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Low Power Wearable Cardiac Activity Monitoring Device: ECG A Review

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Abstract - *The large number of deaths caused by the cardiovascular disease in all over the world during the last decade. Cardiovascular disease affects the blood vessel and the heart, and this may lead disease like the heart attack, arrhythmia, cardiomyopathy, coronary artery disease, the heart failure, rheumatic heart diseases, congenital heart disease, and an Aorta disease syndrome etc. As per the report of World Health Organization (WHO) approx. 17.9 million lives have gone globally due to CVDs. The world's 16% deaths are responsible for ischemic heart disease up to 2019 [3]. One third deaths under the age of 70 and 4 out of 5 deaths are caused by strokes and heart attacks. Regular monitoring of patients may improves the health condition of the patients and, reduces deaths. Electrocardiography (ECG) monitoring systems are developed equipment used in healthcare sectors have considerably evolved over time. Wearable health monitoring devices play vital role for monitoring human health conditions. Today's technologies gaining a lot of advancements and flexibility in virtually each application in a numerous field. Wearable technology in a medical field including cutting edge technology of electronic devices like Fit bands, wearable monitor and smart watches can be used by the consumers, and design to collect personal data of his/her health and exercise. The regular monitoring of Electrocardiography (ECG) and the heart rate, can reduce the deaths and cure the cardiovascular disease early. Constant and Real time cardiac activity monitoring device plays an important role in instant treatment of these disease. Electrocardiography is one among the most effective methods to determine the electrical activity of the heart. With early management of abnormal Electrocardiography (ECG) can facilitate within the decrement in variety of deaths. The characteristics of the ECG signal helped to analyze heart rate, heart condition, and heart disease. Long term cardiogram observance is fascinating in several daily healthcare things wherever a wearable device which will continuously record cardiogram signals is required. In this research articles, we carried out various type of wearable health monitoring device i.e. wearable ECG. Person's Health condition can be improved by regular monitoring of ECG and it may cause less number of deaths. But the regular monitoring of ECG is not possible to everyone due to cost and size. Many researchers and healthcare industries are developing wearable devices to eliminate these problems. Wearable health monitoring device is much needed for elderly age person as well sportsperson for regular monitoring of ECG. As traditional ECG device is bulky in size as well expansive, that is not affordable to all, and can't carry everywhere. The main challenge of wearable device is the battery life due to continuous monitoring and recording of the health data. Wearable cardiac device covered market of 1.2 billion US dollar in 2019 and business is growing very fast and can become by a CAGR over 24% by 2026 [12]. Wearable health tech device provides impressive health observance supported parameters like heart rate, blood pressure, ECG, vital sign etc. These devices offer real time health data to patients as well as doctors and doctors can suggests for the prescription as per received data. Several firms are targeted on development of wearable health monitoring devices combination of biosensors. Therefore increasing research and development expenditure leading to involving technology advancement will uplift growth of wearable cardiac activity devices industry and market coverage shown in table 1.*

Table-1: Industry and market coverage of wearable cardiac device [12]

Coverage of Report	Details		
Base Year:	2019	Market Size in 2019	1.4 Billion (USD)
Historical Data for:	2015 - 2019	Forecast Period:	2020 - 2026
Forecast period 2020 to 2026 CAGR:	24.2%	2026 value projection:	6.4 Billion (USD)
Country Covered	France Mexico, Spain, Brazil, South-Africa, France, Italy, U.K, Germany, Australia, Russia, USA, India, Japan, China, Saudi Arabia, UAE, Poland, Canada		
Area Covered:	Application, Product Region		
Growth	Increasing range of patients tormented by vessel diseases. Rapid growth of technological advancements. Growing preference of minimally invasive		

Drivers:	devices.

Key Words: ECG, Heart Rate, Cardiac Activity Device, Bluetooth Low Energy, Low Power, Health Monitoring

1. INTRODUCTION

Kollicker and Muller have discovered electrical impulses in the heart, first time in the year 1856 [1]. Electrocardiography is a common medical investigation that can be measure electrical activity and rhythm of your heart. Earlier experiencing a sensitive Electrocardiograph system was a big challenge. The electrical heart signals attenuates whereas traveling through tissue of the body and becomes weak in strength on the surface of the skin. Somehow Einthoven [72] succeed to enhance the sensitivity of graphical record (ECG) sensing system by employing a Galvanometer. This advancement was thought about to be an enormous breakthrough for graphical record, since characteristic peaks of the Electrocardiography (ECG) acquainted as P, Q, R, S, and T as shown in fig 1 According to World Health Organization (WHO) the large number of deaths are caused by the cardiovascular disease [3]. According to Global Burden Disease (GBD) report 2017, large number of deaths are caused by CVDs in Asian region as shown in fig. 2. Largest number of deaths due to cardiac disease is 423 out of 100,000 per year in Pakistan and least death is 79 in Japan.

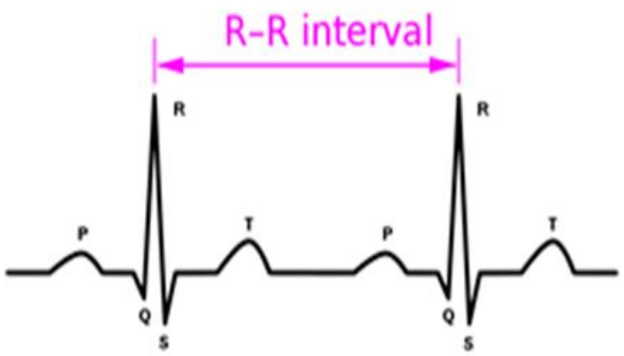

Fig- 1: Basic features of ECG signal waveform

Whereas the death rate due to heart disease in India is 282 every year.

