THE FUTURE OF ELECTROCARDIOGRAPH TELEMETRY SYSTEMS

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ABSTRACT

The Electrocardiograph (EKG or ECG) measures electrical changes of tissue surrounding the heart to create a time-based representation of the physical operation of the heart. The purpose of this paper is to explore the future of ECG telemetry systems and how they are used in health care. The initial goal is to develop an inexpensive, efficient, and robust real-time ECG telemetry system. The future goal is to create a wireless network of miniature body sensors capable of measuring ECG data and other vital signs.

KEYWORDS

Wireless Electrocardiogram, Wireless Electrocardiograph, EKG, ECG, Medical Telemetry, and Medical Instrumentation.

INTRODUCTION

Chambers in the heart, the atria and ventricles, contract in a specific method, pumping blood through the body. The rate, order, and rhythm of these contractions are extremely important to insure proper blood flow. Normally, the heart's internal electrical system initializes depolarization of the myocardial cells causing physical contraction.

These cells are polarized, their interior has a negative charge and the outside a positive charge, in their resting state and when stimulated electrically they depolarize and contract. Depolarization consists of the negatively charged interior of a myocardial cell becoming positive, causing the cell to contract. After the initial electrical stimulus of one myocardial cell the depolarization spreads concentrically from one cell to another. This depolarization process can be viewed as a positive electrical wave passing through the heart tissue, resulting in a progressive contraction of the myocardial cells. After the depolarization wave passes and the heart is contracted the myocardial cells must recover electrically or repolarize. During repolarization, which is a purely electrical process, the myocardial cell interiors return to the resting negative charge state.

One cycle of the heart consists of depolarization of the left and right atrium, depolarization of the left and right ventricles, and repolarization of the atria and ventricles. The process begins in the posterior wall of the right atrium at the Sinoatrial

(SA) Node, which initiates the wave of depolarization that spreads through both atria and results in a wave of atrial contraction. As the positive wave of contraction approaches the ventricles it reaches the Atrio-ventricular (AV) Node. It takes about 1/10 second for this wave to stimulate the AV Node, which allows time for blood leaving the contracting atria to pass through the AV valves into the ventricles. After the AV Node is stimulated it passes the electrical wave down the AV bundle, and to the left and right bundle branches. The left and right ventricle branches end in fine Purkinje fibers that pass the stimulus to the ventricle myocardial cells. This causes them to depolarize and contract. While the ventricles are depolarizing the atria are repolarizing. Finally, the ventricles repolarize and the cycle repeats when initiated again by the S A Node.
(Figure 1.) [3], [8]

