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MOBILE ECG AND SPO2 CHEST PAIN SUBJECTIVE INDICATORS OF PATIENT WITH GPS LOCATION IN SMART CITIES

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ABSTRACT

Subjective indicators of chest pain in this article describe a system based on devices for measuring ECG (Electrocardiogram) and SPO2 (Saturation of peripheral Oxygen) signals with PPG (Photoplethysmograph). The development system used for ECG detection signals is created in the SMT technology technique. Preparing for ECG (Electrocardiogram) signal analysis is realized on the coordinator side of the WSN (Wireless Sensor Network) node and LabView application interface. Existing model RPC-50E, as SPO2 detector is used for a measurement device. SPO2 performance upgrade was realized by installing hardware module XBee PRO S2B in the function of router-end device working mode. Except for ZigBee wireless transmission technology, it leaves a possibility to expand with Bluetooth module. The technical description is strictly related to the location of the patients using the GPS signal when it comes to undesirable measuring sizes of each decentralized measuring device. Possibilities to measure beats per second (bps) is also included in the measurement device for saturation of peripheral oxygen. Smart city integration is part of upgraded hardware which operates on the level of hospital cloud. With existing smart city infrastructure, it is easier to connect mobile IoT (Internet of Things) logger of ECG and SPO2 measurements. This article describes only the main reasons for chest pain. Acute and chronic chest pain is defined with ECG signal waveforms in certain cases. Measuring graphs are based on 12 measurement points that lead to the electrocardiogram device.

KEY WORDS

mobile ECG/SPO2, chest pain, WSN, GPS, smart cities

CLASSIFICATION

JEL: Q53, R41

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INTRODUCTION

Subjective indicators are usually related to electrolyte abnormalities of ECG. Abnormalities of the plasma levels of potassium, calcium, and magnesium affect the ECG, while changes do not affect the plasma sodium level. The T wave and QT interval (measured from the onset of the QRS complex to the end of the T wave) are most commonly affected. A low potassium level causes a T wave called U wave. A high potassium level causes peaked T waves with the disappearance of the ST segment. The QRS complex may be widened. The effects of abnormal magnesium levels are similar. Low plasma calcium level causes prolongation of the QT interval, and high plasma calcium level shortens it. Nonspecific changes are coherent also with the ST segment. T wave flattening or peaking with an unusually long or short QT interval may be due to electrolyte abnormalities, but many minor ST-T changes are nonspecific like NSTEMI.

Methods for measuring ECG signals are based on the n-numbers of leads. Increasing the number of leads, the quality of the signal as a reduction of outliers is proportional. Throughout this article is used 3-leads development measurement system, while the concept of an example method uses 6-12 leads [1]. Method with three leads represents two points of the measurement signals and the third point of reference potential [2]. Measurement method with 6-leads of measuring points is defined with abbreviation: I., II., III., VF., VR. and VL. The measuring method with 12-leads includes all the above-mentioned points with the addition of V1 to V6 abbreviations. Except for defined measuring points, it is important to know that specific summation of primary dislocated points on specific body area are an integral part of virtually treated signals like an LA (left arm), RA (right arm), LL (left leg) [2]. The measuring graph is defined with millimeter paper on which one millimeter represents 50 ms. Observing the inflection point of each QRS wave is defined with a 1s interval.

Presented case of the normal ECG signals with sinus rhythm and the QRS complexes; Figure 1 shows possibilities of minimal ST-segment depression in lead V5. The calculated time heart rate is 60 beats/min. A detail from Figure 1 is described in Figure 3 a) and represents a normal ST segment in lead V4. Example [2] of exercise-induced ST-segment depression is described on the same patient as in Figure 1 but now with ST-segment depression which slopes upwards, Figure 2. Detail from Figure 2 represents the suspicious change in lead V5 but without diagnostic of ischemia, Figure 3 b).

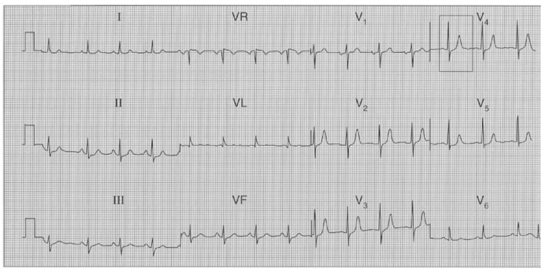


Figure 1. Normal ECG.

