Software Platform for Combined Analysis of Weather Data and Holter Monitoring Data

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***Abstract*—This paper presents the concept of computing software platform that allows for simultaneous analysis of weather and Holter signals. The first part of this paper describes the weather station and the software platform that is currently being developed. The second part of the article presents examples of preliminary analysis that can be performed using the software platform.**

***Index Terms*—ECG, Holter monitoring, weather influence on health, weather monitoring**

I. Introduction

SINCE ancient times, people have been looking for correlation between the state of health, mood and the weather or climate they are living in. Studies on this issue can be found in the works of Hippocrates (460-377 BC). Although this area of medicine is being researched for centuries, it is still an interesting field for further studies [4, 5].

One of the main problems concerning research in this area is the lack of properly constructed databases. Both the medical data and weather data are collected independently by separate research centers. Building a common database that combines both sources can prove to be a difficult task. The most important caveats are: the difficulties in medical and weather data synchronization; occasional monitoring of health status, and the lack of software that allows performing combined analysis.

One of the most important issues in this field is to determine the effect of weather and changes in weather on the human heart function. A very rich research material is provided by commonly used Holter monitor tests. A Holter monitor is a small, wearable device that records the heart rhythm for 24-48 hours during normal activity. 24-hour ECG recordings data can be a very good material to compare with meteorological data. ECGs are marked with the time stamp of the test but it should be noted that there is no guarantee as to the accuracy of the clock therefore minor discrepancies/differences of a few minutes between the indicated and actual time may occur. Within the project entitled *"Sudden Cardiac Death risk stratification based on functional assessment of autonomic nervous system with the use of Holter methods"* the authors are developing software platform for ECG signal analysis. The main goal of this project is the selection of high-risk patients [2]. The platform is aimed to support numerous types of Holter recorders made by different manufacturers (including formats available for authors: CardioPath and Reynolds). The software architecture is designed in a modular manner, allowing extending the platforms functionality with plug-in software without the necessity of rebuilding and modifying the main source code. As a result the platform will be a very convenient tool for performing a complex research and testing of various algorithms for ECG analysis. New algorithms for combined ECG signal and weather data processing seem to be an obvious extension of the platform. Since the authors have their own meteorological station (related to the monitoring of solar panels at DMCS), they have access to the necessary weather data. This article presents the concept of a weather module development and examples of the preliminary results obtained by its use.

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II. Weather Station Description

Weather station is located in the building of the Department of Microelectronics and Computer Science, Lodz University of Technology (Wólczańska 221/223, 90-924 Łódź, POLAND) and is installed on its roof (Fig. 1). The geographic coordinates of the station: 51° 44'46"N 19 ° 27' 20"E [1].

Field meteorological station LB-741 (Fig. 2) is designed for current control of many climate parameters. Absolute pressure measurement is performed using a barometer LB-716AP LAB-EL. Measurement of temperature and relative humidity is performed using a thermometer-hygrometer LAB-EL LB-710R model, designed for LB-719 cages. With the hermetic casing, a teflon filter and electronic circuits placed in silicon, it can be used in conditions of high humidity and significant dustiness.

Measurement of the horizontal component of the wind speed and direction is performed using the meter LB-746 LAB-EL. Its initial purpose for mounting on sea buoys makes it suitable for harsh conditions and highly resistant to corrosion. Measurement of solar radiation meter is performed with LB-900 LAB-EL, equipped with microprocessor-based

Figure 1. Field weather station related to the monitoring of solar panels in DMCS

Figure 2. LB-741 – field weather station

measuring system, and the external CM-21 pyranometer made by KIPP&ZONEN. Pyranometer relative measurement error depends on:

- temperature – over the range of -20 to 50 Celsius degrees the error does not exceed +/- 1%,
- angle of incidence of the light – the largest reaching 3% in the case of a large angle of incidence (the sun is just above the horizon).