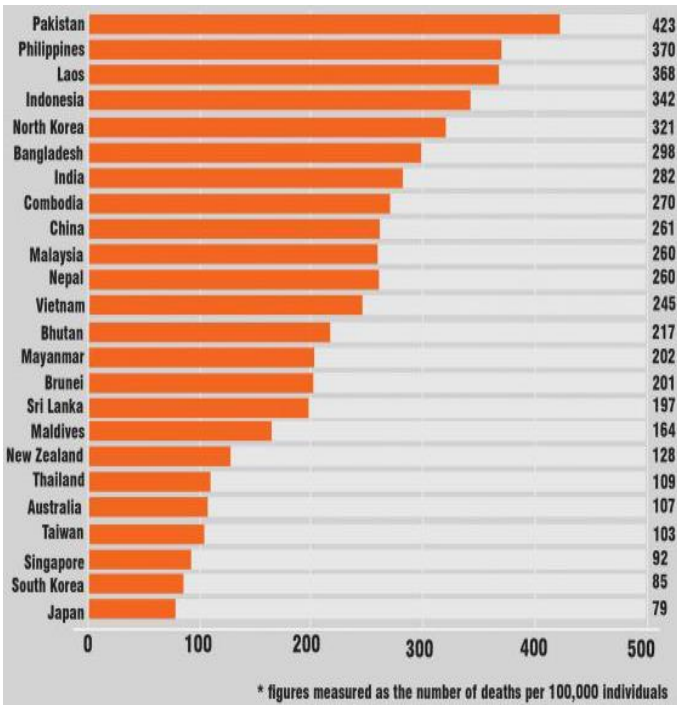

Fig- 2: Number of deaths due to cardiac disease [4]

The characteristics of the ECG signal helped to analyze heart rate, heart condition, and heart disease. Long term cardiogram observance is fascinating in several daily healthcare things wherever a wearable device which will continuously record cardiogram signals is required. Wearable health monitoring devices lead to improve better health condition due to regular monitoring and reduced deaths. Typically traditional ECG signal recording or monitoring system is complicated and painful as electrodes are attached on the chest, hands and legs. Various types of Electrocardiography systems have been launched to enhance the quality of signal in clinical purpose. The traditional Electrocardiography methodology applies a gel between the skin and the electrodes to extend the physical phenomenon to the path of signal. However the wet conductor methodology applies semiconducting gels that contains poisonous materials, which might cause allergic or irritation to the skin of the patients. [5]-[9], [27]. Esen Ozkaya et al. described about a Turkish woman has suffered from Itchy eczematous metal plate on contact sites of self-sticky ECG electrodes [2]. To eliminate such type of allergies and continuous health monitoring, wearable device is introduced. Flexible and dry electrodes have also introduced to measure signals of ECG and allows reliability of health monitoring system. [28, 29, 30, 31].

In our study authors are trying to develop a low power cardiac activity monitoring device using MAX30003 analog front end Ic, which will measure ECG and Heart rate. MAX30003 Ic has various features such as High input impedance, High DC offset range, for longer battery life, small in size, built in Heart rate detection, high speed SPI interface etc. MAX3003 Ic used in application such as Arrhythmia detection, wireless patches in hospital monitoring or at home, ECG on demand application, develop fitness band to measure heart rate for sports person and Bio authentication[73]. TO receive signal from MAX30003, we will use MAX32630 FTHR based on ARM Cortex M4 microcontroller.

Different researchers used different techniques to develop wearable devices, but the most challenging task is to improve battery life i.e. device should be long term performance because of continuous monitoring of health data.

2. LITERATURE SURVEY

Authors have studied various research articles of wearable ECG monitoring device/ system and those research articles have approached various techniques. Chien-Lung Shen, et al. reported a wireless communication enabled fabric based garment sensing system to monitor the activity of Electrocardiography supported by Bluetooth to transfer the desired signals in to programmable differential amplifier (PDA). This wearable garment system continue monitors ECG, R-R interval and Heart Rate Variability (HRV) and experimental results measured in resting, jogging and walking situations [10]. Jakob Justesen et al. proposed an Electrocardiography sensor prototype based on the Blackfin processor and containing Bluetooth for wireless communication, allowing experimentation on sensing element technology and signal processing as well as infrastructure. The developed prototype is presently not optimized for low power consumption. Instead the most focus has been development of a powerful and versatile platform in terms of on board computational power and connectivity to permit a broad range of Electrocardiography signal processing algorithms to be used [11]. C.J. Deepu et al. described an integrated chip having low power signal processing for wearable devices application. The chip contains programmable gain amplifier, a BPF, a 12 bit ADC and Successive Approximation Register (SAR), a completely unique QRS detector, 8k Static RAM, relevant management electronic circuit and central processing unit interfaces. This chip consume less power as analog circuits and ADC having 0.85μW for 1 volt, QRS detector having 1.1μW for 3.3V and CCU and other digital circuits having 7.6μW for 3.3V [13]. Meiran Peng et al. designed a wearable heart rate belt for electrocardiogram observance which may be well worn on the waist or chest. Electrodes were designed and made by textile for electrocardiogram recording. Circuit were designed such that operated by a battery and having a DSP for signal processing, 3-D accelerometer for body movement, a SD card slot for data storage.

