The sound will indicate when they start to inhale and exhale to the participants.

2.6 Words

Chapter 3

Data Analysis

Chapter 4

Result

4.1 Mean absolute error (MAE)

Mean Absolute Error MAE is the average absolute error between actual and predicted values. It is a measure of model accuracy given on the same scale as the prediction target, it can be seen as the average error that the model's prediction has in comparison with their corresponding actual targets.

4.2 Mean absolute percentage error (MAPE)

Mean Absolute Percentage Error (MAPE) is the mean of all absolute percentage errors between the predicted and actual values. MAPE can be interpreted as the inverse of model accuracy, but more specifically as the average percentage difference between predictions and their intended targets in the database.

4.3 Root Mean Square Error (RMSE)

Root Mean Squared Error (RMSE) is the square root of the mean squared error between the predicted and actual values. RMSE is a weighted measure of model accuracy given on the same scale as the prediction target. It can be interpreted as the average error that the model's predictions have in comparison with the actual, with extra weight added to larger prediction errors.

Abbreviations:

- SGf = Savitzky–Golay filter
- resp rate = data extracted from Noxtural
- toolbox = toolbox for analyzing respiratory recordings [1]

The study of the following papers was fundamental for the choice of metrics: [2] [3] [4]

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
12.8529	14.8438	12.8333	14.7353	13.485	14
12.0909	14	12.0909	14	13.1443	13
11.9167	15.125	11.9167	15.125	12.5154	13
13.3333	13.8333	13.4	13.8333	13.117	13
12.2857	14.4286	12.2857	14.4286	13.6077	14
12.5833	15.5	12.3077	15.5	13.8993	15
11.6	15	11.6	15	12.0681	15
9	11	9	11	11.4768	15
11.1667	14.3333	10.625	14.3333	12.1549	14
14.5	17	14.5	17	12.8028	13
14.3333	15	14.3333	15	12.3275	14
11.625	14.1667	11.625	14.1667	10.9785	11
13.125	15.125	13.125	15.125	11.8441	11
13.1111	14.7778	13.1111	14.7778	12.6438	10
13.3077	15	13.3077	15	11.5351	11
13.6667	14	13.6667	14	11.99	10
11.5	14.2222	11.5	14.2222	11.9868	10
11.4545	14.1667	11.2308	13.8571	11.7824	10

Table 4.1: Breath per minutes for each approach, result from Noxtural and toolbox - Back position still mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	1.2517	2.4000	1.3043	2.3806
RMSE tool	2.4481	2.9583	2.4960	2.9332
MAE resp	1.0796	2.1731	1.1422	2.1499
MAE tool	2.0256	2.4179	2.0633	2.3947
MAPE resp	8.7793	17.8104	9.2789	17.6198
MAPE tool	16.3648	21.3416	16.5938	21.1266

Table 4.2: Metrics to evaluate the participant in back position with still mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
14.1667	15.5	14.1667	15.5	10.7609	8
14.0667	16.1333	14.0667	16.1333	11.3077	6
13.5	15.3333	13.5	15.3333	13.1449	8
13.75	14.9474	13.75	14.9474	11.3366	8
12.9474	15.1	12.9474	15.1	12.7314	6
12.4615	15.6364	12.4615	15.6364	11.8892	9
12.6875	14.6923	12.6875	14.6923	11.42	9
13.5	15.2222	13.6364	15.2222	13.0092	10
14.6154	15.1667	14.6154	15.1667	13.2539	12
13.1429	14.6667	13.1429	14.6667	11.6391	11
14.375	15	14.375	15	12.2165	11
15.4286	14.75	15.4286	14.75	11.9216	12
14.6667	15	14.6667	15	11.3091	13
14.8182	14.625	14.8182	14.625	13.8905	12
14.5385	15.6154	14.5385	15.6154	11.3344	13
13.9091	15	13.9167	14.8182	11.4474	11
13.8824	15.1765	13.8824	15.1765	11.6675	11
13.8667	14.6154	13.8667	14.6154	13.4799	12

Table 4.3: Breath per minutes for each approach, result from Noxtural and toolbox - Back position moving mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	2.1340	3.2155	2.1365	3.2047
RMSE tool	4.2192	5.5405	4.2259	5.5334
MAE resp	1.8091	3.0234	1.8171	3.0133
MAE tool	3.7957	5.0100	3.8037	4.9999
MAPE resp	15.5385	25.7324	15.6004	25.6442
MAPE tool	44.4027	58.5849	44.4823	58.4931