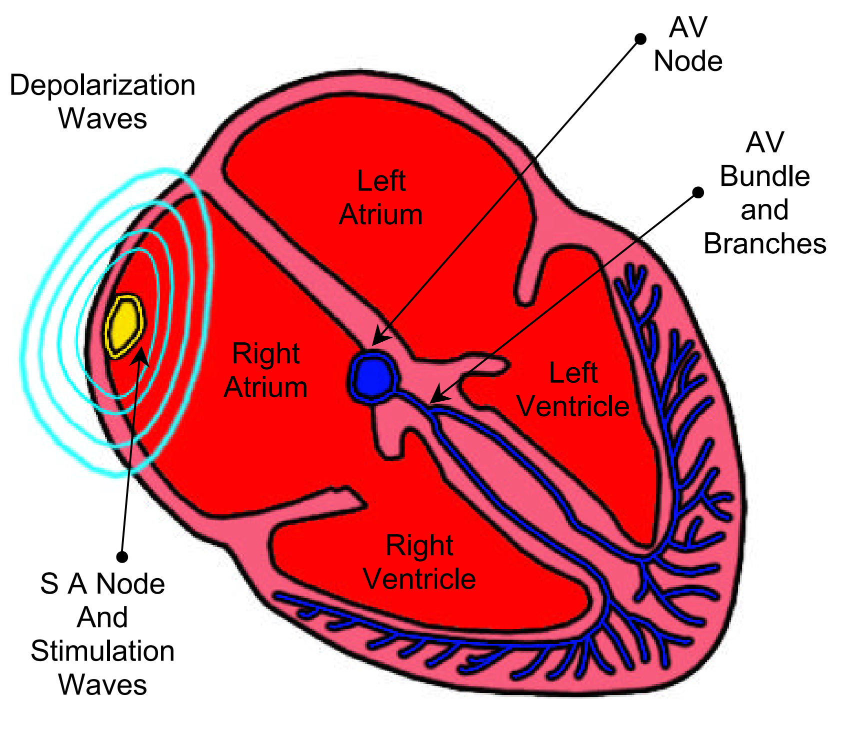

Figure 1. Heart Cross-section

ECG OPERATION

The basic principle of the ECG is that as the myocardial cells depolarize the resulting wave of current can be measured as it passes though the heart and surrounding tissue. By placing an electrode on the skin near the heart and another at a distance away from the heart the current wave can be measured as an induced voltage on the skin. This pair of electrodes is called a “lead” and consists of a positive electrode and a negative or reference electrode. Also, a third electrode placed away from the other electrodes provides a measurement reference. The positive and negative areas of an ECG represent a positive wave of voltage traveling towards or away, from the positive electrode. [3], [8]

The general physical cycle of the heart is represented graphically on an ECG by the P-wave, QRS complex, and T-wave. The P-wave represents the wave of contraction in both atria. The QRS complex represents the depolarization of the ventricles, specifically the electrical impulse travelling from the AV Node, to the Purkinje fibers, and finally to the ventricle myocardial cells. During the QRS complex the atria repolarize, but this is visually unnoticeable. The T-wave represents the repolarization of the ventricles. (Figure 2.) [3], [8]

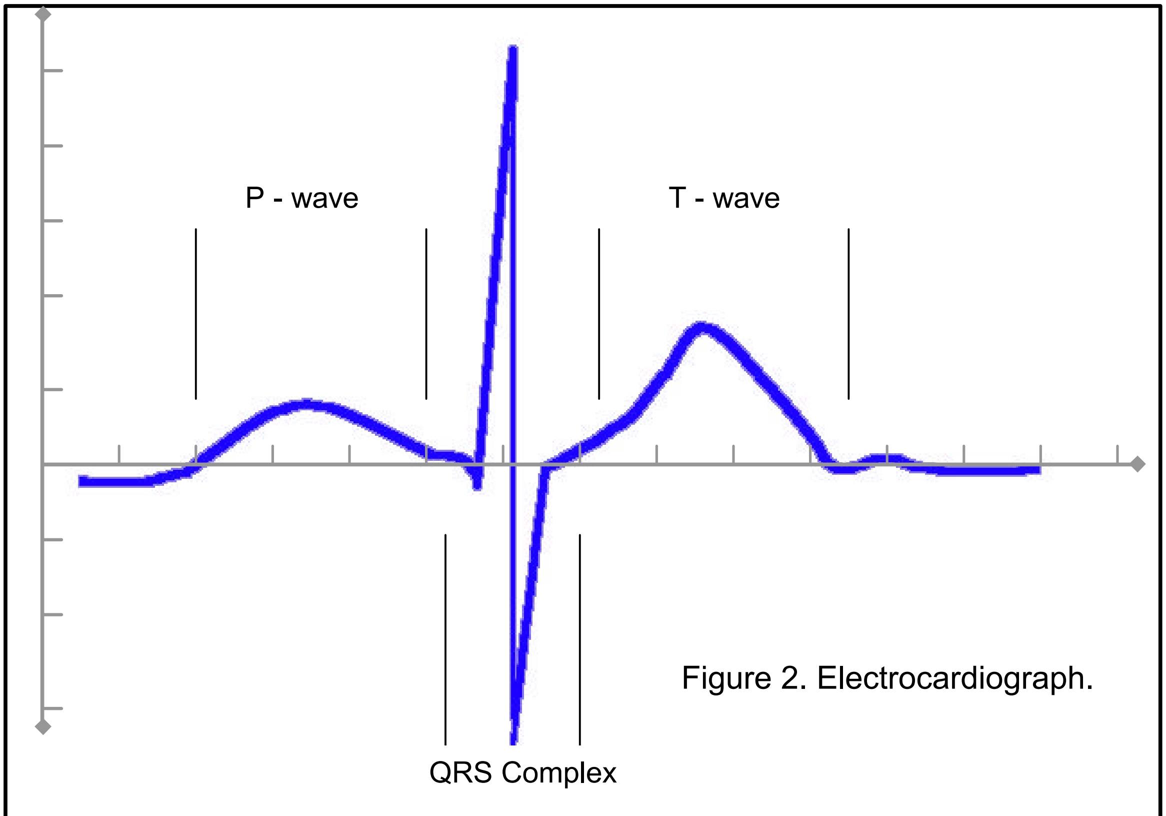

Figure 2. Electrocardiograph.