The system transfers the health monitoring data on smart phone. Proposed system is integrated in a sport-shirt based on android app and measure system is easily worn by the users during daily activity. [14]. Kevin C. Tseng proposed a wearable ECG monitoring system consists of an ECG acquisition device, a healthcare server, a mobile phone. Electrodes are made from dry foam and embedded with the acquisition device and gives good conductivity to obtain ECG signal without using gel. Proposed WMEMS will observe the user's cardiogram state unendingly and anywhere within the globe if they're to a lower place the coverage of GSM cellular network [15]. Elisa Spano et al. proposed a wireless communication Electrocardiography (ECG) monitoring system for non- tech peoples in need for continuing health monitoring at home and integrated with IoT infrastructure. This device is cost effective as well as energy efficient. They also suggested that additional health parameters can be added in the future and can improve system reliability to patient mobility and connectivity losses. [16]. Byungkook Jeon et al. developed ECG enabled smart shirt to monitor real time ECG data and transferred on mobile. Healthcare professionals can easily access real time data of patient's on their smartphones [17]. Vega Pradana Rachim et al. proposed an armband embedded system consisting of capacitive coupled electrodes, Bluetooth low energy protocol for data transmission. Which leads to reliable, robust and low power data transmission. The proposed system has less than 10 % heart rate error than standard system [18]. Wenxin Tong et al. experimentally observed sensitivity based on textile ECG sensing to factors like textile placement, contact pressure, muscle activity, and user's activity. Heart rate and ECG signals are then compared with true signal (used by standard gel electrodes) [19]. Zhendong Ai et al. proposed a wireless ECG monitoring system consisting of BMD 101 sensor chip, CC2640R2F Bluetooth LE MCU. This is wearable ECG telemetry device that records the signals and send it to nearby users' phone to display the desired data [20]. Abhinay Vishwanatham et al. proposed an end to end healthcare workflow system consisting of BLE 5-lead electrocardiogram electrode, android based mobile system which displays graphs and data and next is the cloud server that stored the patient's data for diagnostic of a healthcare professional. They also suggested for using Machine learning technique to automate the system as well using wireless charging system to improve portability system. [21]. Prachi Kamble et al. proposed Internet of Things (IoT) enabled ECG recording system consisting of Wi-Fi, and the data is transmitted wirelessly over the cloud server i.e. online and offline data can be stored in the SD card. The ECG wave is displayed on the local LCD and developed web interface/ mobile application [22]. Aleksei Anisimov et al. proposed power efficient algorithm enabled low power portable cardiac device [23]. Shakthi Murugan et al. proposed the wearable heart monitoring device consisting of pulse oximeter sensors, silver chloride electrodes and using by optical techniques [24]. Byungkook Jeon et al. designed and implemented a wearable ECG monitoring device real time data of the patients [25]. BOR-SHYH LIN Et al. proposed a non-contact electrode circuit to help in developing mobile ECG monitoring device to detect arrhythmia, which is integrated in thin cloths that measures ECG signal of users in daily life. They have also focused to reduce the consumption of power [26]. Tomas Komensky et al. have designed an Ultra-Wearable Capacitive Coupled and Common Electrode-Free ECG Monitoring System. The designed system relies on isolated electrical phenomenon electrodes where galvanic contact does not required to the patient's body as well as need not to the common right leg electrode. Measurements done under actual conditions so that it is attainable to accumulate documented cardiogram waveforms while not the common conductor once the patient is throughout walking or even sitting. The designed system's performance is validate with the traditional cardiogram system and found the same result as well as wearability is also increased. The designed system could be an optimistic approach for biomedical sector, as a result of standard cardiogram systems don't full-fill the conditions for long term monitoring in home. The overall system's cost is reduced due to uses of capacitive probes as well as application time as gel is not required. [32].

Y. Ye-Lin et al. targeted to designed and validate a multichannel wireless Electrocardiogram monitoring system supported a brand new versatile ring electrodes. The system allowed high-accurate electrocardiogram signals by a straightforward procedure. The bipolar coaxial Electrocardiography signal's amplitude and signal to noise ratio increase with the concentric ring electrode's outer ring dimension. They observed that BC- ECG signal amplitude and signal to noise ratio increase with the size of concentric ring electrode. The obtained signal is in real time and communicate wirelessly [37].

B. Chamadiya et al. developed a contactless electrocardiography to measures the vital signal by using capacitive sensors attached in different location of patient's fitments e.g., wheelchairs, health center's bed and stretchers. A stretcher typically could be a patient's initial step to approach the clinical atmosphere. It is the main approach with back of patient and hence gives a decent platform to catch CCECG in ambulant situation in America. The textile electrode receive the electrical signal from the patient's body. A square shaped electrodes is attached at lumber section which is facing backward of the patient, where R-ECG is attached on stretcher's hand rest such that patients' hand can reach easily. Patient spends most of time on the clinical bed after admitted in the hospital. Contact electrodes are attached left and rig of the bed sheet so that it can be easily accessed by volunteer's hand. Wheelchair can be used during recovery of the patient to mobilize from one place to other place. CCECG attached between back side of the patient and back rest of wheelchair. Driven electrodes are attached at seat and electrocardiogram electrodes are attached at on left and right arm rests of the wheelchair respectively [38]. Kevin c Tseng et al. proposed wearable ECG monitoring system using a healthcare server and mobile phone. Dry foam electrode, wearable ECG vest and ECG acquisition module are used to obtain ECG signal. Vest obtains the ECG signal from the users and transmit data to the smart phone using Bluetooth and signal is monitored regularly by MIDlet program is installed in smart phone. The system is developed such that the program can send the average value of vital signal to healthcare server through SMS in regular interval of two hour. Whenever the abnormal ECG signal occurs, program sends an alert SMS congaing raw ECG signal as well users

location trough GPS to the healthcare server as well as a physician, [41]. Yishan Wang et al. presented a wearable electrocardiogram recording system supported by 3-Lead electrode arrangements which leads long-lasting home

healthcare. Electrodes are attached on the body's skin and Sensor nodes are operated by the rechargeable battery which detects the ECG signal. These signals are processed through amplification and filtering process and finally transmitted to the PC. The received ECG signal is displayed on the GUI [43].

Details of various ECG monitoring systems like ambulatory ECG system and ECG SoC have been summarized in table2 and table 3 respectively. Some commercial ECG is also summarized in table 4.

Table- 2: Comparison of Ambulatory Monitoring System

Proposed System	Electrode Type	Electrode Size	Attachment Method	Data Transmis-sion	Performance	Size	Freq.	CMMR (dB)	A/D	Battery Life, Power	Ref
Common Electrode Free ECG Monitoring System	Active Capacitive Electrode	5cm× 3 cm	Adhesive tape	--	Morphologically similar to conventional ECG	--	2kHZ	120	24 bit	--	32
Low Power System With Flexible Electrodes	Dry PDMS Electrode	--	Conductive snap	--	Morphologically similar to conventional ECG	5.8×5 ×0.4 cm^3	512 HZ	102	--	3 days with two 2500mAh batteries, 84.83mW	33
Non-Contact ECG monitoring via mobile cloud computing	--	--	Installed at the backrest of the chair	Bluetooth	Compared by visual inspection, lower QRS amplitude	--	--	--	--	--	34
E- Bra ECG monitoring System for women	Dry Electrode	--	Bottom layer of the GPRS brassiere	--	--	--	100 HZ	--	10 bit	100mAh 3.7 V, poly-Lithium battery	35
Sensorized T-shirt	Dry textile electrodes	--	Snap buttons	Bluetooth LE	--	--	512 HZ	--	24 bit	--	36
Wireless ECG monitoring containing flexible ring electrodes	Dry multiring electrode	34mm, 46mm	--	Bluetooth	SNR:14-22 dB	80× 42× 10 mm^3	1000 HZ	129	24 bit	10.4, 59.1, 34.7 mA (standby transmission, data storing)	37
Non-contact ECG Monitoring	Capacitive textile electrode	--	Installed at the backrest of the chair	--	--	--	5 KHZ	--	18 bit	--	38