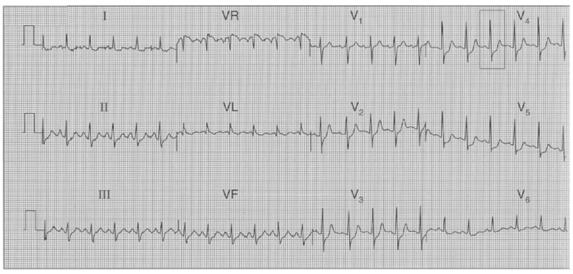
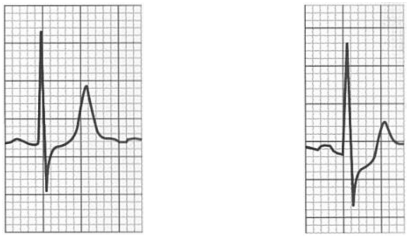


Figure 2. Exercise-induced ST segment depression.



a) b)

Figure 3. a) Normal ST segment in lead V4, b) Upward-sloping ST segment depression in lead V4.

MONITORING SYSTEM AND WIRELESS DATA DISTRIBUTION

The main concept idea of the prototype is to reassemble all available embedded devices from the biomedical-electronic area and summarize quality signals for the unique alarming system. The used device is developed break board for measuring ECG signal with 3-leads and SPO2 wired online monitoring device with beats/min. Extra display on the SPO2 device provides a recordable photoplethysmograph. Standard wired SPO2 is upgraded to ZigBee (XBee PRO S2B) and second wireless option cross Bluetooth [3, 4] wireless transmission media. A practical example (Figures 1, 2 and 3) shows better performance of measured signals because is used the 12-leads measuring system. A combination of 3-leads ECG wireless monitoring signals and upgradable SPO2 is a cost-effective solution for the alarming of dispatcher doctor, Figure 4. An alarming signal is mostly routed on the synchronization of ECG (ECG development board) and beats/min. which is integrated on SpO2. Except for monitoring these two sensors, the important measured value is PPG [5-9]. During the measurements, SPO2 system shows a graph with a specific function. Slope PPG function describes the alarming level of actuator operation. The main reference for alarming dispatcher doctor and activation of GPS circuitry for the location of the patient is the PPG slope function. A large function slope means that oxygen content is decreased and patient health is in danger. GPS location of a patient with the developed device set with mobile ECG and SPO2 cross ZigBee and Bluetooth wireless technology is presented thought block diagram of monitoring infrastructure in Figure 4. The data storage solution is a standard cloud or device cloud with an embedded distributed coordinator system [2, 10-12]. With this scenario, intranet and internet access for dispatcher doctor is available and configurable.

The data transmitting range is limited on distance of ZigBee and Bluetooth devices which is 300-1600 m, theoretically. Hospital areas can be interpreted as a wide working area of wireless embedded devices with cost-effective energy consumption properties. Bluetooth networking, in this case, should be used for small clinical areas and designed to work in ad/hoc mode. Depending on the network topology, ZigBee with a small speed rate at maximal 250 kbps satisfies requirements for data transmission. These networks can work in router/end-device mode. Network media access itself is extensible in comparison to the number

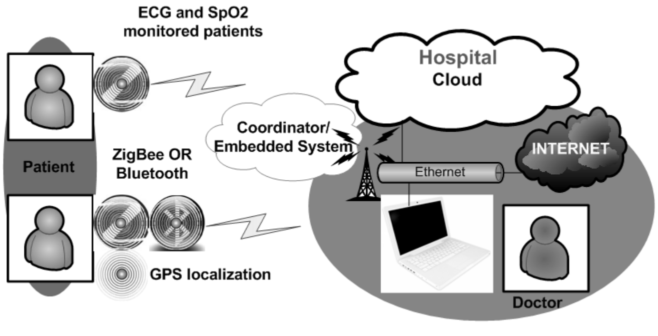


Figure 4. System monitoring infrastructure.

of wireless nodes. Locally, in hospital areas, it can be created a low latency network with even higher density coverage of ZigBee coordinators. Such a priority mode in subnetwork can bring this alarming status of the patient to a higher level of interaction. A hospital cloud system can be always separated later on when a patient is under observation. That means that IoT measuring device ID is just migrating from hospital to smart cities network. The application layer stays the same while the transportation layer is changing in a way of different "room". Since the SPO2 measuring device has significantly bigger power consumption it is considered to use sequences of measurements while patients are in smart cities environment.