A standard diagnosis ECG consists of 12 leads; six limb leads and six chest leads. The six limb leads (I, II, III, AVR, AVL, and AVF) are placed on the arms and legs and form six intersecting lines that create a plane on the chest called the frontal plane. The six chest leads (V_1, V_2, V_3, V_4, V_5, and V_6) are placed across the left chest area over the heart and form six intersecting lines horizontally through the chest from front to back. This is known as the horizontal plane. Each of the 12 leads represents a view of the same electrical activity, but from a different position or view. The electrical function of the heart is seen through analysis of these different electrical views. [3], [8]

It is common to use a less complex 1-lead or 3-lead ECG device when the detail of a 12-lead system is not needed. For example: When a patient does not show any ischemia, (lack of blood flow) during a resting 12-lead ECG, but still has other symptoms, like rhythmic anomalies, it is often desired to monitor the heart activity in everyday life conditions. This allows the correlation of ECG data with other physical signs of heart malfunction, like dizziness, fatigue, or loss of breath. A Holter device is normally used in this application and is discussed later.

CURRENT ECG TECHNOLOGY

With the increase in computer processing power and availability, ECG technology has progressed far in the last 20 years. ECG data is now recorded and displayed digitally, opposed to analog strip charts, and with intelligent analysis software, many heart conditions can be discovered automatically. Many ECG systems still consist of a traditional “wired” set of leads attached to a central display and analysis unit.

Wireless ECG systems have been around since the 1960s, but until recently were merely portable ECG data storage devices. The original and most widely used ECG storage device is the Ambulatory or Holter ECG. As mentioned previously, when a 12-lead hospital based ECG does not display the needed data or data is required for extended periods of time a Holter ECG is used. The Holter ECG consists of 3-leads placed on the chest area wired to a small storage unit worn on the waist. This is normally used to record 24 hours of ECG data at about 256 samples per second. After the data is recorded the unit is physically returned to the physician for analysis. This method of ECG monitoring is very useful, but it is purely passive. If a serious heart condition, an evolving Myocardial Inclusion (eminent heart attack), were recorded it would not be discovered until the data was reviewed, possibly 24 hours later. Some newer Holter devices attempt to solve this data lag problem by using a telephone or Internet connection to upload a sample of ECG data as often as needed, but this still leaves a data lag.

In recent years with the decrease in size of wireless technology true real-time wireless ECG systems are becoming available. Wireless 5 and 12-lead systems are used in hospitals to allow patients freedom from cumbersome ECG wires while recovering from surgery. This also allows one nurse to monitor multiple patients’ ECG data from a central location. These systems are similar to Holter devices in that they consist of wired leads attached to a body worn central collection unit. Instead of recording the ECG data the collection unit transmits it, via a RF link, to a central display and analysis station. These systems must be very robust, secure, and immune to interference or cross talk because of the electrically noisy environment in a hospital. For this reason, they are very expensive and are too large to be worn on a daily basis outside of the hospital.

FUTURE RESEARCH

There are many different efforts to develop a real-time wireless ECG system for home use, but currently nothing has matured to the final product stage. Most of these systems are 1 or 3-lead with wired electrodes connected to a waist worn unit that either transmits locally, via a digital RF signal in the 400-900 MHz range, or to a remote Internet sever, via a cellular telephone connection. In both cases a computer system receives the ECG data and logs it into an online database. The database can be monitored in real-time by either a physician or with intelligent analysis software. The software can automatically notify a physician if a critical heart arrhythmia is detected.

The next logical step in real-time wireless ECG systems is a totally wireless body sensor network. Each electrode is a separate wireless node that collects data and sends it to a central collection unit. The collection unit, either body worn or located nearby, combines and transmits the data to a remote location or computer database. This is another area of research that is in even earlier stages of development. There are two complications with this approach.

First, because the electrodes are not physically wired together they are not electrically referenced to the same ground point. This means that traditional amplification methods used for measuring and comparing skin voltage potentials cannot be used. The second problem is that each wireless body sensor must not interfere with the other sensors' RF communication. This means that some sort of networking protocol, like Bluetooth™, must be implemented, or each sensor must transmit on a different radio frequency.