Armband for mobile ECG monitoring	Dry capacitive electrode	3cm× 3cm	Sewn in to the armband	Bluetooth LE	Comparable to standard lead 2 wet electrode system	48 mm	--	--	--	--	39
Chest belt for multiple patient ECG monitoring	Dry plastic electrodes	--	Snap buttons to connect the starp	ZigBee	Morphologically similar to conventional ECG	65× 34× 17 mm^3	320 HZ	112	24 bit	5-6 days, 3V Lithium - battery	16
H- shirt with integrated ECG electrode	Conductive fabric electrode	43mm× 30mm	Sensors are attached in the shirt by pressurized welding	Bluetooth LE	--	15× 50× 1.5 mm^3	250 HZ	40	12-bit	24 h, 150 mAh, 3.7 V Li battery	40
mobile based wearable ECG monitoring system	Dry foam electrodes	18mm×8 mm× 8mm	Embedded into small cases in the vest	Bluetooth, GSM	99.51% accuracy co relate with prerecorded ECG, approx. 98% accuracy of QRS detection.	4×2.5 ×0.6 cm^3	512 HZ	--	12 bit	33h, 1100 mAh Li-ion battery.	41
Wearable flexible ECG system based on PCB	3M2560 red dot wet ECG electrodes	--	PCB has metal buttons on the back side	--	predictability and Sensitivity of QRS 89.21, 99.68 %	114× 114 mm^2	250 HZ	40	12 bit	28d, 0.9mA from 150mA 3.7 V Lithium battery	42
Wearable ECG system with novel electrode placement and dynamic power adjustment	--	--	Snap buttons to sensor node	ZigBee	QRS sensitivity: 97.22% (at rest), 91.25% (running)	5.5× 2.5 cm^2	200 HZ	--	--	52h, from 600mAh	43
HBC based wearable ECG	--	3 cm×3 cm	Directly attached to the chest	Human body communication and USB	95% correlation with Holter ECG	--	500 HZ	--	10 bit	--	44
Smart based ECG monitoring system	Dry non-contact electrode	2 cm	Velcro was used to attach the electrode to cloth	Bluetooth	98% result matched with ECG from disposable electrode	7.5× 3.5 cm^2	512 HZ	--	12 bit	35h, 3.7 V Li battery	45

Table- 3: Comparison of ECG SoCs (System on Chips)

Proposed Device	CMOS Technology (nm)	Power Supply	Power Dissipation	Area	Input Impedance	B.W	Noise (µVrms)	CMRR (dB)	Summery	Ref.
Fully integrated wireless ECG SoC	130	0.25-0.7 V	74.8 µW	2.4×2.5 nm^2	< 10 MΩ	150 HZ	6.9 (0.05 HZ -150 HZ)	59	3 lead wireless ECG, RF TRx, power efficient µC.	46

CMOS based signal acquisition IC	65	0.6 V	3 nW (System) 1nW (AFE)	0.2 mm^2	--	1.5 - 370 HZ	26 HZ	60 dB at 100 HZ	DC offset compensation of Amplifier and input impedance is improved by positive feedback.	47
3-lead On chip QRS detection	350	2.4V	0.96 µW	1.56 mm^2	--	250 HZ	1.95 (0.05 to 250 HZ)	82	--	48
Low power leadless pacemaker for ECG acquisition	180	1.3 – 1.8 V	0.9 µW	8.6 mm^2	--	130 HZ	4.9	> 90	A sub-graphical record acquisition IC group action analog feature extraction is bestowed for a single-chamber lead-free pacemaker application.	49
Ultra-low power syringe implantable ECG SoC	65	0.6 V	64 nW (system) 16.8 nW (AFE)	3.7 mm^2	> 100MΩ for < 500 HZ	0.5 – 250 HZ	6.52	55	Developed syringe injectable ECG and done experiment with an isolated sheep and a live ship.	50
Wearable Context aware ECG monitoring system based on smart phone	180	3 V	12.5 mW	1.3 × 1.1 mm^2	> 5 MΩ	--	1.5	85	Low power ECG monitoring system which improves diagnosis performance of arrhythmia. The system is integrated with SD card, Bluetooth and microcontrolle r	51
Low power bio signal acquisition SoC	180	1.2 – 1.8 V	25 mW	9 mm^2	--	--	--	--	The system is fully integrated with power management unit, SIMO, RF Communicatio n and TEG	52
Wearable ECG ASIC heart rate monitoring device	180	0.8 V	58 nW	0.76 mm^2	--	0.5 – 22 HZ	2.7	66	Proposed device contains PGA, CMOS technology, 0.7mah li-ion battery.	53