Calibration is performed individually for each device and stored in non-volatile memory, and the measurement results are sent in digital form to the host (PC computer).

Weather data reading/collecting was performed every second and averaged for a period of one minute in order to avoid oscillations of the instantaneous measured values.

III. Description of the ECG Analysis System

Software platform will be implemented with the use of Java technology (plug-in architecture [3]), which will allow using is in any popular operating system. Platform functionality will be divided into following modules:

- Patient database;
- Signal acquisition - importing Holter recordings from various file formats;
- ECG signal segmentation and analysis;
- Statistical module;
- Weather module.

The main task of the weather module is to read data from weather station stored in CSV file format. Then the data can be averaged over a period of time (per minute, per hour or per day). Since medical records have a time stamp the platform can apply them to the relevant weather data and make combined analyses. The next part of this paper presents two combined analysis examples.

IV. Example 1 – Holter ECG Signal Analysis

The authors conducted a statistical analysis of data recorded with the use of the 24-hour Holter monitors in 2009 in the Wł. Biegański's hospital in patients living in and around Lodz. The database consisted of 568 registered 24-hour Holter ECG signals (434 patients were tested with the use of DMS CardioScan, and 134 with the use of Reynolds Medical). This study included all of the archived data available for the authors. Table I and Fig. 3 presents ECG data characteristics. Table II and Fig. 5 presents weather data characteristics.

At this stage of the project the software platform for ECG signal analysis has limited list of implemented analyses which are mainly related to the segmentation of the signal into individual heartbeats and assessment of the heartbeat correctness. Therefore the numbers of verified correlations have only preliminary character.

TABLE I.
ECG DATABASE FEATURES

Number of days with at least one ECG recording	293
Total time of ECG recordings	11946 h
Total time of properly recorded ECG	11799 h
Total time of possible heart rate disorders (arrhythmias)	1195 h
Total time of artifact occurrence in recorded ECG signals	147 h

The first available comparison is a combined analysis of averaged (per day or per hour) weather data and frequency/incidence (content) of possible heart rate disorders (arrhythmias) in patients ECG. This parameter is expressed as the ratio of time of possible heart rate disorders (bigemini ventricular and tachycardia) of the ECG to the total time of properly/correctly registered (after elimination of artifacts) ECG signal in all tests performed that day.

TABLE II.
WEATHER DATA REGISTRATIONS STATISTICS

	Temperature [°C]	Atmospheric pressure [hPa]	Wind speed [m/s]
min	-15.4	958.8	0.0
mean	9.5	990.7	1.25
max	33.1	1008.8	11.1
max change per day	18.4	21.7	11.1
mean change per day	7.9	5.6	5.7
max change per hour	8.8	3.7	11.1
mean change per hour	0.75	0.4	3.2

The second available comparison is a combined analysis of averaged weather data referred to the frequency of artifacts (noise) in the ECG waveform. The main reason that disrupts Holter analysis is the electrodes peel off, which may be related to the patient's skin condition and this in turn with the weather.

Statistical analysis showed no increased relation between incidence of arrhythmias or artifacts and the weather (Table III). In the case of artifacts the authors expected relation to a temperature. Fig. 4 shows an increase in the number of artifacts observed in the warmer months (from late April to mid-September) compared to other months. However in contradiction to this conclusion there is very large number of artifacts observed in the first half of February. It is reasonable to compare all the statistics in the following years.