OBJECTIVES

The purpose of this project's research is multi-leveled. The first step is to develop an inexpensive, yet accurate real-time wireless 1-lead ECG device. (Figure 3.) This device needs to be small and efficient so that it can eventually be worn for long periods of time and powered by a small button cell battery. Next, software is needed to display and analyze the measured ECG data on any computer. The first wireless 1-lead ECG is just a small step toward the ultimate goal of creating a wireless and wire-free, intelligent, and possibly self-powered body sensor network. The initial and future design goals are detailed in the following sections.

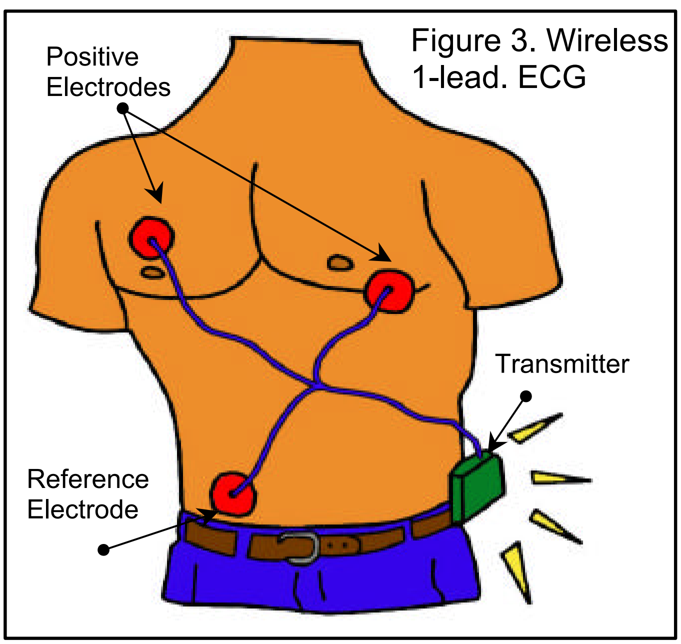

Figure 3. Wireless 1-lead. ECG

INTIAL DESIGN

The chosen initial design uses a traditional physiological amplifier circuit to measure the voltage fluctuations on the surface of the skin caused by the contractions of the heart. The physiological amplifier chosen uses three electrodes, but is actually just a 1-lead ECG. Two leads are used to measure the heart potentials and the third lead provides a common ground for the system. All of the devices in this design were chosen for their small physical size and low power requirements. Figure 4 shows the overall system block chart for the initial ECG system.

The physiological or instrumentation amplifier measures the voltage difference between the two chest electrodes. The TI-INA321 amplifier was chosen because it has a high Common Mode Rejection Ratio (CMRR) and is a low power single supply device. The electrodes pick up a considerable amount of noise from the skin, caused by electromagnetic interference and physical sensor movement. A high CMRR amplifier attenuates or rejects this noise. The difference in electrode potentials is only a few millivolts and is amplified to a more usable voltage of about 500mV.

The TI-MSP430 microprocessor serves many purposes. It converts the analog signal from the amplifier to an 8-bit digital value. It then formats the data into a RS-232 serial format to be transmitted. This processor was chosen because it is a low power single supply device and is powerful enough to perform real-time digital filtering or even analysis.

There are many digital transmitters that are possible solutions for the wireless link. The transmitter needs to be small, no larger than a quarter, require few external parts, support 10k to 115k bps data rates, operate on low power, and preferably transmit in the Industrial and Medical (ISM) frequency range. This frequency range should help with avoiding noise from other devices, like television broadcasts, that could interfere with the ECG signal. A few transmitters that are being considered are: the ES Series from Linx