Wearable health monitoring based on ECG processor.	130	1.2 – 3 V	18.24 µW to 3 mW	6.9 × 6.9 mm²	--	100 HZ	--	73	Developed algorithm to measure p, QRS and T wave. System is designed to measure ECG on the android phone.	54
Low power bio potential front end amplifier	180	0.6 V	0.6 µW	0.28 mm²	--	0.5 – 100 HZ	5.41 (0.5 – 100 HZ) 0.88 (0.5 – 100 HZ) 72.1 (0.5 – 100 HZ)	> 120	Bio signal recording is done by suing the bio potential amplifier. MOS transistor in the proposed Ic is such that the system power is reduced.	55
Low power remote ECG monitoring system based on ASIC	180	1.8 V	9.47µW (whole system)	1.74 mm² (whole system)	--	250 HZ	5.2 (0.25-250 HZ)	150	The proposed system is IoT based and having low power. Achieved approx. 99% accuracy for normal and abnormal ECG signals.	56
Fully reconfigurable low noise bio-potential Amplifier	350	2.5 V	0.62µW	0.17 mm²	--	10 KHZ	2.8 (0.05-200 KHZ)	> 70	Proposed bio potential amplifier may achieve the great efficiency between power and noise.	57
Time based AFE	40	0.6 V	3.3 µW	0.015 mm²	~50 MΩ	0.15 KHZ	7.8, 20 (1-150 HZ)	60	Achieved a large DR readout.	58
Fully integrated wireless ECG SoC	130	1.2 V	2.89 µW	8.75 mm²	3.6 GΩ	0.15 KHZ	3.06 (0.5-150 HZ)	64.9	Clock-less ECG with on chip IR-UWB Tx antenna.	59

Table- 4: Comparison of Commercial ECG Monitoring

System, Manufacturer	Size (mm³)	Connectivity	Real Time Transmission	Memory Type	Storage	Wearable?	Continuous reading	Battery (Quantity)	Battery Life	Recording Duration	Feature	Ref
Kardia Mobile by Aliveco Inc.	81× 35.5× 5	Bluetooth	√	Smart Phone Memory	~	√	×	3 V coin Cell (1)	200 hr., 12 months approx.	30 s- 5 min	Measures ECG and graph is displayed on the mobile	60

(US)											phone.	
QARDI Ocore by quardio Inc. (USA)	185×87 ×9	Bluetooth 4.0	√	Smart phone memory	~	√	√	Li-ion polymer (1)	1 day in continuo-us mode	Up to 1 day	Wearable device to measure electrocardiogram, body Temperature, respiratory rate.	61
Heart rate monitor by AfibAlert (USA)	149.5× 70×28	USB	×	Embedded	34 records	√	×	AAA Alkaline (2)	27 days	45 s	Instantly recorded ECG with 94.6% detection of atrial fibrillation.	62
Cardio-B palm Bluetooth with software ECG by Gima (Italy)	125×70 × 21.5	USB	×	Embedded	1200 records	×	√	AAA Alkaline (2)	--	30 s	This system is handheld which records and measure ECG signal.	63
The Heart Check PEN handheld ECG by Cardiocomm Solutions Inc. (Canada)	130× 30× 20	USB	×	Embedded	20 records	×	×	AAA Alkaline (2)	--	30 s	Handheld ECG recording, monitoring and measurements.	64
The Heart Check handheld ECG device by Cardiocomm Solutio	136×84 × 21	USB	×	Embedded	200 records	×	√	AAA Alkaline (2)	~400 ECG recordings	30 s, continuous	Handheld ECG recording, monitoring and measurements.	65

ns Inc. (Canada)												
Easy ECG check by cardiac Designs (USA)	118×62 × 17	Bluetooth 4.0	√	Smart phone memory	~	×	×	3 V coin cell (1)	8 hr. (~480 recordings)	30 s	Monitoring and analysis of ECG in a smart phone.	66
Color portable ECG monitor by Dimetek digital technologies Ltd. (China)	90× 60× 16	USB, Bluetooth	×	SD Card (2GB)	600 hrs. of records	×	√	AAA Alkaline (2)	24 hours continuous	12 s – 32 hr.	Provide ECG traces, cardiac healthcare and early warning against cardiac risk.	67
Handheld ECG monitor MD100 B by Choice MMed technology India Pvt. Ltd, Delhi, India)	136× 84× 21	USB	×	Embedded	200 records	×	×	AAA Alkaline (2)	400 recordings	30 s	Monitor and records, 1,2,3 lead ECG, displays to the professional healthcare	68
Handheld ECG monitor MD100 B by Choice MMed technology India Pvt. Ltd, Delhi, India)	140× 75× 26	USB	×	Embedded	100 records/ 24 hours	×	√	AA Alkaline (2)	500 recordings	30 s- 24 hrs.	Monitor and records, 1,2,3 lead ECG, support micro SD card	69

Easy ECG monitor – PC-80- A by Heal force Bio-medicte ch holdings Ltd. (China)	125×70 × 21.5	Bluetooth 4.0	×	Embedded	1200 records/ 10hrs. Continuous.	×	√	AAA Alkaline (2)	--	30 s – 10 hrs.	ECG recording and monitoring.	70
H3+ Digital Holter Recorder by Welch Allyn (USA)	64× 25× 19	USB	×	Embedded	48 Hours continuous	×	√	AAA Alkaline (1)	48 Hours Continuous	30s- 2 days	Record and monitor ECG, provides modified 1, 2, 5 or bipolar channel 1 and channel 2.	71

3. PROPOSED WORK

Authors reviewed various research articles of wearable health monitoring device. They have approached different techniques and communication protocol to obtain health data of the patient. Some of them have used wired and some have used wireless communication to obtaining the data. In this research articles we are proposing a low power wearable cardiac activity monitoring device. Authors are using MAX30003 chip [73], which is a complete bio-potential analog front end (AFE) solution for wearable health tech applications such that to develop a single lead wireless patches and arrhythmia detection for at medical clinic or at home. It is also used for developing in fitness band that measure heart rate and for ECG and bio authentication applications. MAX3003 has EMI filtering, DC lead off detection, ESD protection, internal lead biasing, high common mode rejection ratio, PGA, high resolution ADC and various high and low pass filters. It has feature of ultra-low power 85μW at 1.1V supply voltage that leads longer battery life for the device. The bio-potential channel is DC coupled, can handle massive voltage offsets, and contains a fast recovery mode to quickly pass through electro-surgery and defibrillation. We have proposed block diagram of low power cardiac activity monitoring device shown in figure 3.