MOBILE ECG AND SPO2 (OXIMETER) DEVICES

Mobile ECG is created on a development board with a long-range ZigBee module, Figure 5 [13]. The same wireless module is used for SPO2 device and data content is transmitted through the serial port interface. RS232 port on the ZigBee module for ECG is used for GPS NMEA protocol. Measurements of the ECG curve and QRS complex are realized through the ADC input of the module. Multiplication of ADC and serial data was processed in the Freescale processor on the XBee PRO module. Coordinator module with parsing data deploys vector "raw" information to the hospital database cloud. Active electronic is designed to work on 3,3 V, the same voltage level as a module. With the same voltage level for power supply of filter and amplifier chipset, the developed set is compatible device unit. Instrumentation amplifier AD623 can operate on a single supply voltage. Reference voltage for other circuitry is provided by 1,2 V from the MAX6120 chip. Integrated series parts of filters are OpAmps OPA237 which work on the voltage level of 1,2 V. The small dimension of the developer board is possible to put in the box with battery power supply and lead connectors. To gain a higher range it's possible to use embedded XBee PRO S2B module with RPSMA connector. Bluetooth integration necessary requires the implementation of a pre-programmed microcontroller with quality ADC conversion and serial channel. A graphical interface is created in the LabView development software tool. Programming in a graphical block diagram is represented in Figure 6. The existing solution of data collection is created for XBee Series 2, while in this case is adapted for formatting data string and fragmentation of packet for XBee PRO S2B.

A measured variable in the block diagram is multiplied with a reference voltage (3,3 V) and divided with 1023 because the ADC of the module is 10bit level distribution. Local analytics is manifested through a graphical interface compiled from LabView front panel, Figure 7. Data extension from Coordinator/Embedded System to local or external cloud services is realized with LabView Network Tools kit, Figure 4. The existing library for a specific protocol (TCP/IP, UDP, etc.) is integrated into the kit module with covered standardization. ZigBee module has RS232 interface and with GPS receiver NMEA protocol is received on

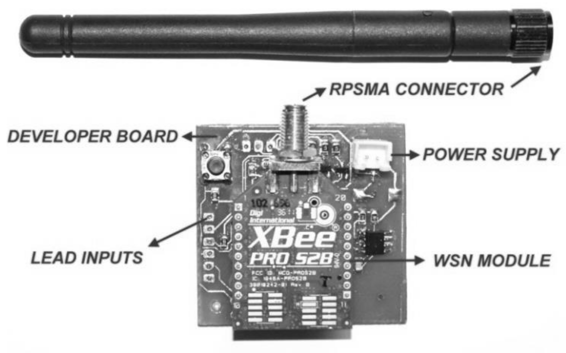


Figure 5. ECG developer board [13].

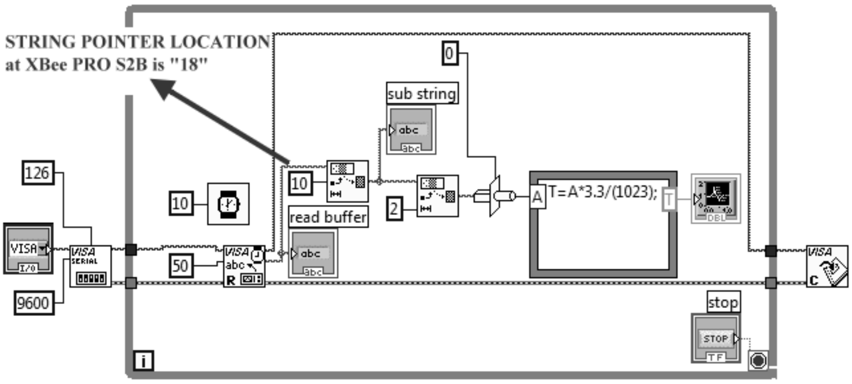


Figure 6. Adaptation of "G" code in block diagram for XBee PRO S2B module [13].

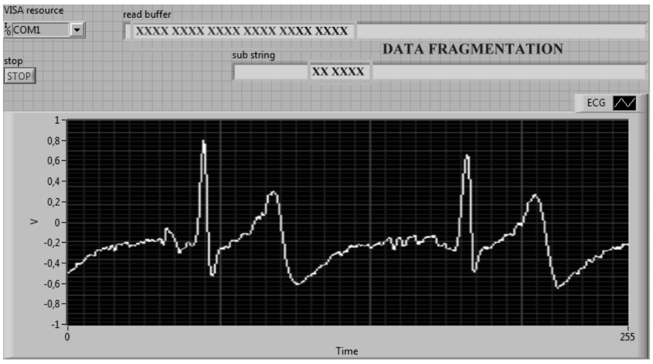


Figure 7. ECG local logging application (front panel) [13].

the same transmission media channel. In this case, is used another "G" code in LabView with alarm manifests. This kind of interrupt On_Serial_Rx activates remotely dislocated browser with GoogleMaps and displays patient location. Thus, in a very quick way is possible to locate and ensure patients with a supposed diagnosis of chest pain.