Table 4.4: Metrics to evaluate the participant in back position with moving mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
13.375	14.6364	13.375	14.6364	11.2045	10
13.6667	15	13.6667	15	12.7397	11
14	16	13.5	15.25	13.0613	12
14.3571	14.2	14.3571	14.2	12.2669	12
14	19	14	19	12.1628	13
12.8	15	12.6667	14.5	13.6039	13
11.8	14.2222	11.8	14.2222	13.1398	13
14	15.6667	14	15.6667	11.5445	14
13.8333	14.7	13.8333	14.7	10.77	11
13.8889	15.8571	13.8889	15.8571	14.2216	12
13.0833	15.5556	13.0833	15.5556	13.1656	12
14.1111	16.5714	13.7	16.5714	12.9764	12
14.2	15	14.2	15	10.9055	13
13.25	15.125	13.25	15.125	13.2294	11
12.7692	15.7143	12.2857	15.5	12.8524	11
13.9167	15.2	13.6154	15.2	11.3824	13
13	14.6	13	14.6	13.5579	11
13	15.8889	13	15.8889	11.6069	12

Table 4.5: Breath per minutes for each approach, result from Noxtural and toolbox - Left position still mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	1.7158	3.2950	1.6774	3.2425
RMSE tool	1.8743	3.6582	1.7959	3.5879
MAE resp	1.3922	2.4545	1.3591	2.8934
MAE tool	1.6584	2.9748	1.5716	3.3596
MAPE resp	11.8278	24.62	11.5556	24.0041
MAPE tool	14.4565	29.3635	13.7188	28.6943

Table 4.6: Metrics to evaluate the participant in left position with still mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
13.6875	15.0625	13.6875	15.0625	13.6613	11
14.5294	15.5556	14.5294	15.5556	11.4545	8
14.5	15.8824	14.5	15.8824	12.3288	6
13.9444	16.1176	13.9444	16.1176	10.8865	7
14.0455	15.2083	14.0455	15.2083	11.4082	9
13.44	15.3214	13.4231	15.3103	12.2589	6
13.9091	15.4583	13.9091	15.4583	13.7093	8
14	15.4375	14	15.4375	12.7019	10
14.4	15.2353	14.4	15.2353	13.3305	12
14.5769	15.5556	14.5769	15.5556	13.7078	13
14.7	15.2143	14.7	15.2143	13.5674	14
14.8421	15.2	14.8421	15.1538	11.8694	15
14.85	15.5556	14.85	15.5556	13.4086	15
15.5	14.75	15.5	14.75	13.9781	15
13.6667	14.5	13.6667	14.5	12.4749	13
13.8571	15.25	13.8571	15.25	12.4049	13
13.375	14.625	13.7	14.7273	13.4108	12
13.75	14.2857	14.1667	14.3333	13.4716	14

Table 4.7: Breath per minutes for each approach, result from Noxtural and toolbox - Left position moving mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	1.7259	2.7236	1.7331	2.7232
RMSE tool	4.1782	5.2608	4.1829	5.2627
MAE resp	1.4229	2.4545	1.4592	2.4597
MAE tool	3.0939	4.0953	3.1063	4.1004
MAPE resp	11.6751	19.9605	11.9443	19.9959
MAPE tool	39.3516	50.7242	39.4533	50.7631

Table 4.8: Metrics to evaluate the participant in left position with moving mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
15.3	15.7	15.3	15.7	11.5949	14
14.8125	15.7333	14.8125	15.7333	11.1628	16
14.2	16.1	14.2	16.1	11.0005	16
14.8889	15.6667	14.8889	15.6667	10.4762	15
13.5	15.25	13.5	15.25	10.4723	15
13.8571	14.5714	13.8571	14.5714	9.5345	14
13.8571	15.5714	13.8571	15.5714	9.5467	13
14.3	15.875	14.3	15.875	13.5758	14
15	14	15	14	11.1779	14
13.9	14.375	13.9	14.375	9.5345	14
13.8667	14.4667	13.8667	14.4667	9.5841	15
13.8235	14.5	13.8235	14.5	11.8196	14
14.0714	14.2143	14.0714	14.2143	11.8153	10
13	13.9474	13	13.9474	9.5223	8
14.4828	15.037	14.4828	15.037	10.8508	8
14.3793	14.931	14.3793	14.931	10.8876	7
13.7	15.25	13.7	15.25	10.9705	7
14.1818	15.3333	14.1818	15.3333	11.237	6

Table 4.9: Breath per minutes for each approach, result from Noxtural and toolbox - Belly position still mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	3.4835	4.3281	3.4835	4.3281
RMSE tool	3.8127	4.3162	3.8127	4.3162
MAE resp	3.3532	4.2088	3.3532	4.2088
MAE tool	2.6347	2.8957	2.6347	2.8957
MAPE resp	31.914	39.9076	31.914	39.9076
MAPE tool	32.6041	36.5982	32.6041	36.5982