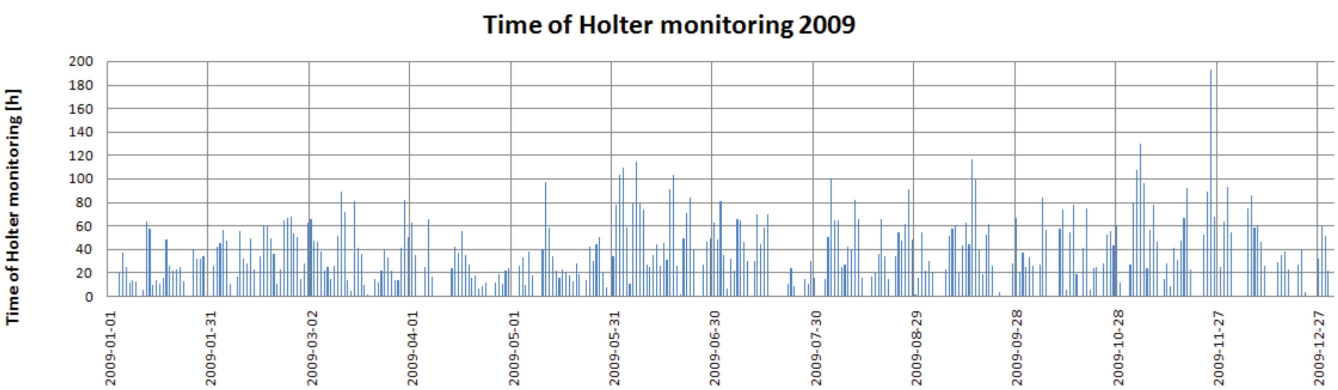

Figure 3. Total number of hours of Holter monitoring in Wł. Biegański's hospital in 2009

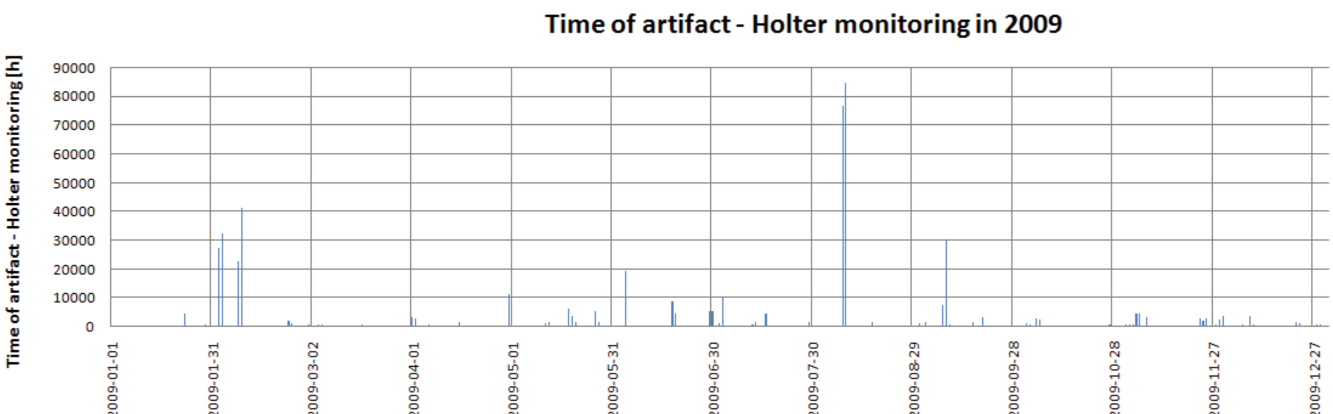

Figure 4. Total number of hours of artifacts observed in ECG in Wł. Biegański's hospital in 2009

