Designing a 3-lead cost effective ECG recording glove for home monitoring

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DESIGNING A 3-LEAD COST EFFECTIVE ECG RECORDING GLOVE FOR HOME MONITORING

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ABSTRACT

The EKG Glove is a wearable glove-based device on which all the necessary electrodes are pre-positioned hence the patient simply inserts his right hand into the glove and properly position the glove his chest to record a standard ECG. It is the first, lead wire free, simultaneous, and fully diagnostic ECG recording system in Pakistan with easy, natural and almost automatic placement of the electrodes, hence eliminating the difficulty of lead wire entanglement and electrode misplacement.

KEYWORDS

Electrocardiogram, Electrical Activity, Glove, Patient Ease, Medical Imaging

1. INTRODUCTION

An electrocardiogram (ECG) is routinely performed by a skilled operator familiar with the placement of individual electrodes on a patient. Incorrect positioning of the electrodes can lead to critical errors in the diagnosis and treatment of heart disease. Furthermore, the conventional ECG perusing methodology might create a hindrance and consume a lot of time even for a well-experienced operator for the electrodes placement on the patient prior to the acquisition which can be a depreciative issue in the situation of an emergency.

In this research paper, we have discussed the design a wearable glove-based device on which all the necessary electrodes are mounted for a standard ECG recording. Even an amateur individual can use this device. The glove is placed on the chest of the patient with the electrode on the thumb resting right under the collarbone and the fingers cupped under the left underarm. The output of the glove is transmitted to a standard PC through the audio cable for the recording of the ECG.

2. BACKGROUND

EKG or ECG stands for Electro-kardio-gram or electrocardiogram. It is an electrical recording of the heart and is used in the investigation purposes of the heart disease. Electrocardiogram is used to record the electrical action of the heart over a specific intervals of time. The Electrocardiogram is recorded Electrocardiograph which can then provide information about a wide range of cardiac disorders. Electrocardiography is commonly used in the cardiac labs, CCUs, ICUs and for regular diagnostic usage in cardiology.

An ECG is used to observe the heart's electrical conduction system [1]. An ECG detects electrical impulses induced by the depolarization and polarization of cardiac tissue and deduces into a waveform which is then used to calculate the rate and normality of the heart beats, along with the location and morphology of the cardiac atria and ventricles, the occurrence of any heart impairment and the impact of cardiac drugs or instrumentation.

2.1. The Evolution of the Electrocardiogram

The first device developed to sense electrical activity of the heart was known as a "galvanometer" (1794), which sensed rather than measuring electricity. In 1849 however, DuBois-Reymond made modification of the existing device by adding a two position switch in order to measure the current. This device then came to be called a "Rheotome" [2]. In 1868, Julius Bernstein, a student of DuBois-Reymond, made alterations to the rheotome again so that the interval between sampling and simulation was variable. This came to be known as "the differential rheotome" and become the apparatus through which the first EKG was ever obtained. The heart of frog was used for most of these EKG, with the placement of electrodes being the heart of the frog. The differential rheotome however, was not sensitive hence, this lead to the developing of a “capillary electrometer” in 1872 by Gabriel Lippmann.

Alexander Muirhead is stated to have connected wires to a wrist of an agitated patient to obtain a reading of the heartbeat of a patient while pursuing his Science Doctorate at St. Bartholomew's Hospital in 1872 [3]. A British physiologist John Burdon Sanderson directly visualized and recorded the reading with the help of a Lippmann capillary electrometer [4].

Augustus De ‘sire' Waller managed to be the first person to discover that the capillary electrometer could record the electrical activity of the human heart without exposing the heart by cutting the chest open. This allowed him to be the first in 1887, to observe the electrical activity of the human heart [5]. However, Waller coined the term electrogram for his recordings in his initial paper, and only after a year delay was he able to change the name to “cardiograms”.
In 1900s, after being disappointed with the capillary electrometer, Einthoven started to design his own galvanometer. Completely finished in the 1903, this invention came to be known as the “String Galvanometer” although the initial report of this device was published by Einthoven in the 1901 [6]. The electrocardiograph designed by Einthoven was initially manufactured by Edelmann and Sons of Munich in Germany. The manufacturing rights were later transferred to the British Cambridge Scientific Instrument Company, Ltd.