Table 4.10: Metrics to evaluate the participant in belly position with moving mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
14.6667	16	14.6667	16	12.6296	9
14.0455	15.3684	14.0455	15.3684	14.168	12
14.3478	15.6818	14.3478	15.6818	13.2588	13
14.381	15.5	14.3636	15.4286	13.8107	13
13.7143	15.8333	13.7143	15.8333	13.485	13
14	16	14	16	12.6052	14
16.1	16	16.1	16	11.0417	17
15.7647	15.7059	15.7647	15.7059	12.9088	17
14.7333	15.5333	14.7333	15.5333	13.0502	16
14.6	16.3333	14.6	16.3333	11.1723	17
14.3846	14.5625	14.3846	14.5625	14.6869	16
13.8889	15.5294	13.8889	15.5294	11.3484	13
13.7273	14.7273	13.7273	14.7273	13.0399	11
13.8235	14.7778	13.8235	14.7778	9.5487	10
13.6111	15.4444	13.6111	15.4444	11.7918	11
13.2667	14.9286	13.2667	14.9286	12.8182	8
12.9375	15.8333	12.9375	15.8333	9.5345	8
13.3	14.619	13.3	14.619	9.5416	13

Table 4.11: Breath per minutes for each approach, result from Noxtural and toolbox - Belly position moving mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	2.4778	3.6110	2.4775	3.6092
RMSE tool	2.7357	3.8447	2.7352	3.8422
MAE resp	1.9835	3.2326	1.9825	3.2286
MAE tool	2.1737	3.2326	2.1728	3.1687
MAPE resp	17.8949	28.5509	17.8879	28.5221
MAPE tool	20.8138	30.5337	20.8064	30.5032

Table 4.12: Metrics to evaluate the participant in belly position with moving mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
14.5714	16.1667	14.5714	16.1667	12.4771	17
14	17.75	14	17.75	13.0835	17
16.5	16.5	16.5	16.5	14.3858	17
14.7778	15.25	14.7778	15.25	12.7261	17
14.5	15.8333	14.5	15.8333	13.4867	17
13.9333	15	13.9333	15	12.9816	16
15	15.2353	15	15.2353	14.0566	15
13.7692	15.1667	13.7692	15.1667	12.038	16
14	15.5	14	15.5	11.4923	12
14.6	13	14.6	13	11.9625	10
15	13.3333	14.3333	13.5	11.0151	9
16.5	15.5	16.5	15.5	11.9016	10
14.5	14.3333	14.5	14.3333	11.4255	10
12.2857	13.8333	12.2857	13.8333	12.5227	7
12.8333	15.2	12.8333	15.2	11.5945	10
12.3333	14.0909	12.3333	14.0909	13.4141	8
12.3636	14.5	12.4783	14.4286	13.5282	11
13.4286	15.2308	12.875	15.2308	12.9839	11

Table 4.13: Breath per minutes for each approach, result from Noxtural and toolbox - Right position still mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	2.1572	2.7087	2.0877	2.7156
RMSE tool	3.5099	3.6341	3.4330	3.6416
MAE resp	1.8214	2.4638	1.7593	2.4691
MAE tool	3.0440	2.9772	2.9826	2.9825
MAPE resp	14.9336	19.9146	14.4066	19.9693
MAPE tool	28.9627	30.229	28.3295	30.2958

Table 4.14: Metrics to evaluate the participant in right position with still mattress

Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft	resp rate	toolbox
14.2273	15.8095	14.2273	15.8095	11.7955	10
13.625	15.2105	13.5294	15.1	11.9185	9
13.9524	15.5652	13.9524	15.5652	11.8639	8
15	15.8261	14.7826	15.8261	12.28	10
14.5652	15.6667	14.375	15.6667	12.0136	10
13.625	15.1176	13.625	15.1176	12.8838	10
14.4118	15.3571	14.4118	15.3571	11.5695	12
14.72	15	14.72	14.8696	12.8922	13
14.85	15.1176	14.85	15.1176	11.587	14
15	15.2857	15	15.2857	11.2449	14
15.2917	15.3333	15.28	15.3333	11.7082	15
15.5294	15.3684	15.5	15.35	13.9497	15
14.5625	15.6154	14.5294	15.4286	11.6145	16
14.8182	15.4286	14.8182	15.4286	13.9913	16
14.7333	15.2727	14.7333	15.2727	11.6172	16
14.8824	15.3	14.8824	15.3	13.3257	16
14.75	15.1667	14.75	15.1667	13.5179	16
15.0667	14.9231	15.0667	14.9286	13.5767	16

Table 4.15: Breath per minutes for each approach, result from Noxtural and toolbox - Right position moving mattress

	Binary SGf	binary Waveleft	weighed SGf	weighed Waveleft
RMSE resp	2.4083	3.1106	2.3763	3.0860
RMSE tool	2.9182	3.6785	2.8737	3.6656
MAE resp	2.2367	2.9452	2.2046	2.9208
MAE tool	2.3325	2.7195	2.3041	2.7152
MAPE resp	18.5442	24.4008	18.2803	24.1986
MAPE tool	22.0502	26.6562	21.761	26.5883

Table 4.16: Metrics to evaluate the participant in right position with moving mattress

Chapter 5

Conclusion and future discussin

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