Proposed block diagram consisting of a MAX 30003 SoC, a microcontroller unit (MCU) MAX32630 FTHR, external filter, RC filter, two physical electrodes, and an Output display unit. MAX32630 FTHR board is a development board with MAX32630 ARM cortex M-4 microcontroller. It has various features like Bluetooth low energy to transfer heart rate and ECG signal to the smart phone. Micro secure digital card is utilized to store the health records of the users. To obtain the electrocardiogram and HR data we need to interface microcontroller with Mbed OS platform, which is an open source platform, where algorithm can be compile. When the algorithm will compile in Mbed OS platform, the microcontroller communicates with Mbed OS as well as other supportive circuit. Microcontroller will receive ECG signal through physical electrode that is attached with skin's surface and passed through external filter, which removes the noise and filtered signal passed to the microcontroller. Bluetooth low energy enabled microcontroller sends real time data on mobile phone display while SD card is used to store ECG data and can be

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displayed on any other display screen like computer or mobile.

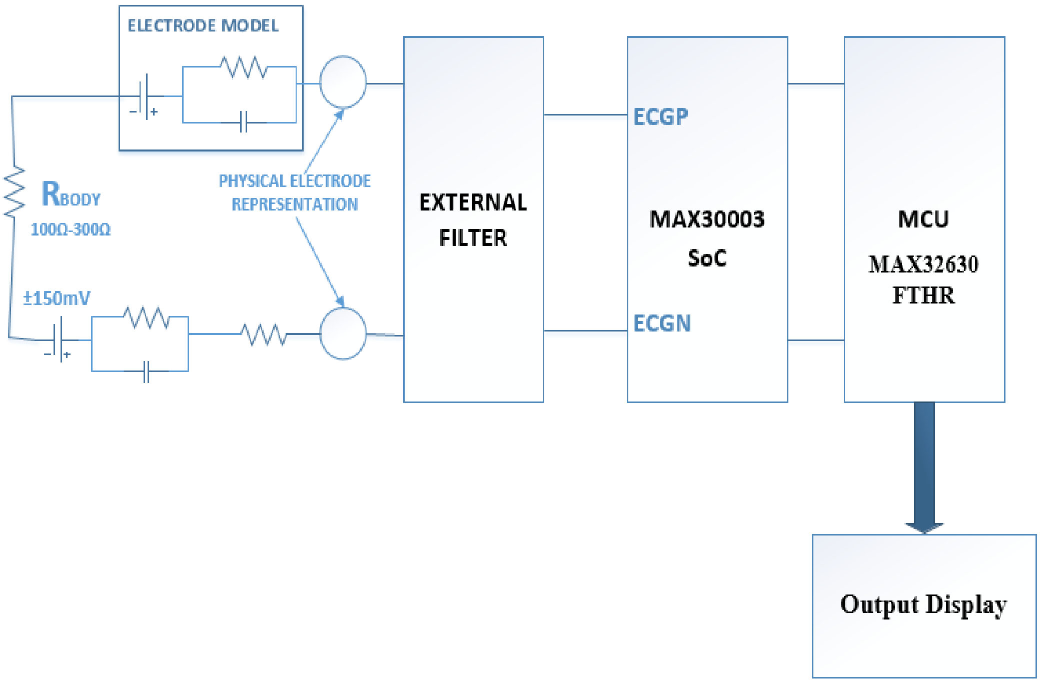

Fig- 3: Block diagram of Proposed System

4. CONCLUSIONS

Mostly researchers focus in wearable monitoring devices for older person and sports person, for regular health monitoring. ECG recording system/ device have been reviewed completely within the literature. However there are multiple aspects of these monitoring devices make it arduous for researchers, academician, and medical practitioners to select between those devices to carry-out their desire requirements like monitoring needs, support to require disease monitoring requirement etc.

In this research articles we carried out various wearable ECG monitoring system targeting different techniques to obtain desired ECG signals, health monitoring devices like heart rate, arrhythmia detection, ECG monitoring system/ devices, have been evolved to attain portability, improve signal detection, low power consumption by requirement of consumers among battery life, size, signal quality and cost effect. We presented and discussed different wearable ECG monitoring devices developed by different researchers and system manufacturers. Authors have also classified ECG system based on their memory type, storage, connectivity, recording duration, power supply, noise, performance, electrode type, battery quantity etc. Over 60 ECG monitoring system research articles has been studied the concept of design and development of wearable ECG monitoring devices based on wireless communication, smart mobile based, wireless textile based and recognized their specifications. Some researchers also designed architecture for Internet of Things (IoT) enabled ECG recording system consisting of Wi-Fi, and the data is transmitted wirelessly over the cloud server i.e. online and offline data can be stored in the SD card and doctors will be able to access the ECG data from anywhere and can diagnose as per received data of patients. In recent advancement ECG is involving with new technologies such that Artificial Intelligence, Internet of Things, and big Data allows powerful monitoring system, fully connect and cost effective. To that finish Authors recommended that this work with a close discussion on several relevant research work of wearable ECG monitoring system. It can help to numerous researchers and academicians within the field to understand, value and contrast ECG monitoring system characteristics. This article also highlights portability, cost, size, battery life etc. Finally this outline can be a future vision for upcoming ECG monitoring System for healthcare.

REFERENCES

[1] Johansson BW, "A History of Electrocardiography", Dan Medicinhist Arbog, Pubmed, pp. 76-163, 2001.

[2] Esen Ozkaya and Pınar Kavlak Bozkurt," Allergic contact dermatitis caused by self-adhesive electrocardiography electrodes: a rare case with concomitant roles of nickel and acrylates," doi:10.1111/cod.12146.

[3] [Online] available: Cardiovascular diseases (who.int)

[4] [Online] available: Why are so many Asians dying due to heart diseases? - Health Analytics Asia Health Analytics Asia (ha-asia.com).

[5] L. Stingeni et al., "The role of acrylic acid impurity as a sensitizing component in Electrocardiography electrodes," Contact Dermatitis, vol. 73, no. 1, pp. 44–8, 2015.

[6] E. Ozkaya and P. Kavlak Bozkurt, "Allergic contact dermatitis caused by self-adhesive electrocardiography electrodes: A rare case with concomitant roles of nickel and acrylates," Contact Dermatitis, vol. 70, no. 2, pp. 121–123, 2014.

[7] N. Sakamoto et al., "Three cases of corticosteroid therapy triggering ventricular fibrillation in J-wave syndromes," Heart Vessels, vol. 29, no. 6, pp. 867–872, 2014.