Einthoven allocated the letters P, Q, R, S and T to the numerous refractions [7], and defined the electrocardiographic characteristics of several vascular conditions. In 1924, he was presented the Nobel Prize in Medicine for his findings [8].

EKG was introduced within the United States by Professor Horatio Williams and brought to existence by Charles Hindle in 1914 [9]. The Hindle EKG machine came into hands of Alfred Cohn in May 1915, and finally on the May 20, 1915, America saw its first EKG observations of the acute anterior infarction in a patient, even though it was not recognizable at that time.

Even though the basic principles defined during the olden times are still considered authentic, the conventional ECG machine has undergone a lot of advances. For example, older ECG models involved cumbrous instrumentation with troublesome electrodes. The bulky apparatus has now been replaced with compact electronic systems which can not only record easily but also give off computerized interpretation of the recorded readings.

2.2. The Standard ECG Wave

The ECG wave is defined as a PQRST complex. The P wave describes the atrial depolarization of the heart while the PR interval shows the time delay from atrial depolarization to the start ventricular depolarization. If a PR interval is longer than usual, it denotes an impaired AV conduction. The QRS complex represents the ventricular depolarization. Normal depolarization occurs when the right and left bundle of His is functioning normally. If any of the bundle branches is blocked, it will result in an abnormally lengthy QRS duration. The T wave represents the ventricular repolarization and the QT interval shows the time between the depolarization of the ventricles and repolarization [11].

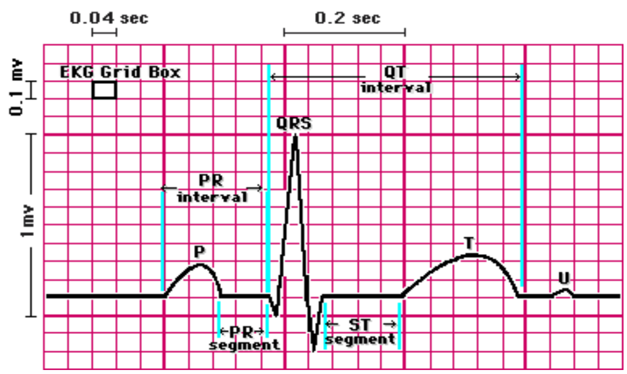

Figure 1. The ECG wave as the PQRST complex

2.3. The Einthoven's Triangle

Whenever ECG is recorded from any one of the bipolar lead pairs, it results in a single dimensional, time variant projection of that specific cardiac vector and can be easily represented with the help of an Einthoven triangle. Usually, a triangle is used to represent the QRS segment. [12]

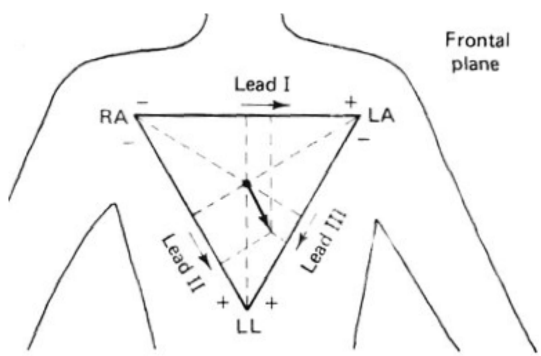

Fig. 2.1. The Einthoven's Triangle

With the help of an Einthoven's triangle we can comprehend the amplitude of the ECG waves. In order to create an Einthoven's triangle, we need to draw an equilateral triangle which is inverted showing the base on top. We need to label the top inverted base as lead I, the right side of the triangle as lead III and the left side as lead II.

After the labelling is complete, we need to plot segment of magnitude that is directly proportional to the QRS complex amplitude, from the midpoint of each of corresponding lead side. After the plotting, we need to trace at the end of each segment, a line that is perpendicular to the segment.

These perpendicular lines will intersect at the center of the triangle, corresponding at the initial vector point. A point to note is that, the vectors should also be an intersection at one point, when traced from their ends. Orientation of heart must be visible within the line between two of the intersections, allowing an explanation in the magnitude variations between nominal data and perceived data. [13]

2.4. Health Consequences

While patients suffering from heart diseases are very much fragile and vulnerable to sudden heart failures which can lead to sudden deaths [14], the ECG glove provides the patient an ease to self-measure his ECG at home without the need of a doctor at a sudden upsetting of his health conditions. If the ECG wave differs from the standard wave, the patient will be sure to call for help. He will no more require trips to the hospital just to have his ECG done.