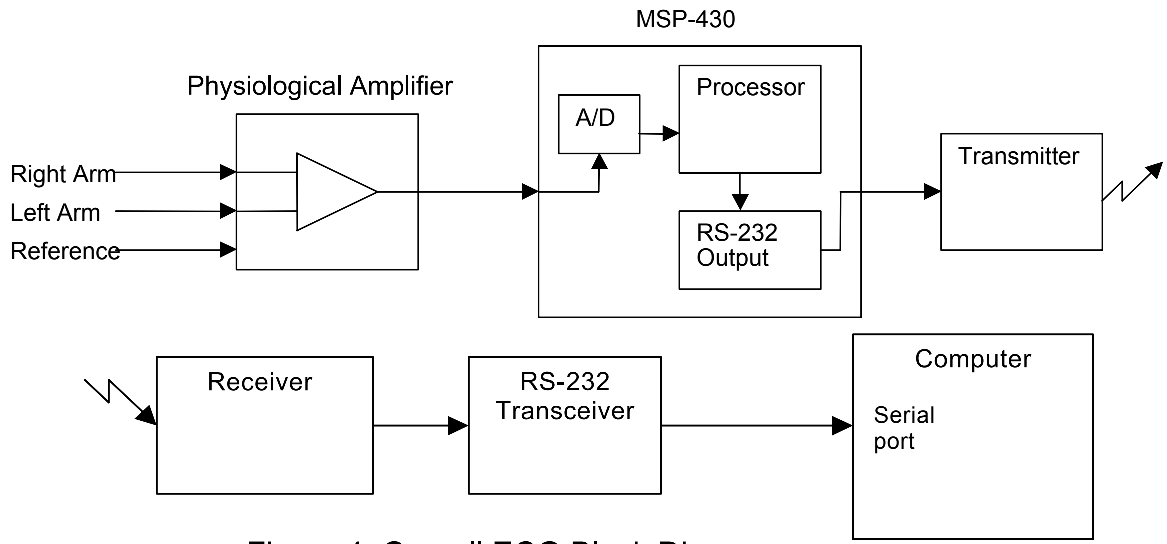

Figure 4. Overall ECG Block Diagram.

Technologies, the DR3000-1 from RFM, the Micrel MICRF102, the Radiotronix RCT-433-AS, and the Radiometrix TX3A.The ECG RS-232 serial data is received with a receiver matched to the transmitter, level shifted with an RS-232 transceiver, and inputted into a computer via the serial port. Because of the graphical nature of the desired software, Visual BASIC was chosen as the primary programming language. The software will allow real time visualization, digital filtering, and analysis of the received ECG data. This could also be implemented in Visual C++ or Matlab.

CURRENT DESIGN STATUS

Prototype transmitter and receiver circuit boards were designed and produced with a few additions to the original design. Additions include: A voltage reference, to decrease noise in the amplifier circuit and a low ripple voltage DC to DC converter, to stabilize the supply voltage as the battery voltage drops.

The analog data from the amplifier is sampled by the MSP430 ADC at 1000 samples per second to insure a clean over sampled signal. The highest frequency content of the ECG signal should be no more then 50 Hz (in the peaks of the heart beat) and Nyquist criteria requires a sampling frequency of at least twice the highest frequency in the signal. The chosen sampling frequency may be reduced at a later date. There are 10 bits per ADC sample, thus the data is streaming at 10,000 bps. The 8 MSBs of this data is shifted into the UART and then shifted out with RS-232 framing. The current RS-232 frame selected is 8 data bits, 1 stop bit, 1 start bit, and no parity (8N1). The transmitter selected is the RFM DR3000-1 because it is very small, low-power, and simple to use. It is set to transmit at 115.2 Kbps. Thus the MSP430's UART is set to output about 10k words/second and 115.2kbps. This creates a constant stream of 115.2kps data that matches the required data rate for the transmitter. A 900Mhz compact antenna (JJB series) from Linx was chosen for its small size and performance.

The RF signal is then received with the same RFM device, set to receive mode, and level shifted with RS-232 transceiver, TI MAX 3221. The serial data stream is then directly connected to the receive pin of a computers serial port.

A Visual Basic program was developed to sample, display, and perform analysis on the received signal. The main window displays the ECG wave, the second window shows a time-averaged version of each heart cycle, and the third window graphs the heart rate variance. The software also allows the user to zoom in on the ECG signal and record it for export to other programs.

FUTURE DESIGN GOALS

Many additions are needed to make the current design more robust. Data encoding implemented on the MSP430, to properly bias the transmitter and receiver, would increase range and decrease bit errors. Also, the addition of error checking could help discover and remove noise from the final displayed ECG signal.

By using the MSP430, or similar microprocessors, real-time digital filtering and analysis can be implemented on the ECG device itself. While this is immediately possible with the current design, making a truly wireless ECG body sensor network is not directly achievable. Many of the parts and concepts used in the initial design can be applied to this future goal.