Pulse oximetry is known as a non-invasive method for monitoring the level of oxygen in the blood. SPO2 measurements are based on successively skin illuminated red and infrared light beams. During skin exposure to modulated frequency of red and infrared light density of oxygen is represented like varying variables [14-16]. The wavelength of the light sources used for the measurement of the SPO2 and PPG is 660 nm and 890 nm. For filtering artifacts and elimination of the hand movement drift on measured signal its used passive filter for elimination of unwanted harmonics and offset reduction. Oximetry is usually intended for measurement on a specific point on the body area. Such an area of points is with many blood circulation in the capillaries like earlap or finger [16, 17].

Purchased SPO2 has later added, integrated Kalman filter and therefore, there was no need for integration and installation of additional electronic or software filters, Figure 8. Kalman filter is used for the quality resolution of data [18]. Utilization is focused on the measurements of a very rapid heart rate where the beats/min. is high. Such cases are in newborns children up to 5 months because they have a high beat rate per minute [19]. An average number of beats/min at newborns children is from 90 to 140 beats/min, while at middle-aged persons is from 60 to 90 beats/min. Oxygen saturation (SPO2) is defined as the ratio of oxyhemoglobin to the total concentration of hemoglobin present in the blood [20]. Also, PPG is a very important value for normal heart rate function detection [7, 8, 21-25]. PPG is part of the complete image of the patient which covers relationships among PPG, PVC (Premature Ventricular Contraction), BP (Blood Pressure), and ECG [26, 27]. Exposition to an irregular operation usually is caused by a rough measurement error like low blood perfusion, dirty sensors or LED lights and improperly position on the oximeter. A frequent reason for the error is the movement of the body parts known as an artifact. Detection of week heart signal in the PPG graph is the main reason for alarming as a long artifact disposes of. Except for long exposure to artifact influence, the system is sensitive on continuous week signal. Measured PPG is relevant data for alarm activation and GPS sending data for the location of patients when health is in danger. If SPO2 percentage or ratio of oxyhemoglobin in a total concentration of hemoglobin in blood is less then manually set up value (default is 85), an internal alarm on a device is activated. This information can alert the patient and detect health status half an hour before the occurrence in the case of a heart attack or cardiac arrest.

A pulse oximeter (SPO2) with PPG for logging data using USB adapter cable for communication with PC. The oximeter device, in this case, is not a USB host controller then just standard "slave" device and because of this adapter is necessary for bridging data. The default adapter is designed on the base of C51 (8051) architecture and works on the principle of the virtual serial port. Usually used the chips for this purpose are PL2303 and FTD232, while FTD232 has better hardware properties in operation. The main difference between default adapter and mentioned adapters is protocol integration in preprogrammed C51 microcontroller. USB mini B connector on the oximeter device is not a hardware compatible pinout for USB. Power supply line (5 V and GND) are compatible with USB mini B connector, while default D+ and D– pin is repurposed to 3,3 V TX and RX communication lines. Addon and communication configuration is realized by bringing the standard vector "raw" data of asynchronous serial packets. In this way parsing of data is done on the Coordinator/Embedded System side and its ready for deployment to cloud. Wireless transmission media is also XBee PRO S2B module with a serial channel. These two channels can be separated with an ECG device or these two devices can use serial multiplexers on single transmission media which means a shared transportation layer.

From a technical perspective to medical calculations hemoglobin molecule can carry a maximum of four oxygen molecules. Thousand hemoglobin molecules can carry a maximum of 4 000 oxygen molecules; if they together were carrying 3 600 oxygen molecules, then the oxygen saturation level would be $(3920/4000)\cdot 100 = 98\%$, Figure 8 [27]. The standard value of SPO2 at a normal heart rate is from 95 to 99%.

Application for measurement and local data storage is used for serial protocol understanding and creation of packet parser. Real-time measurements are available on default installed application with all three parameters, Figure 9. Offline analytics is available in the review application, Figure 10. Logging data on local data storage is editable by any statistic program. During measurement application can create simultaneous three files; *.spo and two *.csv. Extension *.spo is for review application, while *.csv represent format; SPO2, "PULSE" (e.g. 98, "66"). Separated *.csv file content of single value in the time domain, PPG Figure 11.