2.4. Key Features of the ECG Glove

The EKG Glove we have designed is the first, simultaneous, lead wire free and completely diagnostic ECG recording system in Pakistan with natural, automatic and easy placement of the electrodes, hence eliminating the difficulty of lead wire entanglement and electrode misplacement. Due to the ECG glove being reusable, the ECG readings can be reproduced again and again, becoming an appropriate tool for 3-Lead ECG comparisons of the conditions in the same patient as well as an essential device for population analysis in pharmacological studies as well as precautionary cardiology. There is no need for any special training hence, EKG glove can be used by almost anybody. The glove we have designed is ideal for home patient use or for bedridden patients. Best of all, there is no need for special preparation for example shaving of hair, the results are immediate.

3. DEVELOPMENT AND METHODOLOGY

3.1. Materials and Cost

The circuit was designed using the instrumentation amplifier, and then the ECG wave was filtered using a band pass filter, followed by a notch filter, and then finally the output. The circuit was achieved at minimal cost, keeping the cost-effectiveness in mind. The hardware required:

S.No.	Components	Values	Quantities	Cost
1.	Electrodes		3	100Rs.
2.	Instrumentation Amplifier	AD620AD	1	350Rs.
3.	Operational Amplifier	TL-1081, LM353	2	30Rs
4.	Various Resistors			30Rs
5.	Capacitors			30Rs.
6.	Glove		1	200Rs.
7.	Conductive Fiber		1	700Rs.
8.	Audio Jack		1	30Rs
9.	Audio Cable		1	50Rs.
			Total Charges:	**Rs.1500 (PKR)**

Table 1. The Total Materials and Costs

3.2. Working Principle

The ECG Glove is put on the patient's right hand and the patient is then required to put the glove against his chest. The Glove has electrodes embedded into it, which detect the electrical activity of the heart when the hand is placed over the chest and display the result immediately.

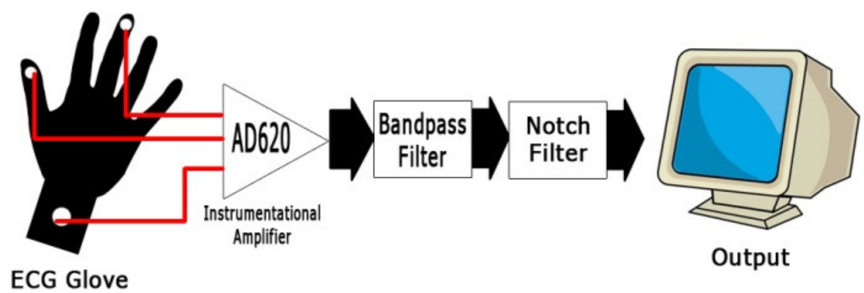

Figure 2. The Representation of the Design Layout

This enables the monitoring person to recognize the patient's condition and take immediate action in the emergency [15], for example to see if someone who has collapsed with chest pain to is under a heart attack and need to be taken to hospital. The glove is easy to use and can also be implemented by the patient itself.

3.3. Methodology

In the world of electrocardiography, evolution is constant, while revolution is rare. We have made a wearable EKG glove, a unique glove based platform for the simultaneous acquisition, storage and transmission of standard 3 lead ECG. The technique of performing diagnostic ECG has remained unchanged for almost 100 years.

Even then, the common ECG is controversial, subjected to many technical errors, time consuming and labor extensive. It is a process that involves constant entanglement of the lead wires, the lengthy practice of prepping the skin and placing the electrodes, the difficulty in the securing of the skin contact with the electrodes and common episodes of misplacement or swapping of the electrodes.