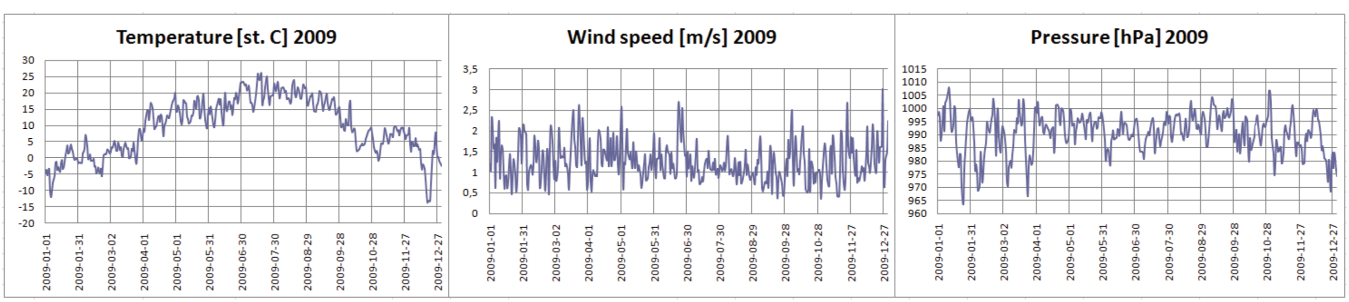

Figure 5. Weather data collected meteorology station of DMCS in 2009

TABLE III.
THE (R) CORRELATION BETWEEN WEATHER PARAMETERS AND ECG ANALYSIS

Parameter	Parameter averaged by day		Parameter averaged by hour	
	Correlation with content of heart rate disorders	Correlation with content of artifacts	Correlation with content of heart rate disorders	Correlation with content of artifacts
Temperature [°C]	-0.022	0.073	-0.001	0.054
Temperature change [°C]	0.027	0.001	0.001	0.002
Atmospheric pressure [hPa]	-0.079	0.002	-0.030	0.024
Atmospheric pressure change [hPa]	0.016	0.004	< 0.0001	0.001
Wind speed [m/s]	0.005	-0.041	0.070	0.016
Wind speed change [m/s]	-0.014	0.009	0.001	0.003

V. EXAMPLE 2 – BLOOD PRESSURE DATA ANALYSIS

The authors conducted a statistical analysis of data recorded with the use of the 24-hour blood pressure Holter monitors in 2009 and part of the year 2010 (from September to December 2010 weather data was not available) in the Wł. Biegański's hospital [6]. Table IV presents ECG and weather data characteristics.

TABLE IV.
ECG DATABASE FEATURES

Parameter	unit	min	mean	max
Patient's age	years	18	60.49	90
Systolic blood pressure	mmHg	66	119.17	210
Diastolic blood pressure	mmHg	29	66.89	163
Atmospheric pressure	hPa	958.9	990.32	1014.1
Temperature	^{O}C	-17.9	8.35	31.9

The database of patients which were tested with the use of blood pressure Holter monitors consists of 416 patients (mean age - 60.50 ± 14.54 years, women - 193). Systolic and diastolic blood pressure was measured at intervals of 15 minutes (30 minutes at night). Some patients were tested several times, hence the final number of 448 records.

In order to determine the correlation between patient's blood pressure and atmospheric pressure authors prepared a dedicated algorithm. It calculates average value of selected weather parameter of 5-minute period surrounding the point in time when the pressure measurement was performed. This method of calculation eliminates the lack of synchronization between the clock in Holter monitor and the weather station clock. But only if the time shifts between the clocks does not exceed 2-3 minutes.

Statistical analysis includes Pearson's correlation (r) between systolic blood pressure and atmospheric pressure. At first glance no statistically significant relationship is observed. However, further analysis shows that in the tested group large number of patients has a strong correlation between systolic blood pressure and the atmospheric pressure. It should be noted that sometimes the correlation is positive (systolic blood pressure increases with atmospheric pressure – Fig. 6) and sometimes negative (systolic blood pressure decreases with an increase of atmospheric pressure). Since for each patient relatively large measurement points were registered (60-70 measurements per day), and calculated correlations are characterized by narrow confidence intervals, it is unlikely to suspect a random relationship in this case. As a result of previous stage correlation analysis patients were divided into 5 groups (Table V).