[8] A. C. Deswysen et al., "Allergic contact dermatitis caused by self-adhesive electrocardiography electrodes in an infant," Contact Dermatitis, vol. 69, no. 6, pp. 379–381, 2013.

[9] B. Nunez-Acevedo et al., "Multifunctional acrylates as possible sensitizers in Electrocardiography electrode allergy," Ann. Allergy Asthma Immunol., vol. 111, no. 1, pp. 77–78, 2013.

[10] Chien-Lung Shen, Tsair Kao, Ching-Tang Huang, Jun-huei Lee," Wearable Band Using a Fabric-Based Sensor for Exercise ECG Monitoring," 10th IEEE International Symposium on Wearable Computers 2006.

[11] Jakob Justesen, Seren Christian Madsen," Wearable wireless EEG monitoring Hardware prototype for use in patients own home," 3rd International Conference on Pervasive Computing Technologies for Healthcare, 2009.

[12] [Online] available: Wearable Cardiac Devices Market Size | Industry Share Report 2026 (gminsights.com).

[13] C.J. Deepu, X.Y. Xu, X.D. Zou, L.B. Yao, and Y. Lian,"An ECG-on-Chip for Wearable Cardiac Monitoring Devices," Fifth IEEE International Symposium on Electronic Design, Test & Applications 2010.

[14] Meiran Peng, Tiandong Wang, Guangshu Hu, Hui Zhang," A wearable heart rate belt for ambulant ECG monitoring," IEEE 14th International Conference on e-Health Networking, Applications and Services (Healthcom) 2012.

[15] Kevin C. Tseng, Bor-Shyh Lin, Lun-De Liao, Yu-Te Wang, and Yu-Lin Wang," Development of a Wearable Mobile Electrocardiography Monitoring System by Using Novel Dry Foam Electrodes," IEEE SYSTEMS JOURNAL, VOL. 8, NO. 3, SEPTEMBER 2014.

[16] Elisa Spano, Stefano Di Pascoli, Giuseppe Iannaccone," Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring," IEEE SENSORS JOURNAL, VOL. 16, NO. 13, JULY 1, 2016.

[17] Byungkook Jeon, Jundong Lee and Jaehong Choi," Design and Implementation of a Wearable ECG System," International Journal of Smart Home Vol. 7, No. 2, March, 2013.

[18] Vega Pradana Rachim, Wan-Young Chung," Wearable Noncontact Armband for Mobile ECG Monitoring System," IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS, VOL. 10, NO. 6, DECEMBER 2016.

[19] Wenxin Tong, Chen Kan, Hui Yang," Sensitivity Analysis of Wearable Textiles for ECG Sensing," IEEE EMBS International Conference on Biomedical & Health Informatics (BHI) Las Vegas, Nevada, USA, 4-7 March 2018.

[20] Zhendong Ai, Lijuan Zheng, Hongsheng Qi, Wei Cui," Low-Power Wireless Wearable ECG Monitoring System Based on BMD101," Proceedings of the 37th Chinese Control Conference July 25-27, Wuhan, China 2018.

[21] Abhinay Vishwanatham, Narendra Ch., Abhishek S R, Ramakrishna Chaitanya R, Siva Sankara Sai Sanagapati," Smart and Wearable ECG monitoring system as a Point of Care (POC) device," IEEE International Conference on Advanced Network and Telecommunication (ANTS) 2018.

[22] Prachi Kamble, Ashish Birajdar," IoT Based Portable ECG Monitoring Device for Smart Healthcare," Fifth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) 2019.

[23] Aleksei Anisimov, Boris Alekseev, Dimitri Egorov," Development of Portable Cardiograph Using Novel Front-End Solutions," PROCEEDING OF THE 25TH CONFERENCE OF FRUCT ASSOCIATION.

[24] Shakthi Murugan.K.H, Sabiya Begum.M, Saranya.B, Vinodhini.S," A Precise on Wearable ECG Electrodes for Detection of Heart Rate and Arrthymia Classification," 4th International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB-18).

[25] Byungkook Jeon, Jundong Lee and Jaehong Choi,"Design and Implementation of a Wearable ECG System," International Journal of Smart Home Vol. 7, No. 2, March, 2013.

[26] BOR-SHYH LIN, WILLY CHOU, HSING-YU WANG, YAN-JUN HUANG, AND JENG-SHYANG PAN," Development of Novel Non-contact Electrodes for Mobile Electrocardiography Monitoring System," WEARABLE SENSORS AND HEALTH MONITORING SYSTEMS, 2013.

[27] Caterina Foti, Antonio Lopalco, Luca Stingeni, Katharina Hansel, Angela Lopedota, Nunzio Denora, Paolo Romita," Contact allergy to Electrocardiography electrodes caused by acrylic acid without sensitivity to methacrylates and ethyl cyanoacrylate. Contact Dermatitis. 2018;1–4.

[28] A. A. Chlaihawi et al., "Development of flexible dry ECG electrodes based on MWCNT/PDMS composite," 2015 IEEE SENSORS, Busan, Korea (South), 2015, pp. 1-4, doi: 10.1109/ICSENS.2015.7370218.

[29] C. L. Lam, N. N. Z. M. Rajdi and D. H. B. Wicaksono, "MWCNT/Cotton-based flexible electrode for electrocardiography," SENSORS, 2013 IEEE, Baltimore, MD, USA, 2013, pp. 1-4, doi: 10.1109/ICSENS.2013.6688179.

[30] Hongqiang Li , Xuelong Chen , Lu Cao , Cheng Zhang , Chunxiao Tang , Enbang Li , Xiuli Feng and Huan Liang," Textile-based ECG acquisition system with capacitively coupled electrodes," Transactions of the Institute of Measurement and Control 1–8, 2015.

[31] M. Magno, L. Benini, C. Spagnol, E. Popovici," Wearable Low Power Dry Surface Wireless Sensor Node for Healthcare Monitoring Application," 1st International Workshop on e-Health Pervasive Wireless Applications and Services (eHPWAS'13).