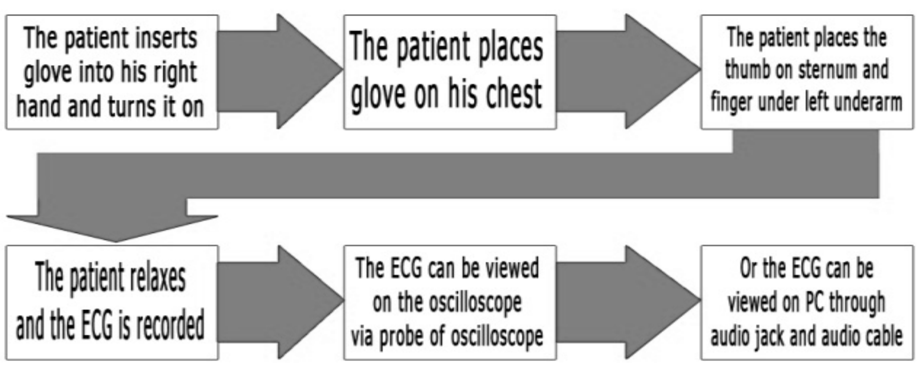

Figure 3. The Functional Diagram of the ECG glove

We aim to revolutionize the technique of performing ECG with a wearable glove platform. The wearable glove, although capable of doing much more, is in its most basic form in essence, a sophisticated replacement for the conventional ECG cable. The glove will incorporate all three required electrodes in the glove itself, and connects to the output to PC through audio cable or through oscilloscope via probe.

The glove will provide a natural alignment of the location of the electrodes by being positioned on the right arm of the user. When the user places the right arm on the chest in a “universal pledge” position, the hand and the lower arm naturally align with the correct anatomic positions which are required to measure the ECG. In addition, the RA, LA and LL electrodes are also incorporated within the glove.

The pressure of the user’s hand against the body maintains constant skin contact without the need of the special preparation of the skin, or application of conducting mediums. The positioning of the glove on the body is natural and does not require knowledge or training of proper sensor placement. This allows for it to be performed by non-technical personnel or even by the patients themselves.

Due to the natural positioning of the hand, the electrodes always settle in the same exact position and there is no chance of electrode misplacement. This ensures that each ECG session is consistently reproducible in exact accordance with the international convention thereby, reducing $1/5^{th}$ of the time required for producing conventional ECG.

3.4. Circuitry

The range of our portable ECG glove is from 0.15Hz to 160Hz [16]. By utilizing the electrodes capable of picking up signals from the body which for example being extracted from the heart, a low pass filter is designed to eliminate frequency above 160Hz, a high pass filter to eliminate the frequency below 0.05Hz and a notch filter was designed to eliminate the line noise of 50Hz, the optimum ECG wave was obtained [17]. The output of this glove was then transferred to PC via audio jack and audio cable or to Oscilloscope via the probe of the oscilloscope.

As the voltage from the heart pulses is incident against the electrodes, it detects the voltages and sends it to the circuit for further amplification. These electrodes are low cost, homemade devices the main problem of which was that they picked up background noise that was difficult to filter out with the ECG. Therefore, a good amount of time was spent on the design of the amplification and the filtering circuit to cut off the undesired noises including line fluctuation, thermal interference and other bodily signals such as EEG.

The main objective of our circuitry was to amplify the ECG signal obtained from the body with a reasonable Signal to Noise Ratio, maintain low power consumption and be cost effective. The frequency response, gain, line noise, thermal and harmonic distortion also must be taken into account when designing the extraction circuit [18]. The circuit itself was divided into five stages: pre-amplifier, amplifier, band-pass filter, notch filter and post-amplifier.

The pre-amplifier was created to increase the low-signal from the electrodes to the line-level for further amplification. A band-pass filter was used to limit the impulse frequencies. The amplifier was then used to supply necessary power to drive the circuit, and then the notch filter was required to eliminate the line noise. Lastly, the post-amplifier amplified the wave to give an optimum result.

4. RESULTS AND DISCUSSION

The circuit was finally designed and then put into order. The output was defined on the PC as well as oscilloscope, and a standard 3 lead ECG was obtained. The final output was obtained by testing the device on the fellow group member as a subject, who was asked to sit up straight and still so that the movement factor does not disturb the ECG signal being extracted from the body. The patient was then asked to wear the glove in his hand and apply a little conductive gel to the electrodes. The patient after wearing the glove then switches the glove on, and places the glove on his chest so that the thumb lies on the sternum and the finger lies under the left underarm. The ECG is then recorded which can be viewed on the laptop or Personal computer through the audio cable, or can be viewed through the oscilloscope via the probe of the oscilloscope.