The recorded scenario shown in Figure 9 and Figure 10 represents two periods of high interrupt pulse rate. This scenario is accompanied by a change of SPO2 value as artifacts in the PPG graph. Normalized PPG graph in periods without interrupts symmetrically follow standardized function curve Figure 11. Ordinate values distribution shows scaled AC on offset area and represent curve characteristic on finger measurement. Different curve characteristics of function are defined with other parts of measurement points on the body [17, 28].

SUBJECTIVE INDICATORS OF CHEST PAIN BASED ON MEASURED SIGNALS

Measured signals, such as the ECG system with 3-leads and accompanied by the early mentioned scenarios with 6-12 lead is a sufficient indicator of the irregularity of heart function. Measurement examples with normal ECG waveform or curve and QRS wave in leads

Figure 8. SPO2 (Pulse Oximeter) with PPG.

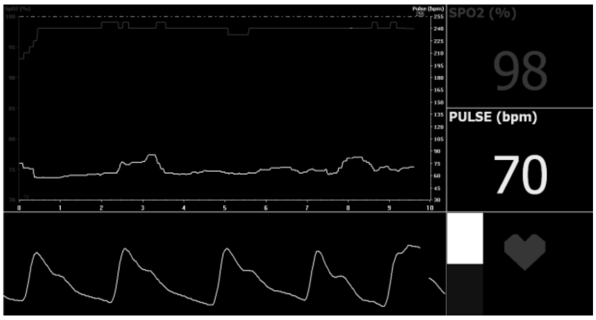


Figure 9. Application view of SPO2, pulse rate and PPG.

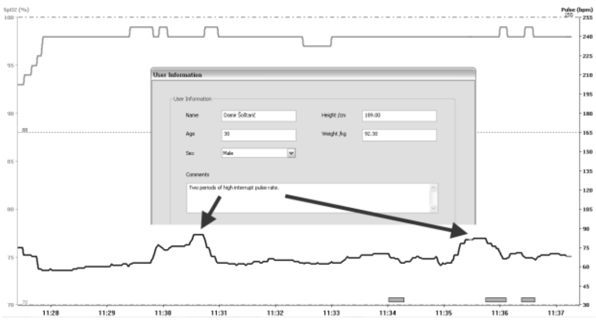
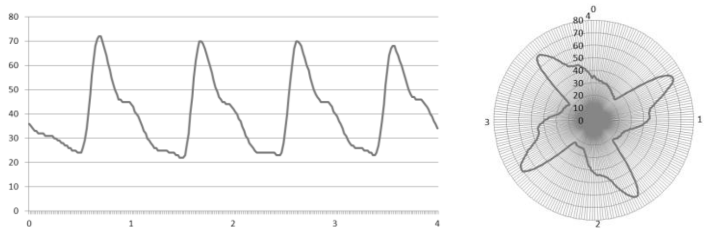


Figure 10. SPO2 and pulse rate.



a) b)

Figure 11. PPG a) standard, and b) polar view.

define very small irregularities in heartbeat. Embedded developed ECG board with three leads is created for sending of an alarm signal. Such a system meets the standards in wireless aspects on the highlighted cost-effective solution. Based on a variety of biological functions, system detection is focused on artifacts elimination of irregularities and achieve better performances of the device. Upgraded oximeter on wireless media has three basic measurements, SPO2 (%), pulse heart rate (bpm) and PPG. A combination of all four signals and synchronization of databases in the hospital cloud system can alert a doctor on duty. Except for four basic data signals, the doctor receives a sequence of NMEA protocol from GPS and it's capable to locate a patient on Google Maps in a few seconds. Subjective indicator of chest pain is precisely defined with the basic four embedded signals of which primary ECG signal can be predicted half an hour before the patient could have a heart attack.

CHEST PAIN HISTORY AND EXAMINATION

There are many causes of chest pain. All the non-cardiac conditions can mimic a myocardial infarction, and so the ECG can be extremely useful when we making a diagnosis. ECG is less important than the history and physical examination because ECG can be normal in the first few hours of myocardial infarction, Figure 12 [1, 29-31]. Details from Figure 12 are enlarged in Figure 13. At first glance it seems that everything is ok; sinus rhythm, normal axis, normal QRS complex, ST probably normal, but T wave in lead III. and flattened T wave in lead VF are indicators of small irregularity.