One method is to make intelligent body sensors, about the size of a normal electrode, that contain the electrode, microprocessor (MSP430), transmitter, and battery. The measurements from each sensor would then be received and compared by a central unit to interpret and transmit the actual measured ECG signal. This is a powerful digital design that could use the Bluetooth™ networking protocol to insure that there is no sensor-to-sensor interference. A drawback of the complexity of this approach is the high power requirements and physical size of each sensor package. This type of ECG system is currently under development by and a company called BioControl.

Another method is to make sensors that are not intelligent and totally analog. The output from an amplifier, like the INA321, could be transmitted with an analog transmitter, like the Linux ES series. Each sensor would operate on a different radio frequency and be received and combined by a central unit. The MSP430 would serve as a good method to combine and digitize the analog signals so they could then be transmitted digitally to a computer. This method is less complex and would require less power for each sensor, thus smaller batteries. Unfortunately, there could be a loss in signal quality due to the analog transmission.

Other technologies being developed for medical and recreational use can be applied for use in future designs. One example is to replace the button cell batteries of the body sensors with a thermoelectric power source, like the Thermo Life from Applied Digital Solutions. This flexible film device, when placed on the skin, produces enough power from body heat to run a microprocessor. Another example is the addition of tiny GPS receivers similar to those in use by Digital Angel Corp. that allow a patient's location to be determined exactly. In the event of a critical emergency, determined automatically by the ECG system, medical aid could be dispatched with little delay. Possibly the most exciting technology that can be applied to ECG devices is Micro Electro-Mechanical Systems (MEMS) or more generally nanotechnology. The body sensors, described previously, could be manufactured so small that they could be injected under the skin. Any number of intelligent mechanical or electrical sensors could be used to gather data like ECG signals and blood pressure. CardioMEMS is currently working on a rice-size sensor that is small enough to be implanted under the skin and measure blood pressure. All of these technologies are very close to being mature enough to make real impacts on ECG and many other medical devices.

CONCLUSION

Just 100 years ago an ECG machine weighed 600 lbs. and used saline baths as electrodes. Now there are ECG devices the size of a deck of playing cards that use tiny gel electrodes. Wireless real-time ECG systems are on the verge of becoming the future of the ECG. Already cumbersome ECG wires are being replaced in hospitals. With future advances in technology ECG devices will become smaller and more robust, eventually leading to implantable wireless body sensor networks. Physicians will be able to access a patient's ECG data and vital signs 24 hours a day. Automated analysis software could also notify physician and emergency personnel of a patient's critical heart condition and even dispatch them directly to the patient's location using GPS coordinates. It is just a matter of time before this technology matures and such devices become a reality.

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REFERENCES

[5] Burke, M.J., and Gleeson, D.T.: 'A Micropower Dry-Electrode ECG Preamplifier, IEEE transitions on biomedical engineering, 2000, Vol. 47, No. 2, pp. 155-163

[6] Carlson, Shawn, "Home is where the ECG is", Scientific American, June 2000.

[7] Chr. Zywietz: "A Brief History of Electrocardiography - Progress Through Time", Biosigna Institute for Biosignal Processing and Signal Research. Hannover, Germany. Available online: http://www.openecg.net/

[8] Dubin, Dale, M.D. Rapid Interpretation of ECG's, Cover Inc., Tampa, Fl, 1970

[9] Oppenheim, A.V., Willsky, A.S., and Nawab, S.H., Signals and Systems, Second Edition, Prentice Hall, Upper Saddle River, NJ, 1996, Chapters 6-8

[10] Applied Digital Solutions: Palm Beach, Florida, http://www.adsx.com/

[11] BioControl Systems: Stanford, CA, http://www.biocontrol.com/

[12] CardioMEMS: Atlanta, GA, http://www.cardiomems.com/technology/

[13] ECG Company Website, http://www.ECGcompany.com/

[14] Institut für Technik der Informationsverarbeitung: Karlsruhe, http://www-itiv.etec.uni-karlsruhe.de/

[15] Jenkins, Dean, and Gerred, Stephen. ECG Library Website. http://www.ecglibrary.com/ecghome.html

[16] Texas Instruments Datasheets: INA321, OPA4336, www.ti.com