Figure. 4 The Cost Effective Wearable ECG glove itself

4.1. Final Output

The output was displayed on the oscilloscope by grounding the probe of the oscilloscope from one end, and connecting the probe to the output on the other end, and the following result was displayed on the digital oscilloscope:

Figure. 5 The Output of the ECG glove on the Oscilloscope

To record the output on the PC, we made use of an audio jack, and the audio cable, and recorded the output via audio cable to the Microphone port of a common laptop. The output will be obtained as the following:

Figure. 6. The Output of the ECG glove on the Laptop PC

Thus, the ECG glove itself proved useful in recording the ECG on the laptop as well as the Oscilloscope software.

4.2. Circuit Calculations

The band pass filter had a range from 0.15Hz to 160Hz, and thus the calculations are given according to the following formula [19].

$$Fc - \frac{1}{2\pi RC}$$

4.2.1. For High Pass of 0.15Hz:

> $RC = \frac{1}{2\pi Fc}$

> $RC = \frac{1}{2\pi(0.15)}$

> $RC = \frac{1}{0.942}$

> $RC = 1.061571$

> $R = 1.061571/0.00001$

> $R = 106157 \cong 100K\Omega$

4.2.2. For Low Pass of 160Hz:

> $RC = \frac{1}{2\pi Fc}$

> $RC = \frac{1}{2\pi(160)}$

> $RC = \frac{1}{1004.8}$

> $RC = 0.0009952$

> $R = 0.0009952/0.00001$

> $R = 995.22 \cong 1K\Omega$

4.3. Problems Encountered

Any successful project is not possible without encountering a lot of problems during the task. We had to go through many problems including:

- The glove was to be originally designed incorporating an entire 12 lead ECG system in it, however, the circuitry we tried could not be made as compact as we needed, which ended up to us designing the product on the 3 lead standard ECG recording instead of a full 12 lead ECG recording
- Synchronizing the output on the laptop as well as oscilloscope played a lot of hurdle, as the output of the oscilloscope was not matching with the output on the laptop, due to the hurdle of audio cable of the laptop, and the line noise due to the oscilloscope, testing that took a lot of time.
- Mishandling of the power, and the components, often led to the loss of the components itself for which we had to replace the new ones.
- The circuit to be embedded on the glove was originally planned to be soldered on a polyamide flexible PCB sheet, but the polyamide sheet was unavailable locally, and even the retailers abroad failed to provide us the sheet without buying the bulk, so we had to go with the Vero board in the end.

4.4. Future Improvements

The first and foremost improvement that we would suggest would be to use a polyamide sheet, for the patient convenience, and to use micro-components to improve the glove functioning and the look. Using the micro-components will also allow the circuit to be made into full 12-lead ECG circuit as well.

Also there are many other good quality differential amplifiers available in the market, like AD624AD, we did not approach them however keeping the cost-effectiveness in our mind. Lastly, the transmission of the signal can be considered a lot [20]. We are using conventional readymade software, or the oscilloscope, but the output can be easily transmitted using the wireless connectivity, or the data can be stored into the SD card or USB to be shown to the doctor directly.

We can also design a good Android application for the ECG software so that the output can be displayed and stored on the smartphone, or use a microcontroller to interface the output signals with the LCD. Unfortunately, time constraints and the various problems encountered did not allow us to implement any of the suggestions made above.

5. Applications in Biomedical Engineering

Personal ECG glove offers many benefits beyond its elder sibling, the conventional 12-lead ECG machine. Our designed ECG glove is cost-effective, simple to use and convenient. The cardiac monitoring can be held anytime within the comfort of home and the desired measurements are recorded and available within minutes. Using the ECG glove is simpler than a blood pressure machine.

Cardiac events tend to occur irregularly and it is not necessary that they may take place at an appropriate time, for they can occur anytime outside the doctor's office [21]. By taking ECG at home, the patient can constantly record, save and monitor his ECG to be used for showing the doctor the analysis later at his clinic. The best time to use the ECG glove is when you're not feeling well at home, and have a fear that you may be experiencing a heart problem.