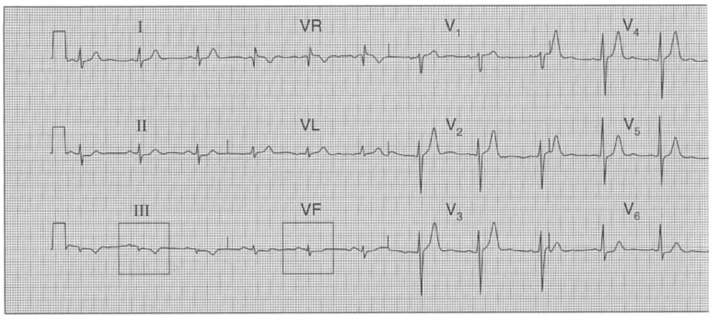


Figure 12. Nonspecific ST segment/T wave changes.

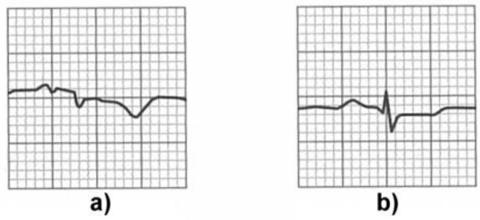


Figure 13. a) Inverted T wave in lead III, b) Flattened T wave in lead VF.

Chest pain can be divided into acute and chronic. Acute chest pain features are divided on; myocardial infarction, pulmonary embolism, other lung diseases, pericardial pain, aortic dissection, esophageal rupture, spinal pain, and shingles. Chronic chest pain usually is intermingling with angina. The main marker of insulation is a commonly middle-age person. This pain is called *atypical chest pain* with an implication of cardiac ischemia but symptoms are atypical. History indices of angina diagnosis are that the pain is; predictable, induced by emotional stress, relieved by rest.

GPS LOCATION OF THE PATIENT AS A PART OF SMART CITY GRID

The location of the patient has been realized with a GPS receiver; “ublox LEA6S” which is compact size, Figure 14. The main advantage is low power consumption and a very fast start. With active GPS and antenna integration, generally is a reduced area for installation in a small box with other monitoring devices. High receive sensitivity enabling us for more satellites and higher precision. The embedded GPS device has a USB connection and an RS232 serial port. NMEA protocol transmitted data with a serial channel is forwarded on Freescale microcontroller in raw format. Accepted data are sent directly to the ZigBee wireless transmission medium on the transport layer. For indoor localizing systems, indoor localization can be done with RSSI signal component of the XBee module [32-35]. The outdoor principle was designed for near-field or short-range of hospital surroundings. Except for hospitals, this system is designed also for home use where user can be connected and registered at home while using private network connection or smart cities infrastructure. When a device is used locally at-home patient has to have a special attached router/gateway on a home network.

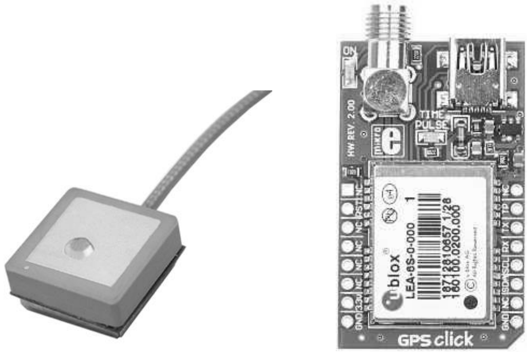


Figure 14. Module of GPS active antenna and receiver.

CONCLUSION

Subjective indicators of chest pain are based on observed measured signals. With only one measured parameter it is possible to detect irregularities of heart rate or to predict a heart attack. The primary measured ECG signal allows us to alarm the doctor if it comes to irregular QRS complexes or ECG waveform. Except for this set of integrated embedded wireless devices for future work on monitoring is considered blood pressure. Measurement of blood pressure with the differential method using interference of two or more light sources is considered. Instead of 3-leads, future work is focused on 6-12 leads based on the Android/iOS platform of an embedded system with ADC multiplication of channels. Such an application is considered to work under a "room" environment where the application level is defined priority. With IoT "room" declaration, ID should be registered on a specific infrastructure, e.g., hospital, home or directly on smart cities. Depending on the case scenario of network infrastructure, future work is to use blockchain technology with different blockchains for each case of infrastructure. In that case, a cloud system can be eliminated because all data are safe and forever written in the chain [36].

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