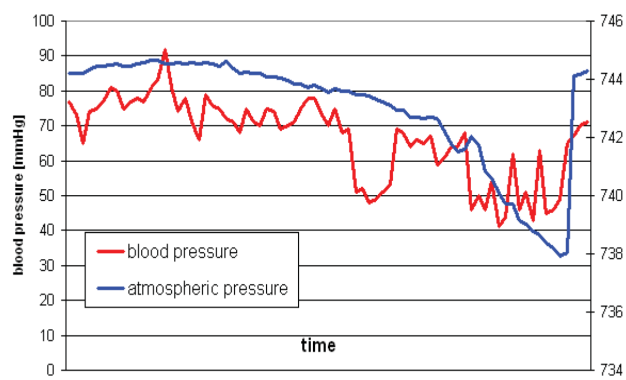

Figure 6. Positive correlation of atmospheric pressure with blood pressure

TABLE V.
GROUPS DUE TO THE CORRELATION BETWEEN SYSTOLIC BLOOD PRESSURE AND ATMOSPHERIC PRESSURE

Correlation group (r)	Number of tests	Number of tests for women	Mean age
> 0.4	53	20	59.5 ± 15.8
<0.2.0.4>	71	32	61.8 ± 15.7
<-0.2.0.2>	193	86	62.8 ± 12.8
<-0.4.-0.2>	74	35	59.3 ± 13.5
< -0.4	57	28	53.2 ± 15.9
All	448	201	60.5 ± 14.4

Such significant correlation seems to indicate a strong relationship of blood pressure in reference to weather conditions (similar observations as for atmospheric pressure could be observed for temperature). Further analysis shows however, that this correlation is random and is related to another factor. In general, the authors found that a stronger correlation has a young group of patients (Table VI). This conclusion leads to the next stage of analysis. Authors decided to study the relationship between weather and blood pressure in dipper - non dipper group of patients (Table VII).

TABLE VI.
GROUPS DUE TO THE AGE OF PATIENTS

Group	Number of tests	Number of tests for women	Mean age	|r|
¼	112	39	41.2 ± 9.5	0.32 ± 0.19
2/4	112	36	57.0 ± 2.6	0.26 ± 0.20
¾	112	58	65.8 ± 3.1	0.24 ± 0.16
4/4	112	68	77.8 ± 4.1	0.25 ± 0.18
All	448	201	60.5 ± 14.4	0.27 ± 0.18

TABLE VII.
GROUPS DUE TO THE AMBULATORY BLOOD PRESSURE MONITORING

Group	Number of tests	Number of tests for women	Mean age	|r|
Reverse Dipper	70	28	69.1 ± 10.2	0.24 ± 0.19
Non Dipper	199	89	61.3 ± 13.2	0.20 ± 0.14
Dipper	163	77	55.9 ± 15.7	0.35 ± 0.18
Extreme Dipper	16	7	58.2 ± 13.3	0.44 ± 0.21
All	448	201	60.5 ± 14.4	0.27 ± 0.18

The fact, that the strongest correlations were observed for the Extreme Dippers group of patients, suggests that the entire effect of the relationship between the weather and the blood pressure is a result of the common influence of the day – night rhythm on the weather and the systolic and diastolic blood pressure observed for some patients.

VI. CONCLUSIONS

This paper presents the computing platform enabling a combined analysis of weather data and medical data from Holter monitor. Platform capabilities are constantly expanded with additional algorithms. So far implemented algorithms do not determine the statistically significant relationships. However, a few general conclusions may be noticed. The time for which the weather data is averaged seems to have a significant impact on the observed correlations. Low sample resolution in a natural way disguises possible correlations. Increasing the resolution, however, is burdened with the problem of synchronization weather and medical data. Different types of arrhythmias are generally short-term phenomena, and thus require more precise weather data synchronization. In the case of historical data it is not possible to check and revise the dates. The authors plan to place an emphasis on the timing of currently built database within the project. So that weather and Holter data synchronization is no longer an issue.

The second example demonstrates another emerging problem in this type of research. The mutual influence of various factors on each other (weather on lifestyle, the day – night rhythm on the weather) may result as a correlation between the weather and the human heart work. This kind of data must be carefully verified.

In the near future authors are planning to improve the synchronization of weather and Holter data and increase the available number of ECG signal analyzes.

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