If a patient is not well, the family members, or the patient himself can take the ECG at home to overrule the heart problem doubts, assess the situation and take proper action. Without the action, the patient may be reluctant to approach a doctor at first [22]. Also, sometimes a heart attack is mistaken for the muscular pain, or vice versa, which again causes a lot of inconvenience for the patient and the family themselves. Hence the ECG recording can clear the doubts, and allow a patient to seek out the doctor if the ECG wave differs from the normal value.

ECG glove is also essential tool for sleep apnea. Researches have shown that obstructive sleep apnea also alters healthy heart conditions. The conventional heart rate usually fluctuates cyclically during intervals of prolonged sleep apnea. This cyclic fluctuation is linked with the apneic period and the renewal of breathing. After the analysis of ECG data, one of the studies has demonstrated that this obstructive sleep apnea can be identified in over 93% of the volunteering test cases. [23]

Henceforth the ECG glove can eliminate the chances of a false heart attack, which can cause a lot of anxiety and stress, in turn triggering the possibilities of a real heart attack. To eliminate the chances of human error, this glove was designed.

ECG glove is also appropriate for home care and nursing homes providers for monitoring the development and conditions of their patients. Ever since the availability of the portable, high quality and affordable ECG monitors, the requirement of training for measurements has become minimal, allowing the ECG glove to be commonly made available to the patients. Even with no training, the patients as well as the healthcare providers can identify abnormal readings and in case of emergency notify themselves and their doctors.

Angiocardiopathy is one of the diseases that have the highest morbidity rate and the death rate at present. According to the research, over 1700 people have died from this disease yearly all over the world. Currently, the diagnosis of this disease mostly depends upon ECG [24]. The ordinary ECG monitors however can only take short-term readings as it is not possible to keep a patient around the ECG for a long time. Whereas, an ECG glove can be carried anytime around and is also feasible for the long-term monitoring of the patient's condition and thus tremendously increase the possibility to find the non-sustained cardiac arrhythmia and temporary myocardial ischemia.

The evolution and applications of the Electrocardiogram with portability initiative have been intertwined into the little glove for patient feasibility. The glove allows the readings to be taken at the comfort of home, office or any place while travelling and be read out during the feel of arrhythmic conditions and be later advised by medical practitioner for reviewing. This would be extremely advantageous for the senior citizens, people with disabilities, and people in remote areas who will have difficulties reaching a proper healthcare facility every day or having the difficulty managing the time out of their daily lives for routinely doctor checkup. The applications of the EKG glove are immense and bound to revolutionize the acceptance Biomedical Engineering field.

6. CONCLUSIONS

Though our research seemingly is sophisticated, however, precautions and tests were needed to overcome the difficulties of the selection of proper glove material, positioning of proper electrodes, and the calibration of the ECG wave. Hence, we had to test our design at every step of the development to ensure promising results. We achieved the tests through labs, overcame difficulties through reference of books and consulted our senior teachers taking help of their expertise, also through individual experimenting and research.

The EKG Glove is a medical device that provides an alternative to the plugs, electrodes and cumbersome cables typically used for recording an electrocardiogram (ECG or EKG). It is reusable, portable and can easily connect to most standard ECG recording. It typically can be used in hospitals, private practice, and home health care and emergency services. Within the sheath of the glove is embedded a conductive circuitry, which never causes any risk by coming in contact with the patient. To obtain a recording, the operator only has to connect the glove to an oscilloscope or laptop then insert their right hand into the glove, properly position it over the chest of the patient and then take the reading.

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Her research interests include implementation of bio-materials engineering and cardiovascular physiology for synthesis of artificial heart valves, relative fluid dynamics and cardiac regeneration. She is also interested in working in the fields of animal rehabilitation, microbial tissue engineering and cost-effect liver damage treatments.This research paper is her effort at the cardiac applications of medical imaging and major credit for the product design and development goes to her. She plans to pursue her MSc at a credible university abroad in subjects not available locally.

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Her research interests include biomedical signaling systems and signal processing, medical imaging, and bioinstrumentation. This research paper is her idea. She plans to pursue her MSc in Australia soon within the specialization of Biosignal Processing and Systems.

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A graduate, he has already taken over Scientific supplies Ltd, as the director of trainees. His research interests include Hematological Equipment, Chemical Analyzers, PCRs and flow cytometry applications. He plans to pursue his career professionally at Beckman Coulter. He helped with the financial resources for this project.