[32] T. Komensky, M. Jurcisin, K. Ruman, O. Kovac, D. Laqua, and P. Husar, "Ultra-wearable capacitive coupled and common electrode-free ECG monitoring system," in Proc. 2012 Annu. Int. Conf. IEEE Eng. Med. Biol. Soc., 2012, pp. 1594–1597.

[33] C.-Y. Chen et al., "A Low-power bio-potential acquisition system with flexible PDMS dry electrodes for portable ubiquitous healthcare applications," Sensors, vol. 13, no. 3, pp. 3077–3091, Apr. 2013.

[34] E.-M. Fong and W.-Y. Chung, "Mobile cloud-computing-based healthcare service by noncontact ECG monitoring," Sensors, vol. 13, no. 12, pp. 16451–16473, Feb. 2013.

[35] H.-Y. Lin, S.-Y. Liang, Y.-L. Ho, Y.-H. Lin, and H.-P. Ma, "Discrete wavelet-transform-based noise removal and feature extraction for ECG signals," Irbm, vol. 35, no. 6, pp. 351–361, 2014.

[36] M. W. Rivolta et al., "A new personalized health system: The SMARTA project," in Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 192, 2017, pp. 375–380.

[37] Y. Ye-Lin et al., "Wireless sensor node for non-invasive high precision electrocardiographic signal acquisition based on a multi-ring electrode," Measurement, vol. 97, pp. 195–202, 2017.

[38] B. Chamadiya et al., "Textile-based, contactless ECG monitoring for non-ICU clinical settings," J. Ambient Intell. Humanized Comput. vol. 4, no. 6, pp. 791–800, 2012.

[39] V. P. Rachim and W.-Y. Chung, "Wearable noncontact armband for mobile ECG monitoring system," IEEE Trans. Biomed. Circuits Syst., vol. 10, no. 6, pp. 1112–1118, 2016.

[40] F. Sun, C. Yi, W. Li, and Y. Li, "A wearable H-shirt for exercise ECG monitoring and individual lactate threshold computing," Comput. Ind., vol. 92/93, pp. 1–11, 2017.

[41] K. C. Tseng et al., "Development of a wearable mobile Electrocardiography monitoring system by using novel dry foam electrodes," IEEE Syst. J., vol. 8, no. 3, pp. 900–906, Sep. 2014.

[42] E. S. Winokur, M. K. Delano, and C. G. Sodini, "A wearable cardiac monitor for long-term data acquisition and analysis," IEEE Trans. Biomed. Eng., vol. 60, no. 1, pp. 189–192, Jan. 2013.

[43] Y. Wang, S. Doleschel, R. Wunderlich, and S. Heinen, "A wearable wireless ECG monitoring system with dynamic transmission power control for long-term homecare," J. Med. Syst., vol. 39, no. 3, p. 35, 2015.

[44] J. Wang, T. Fujiwara, T. Kato, and D. Anzai, "Wearable ECG based on impulse-radio-type human body communication," IEEE Trans. Biomed. Eng., vol. 63, no. 9, pp. 1887–1894, Sep. 2016.

[45] B.-S. Lin et al., "Development of novel non-contact electrodes for mobile Electrocardiography monitoring system," IEEE J. Trans. Eng. Health Med., vol. 1, pp. 1–8, 2013.

[46] M. Khayatzadeh, X. Zhang, J. Tan, W.-S. Liew, and Y. Lian, "A 0.7-V 17.4-μW 3-lead wireless ECG SoC," IEEE Trans. Biomed. Circuits Syst., vol. 7, no. 5, pp. 583–592, Oct. 2013.

[47] P. Harpe et al., "A 0.20 3 nW signal acquisition IC for miniature sensor nodes in 65 nm CMOS," IEEE J. Solid-State Circuits, vol. 51, no. 1, pp. 240–248, Jan. 2016.

[48] C. J. Deepu, X. Zhang, C. H. Heng, and Y. Lian, "A 3-lead ECG-on-chip with QRS detection and lossless compression for wireless sensors," IEEE Trans. Circuits Syst. II, Express Briefs, vol. 63, no. 12, pp. 1151–1155, Dec. 2016.

[49] L. Yan et al., "A 680 nA ECG acquisition IC for leadless pacemaker applications," IEEE Trans. Biomed. Circuits Syst., vol. 8, no. 6, pp. 779– 786, Dec. 2014.

[50] Y.-P. Chen et al., "An injectable 64 nW ECG mixed-signal SoC in 65 nm for arrhythmia monitoring," IEEE J. Solid-State Circuits, vol. 50, no. 1, pp. 375–390, Jan. 2015.

[51] F. Miao, Y. Cheng, Y. He, Q. He, and Y. Li, "A wearable context-aware ECG monitoring system integrated with built-in kinematic sensors of the smartphone," Sensors, vol. 15, no. 5, pp. 11465–11484, 2015.

[52] A. Klinefelter et al., "21.3 A 6.45μW self-powered IoT SoC with integrated energy-harvesting power management and ULP asymmetric radios," in Proc. 2015 IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, 2015, Paper 21.3, pp. 383–386.

[53] D. D. He and C. G. Sodini, "A 58 nW ECG ASIC with motion tolerant heartbeat timing extraction for wearable cardiovascular monitoring," IEEE Trans. Biomed. Circuits Syst., vol. 9, no. 3, pp. 370–376, Jun. 2015.

[54] S. K. Jain and B. Bhaumik, "An energy efficient ECG signal processor detecting cardiovascular diseases on smartphone," IEEE Trans. Biomed. Circuits Syst., vol. 11, no. 2, pp. 314–323, Apr. 2017.

[55] Y. Tseng, Y. Ho, S. Kao, and C. Su, "A 0.09 μW low power frontend biopotential amplifier for biosignal recording," IEEE Trans. Biomed. Circuits Syst., vol. 6, no. 5, pp. 508–516, Oct. 2012.

[56] N. Vemishetty et al., "Low power personalized ECG based system design methodology for remote cardiac health monitoring," IEEE Access, vol. 4, pp. 8407–8417, 2016.

[57] T.-Y. Wang, M.-R. Lai, C. M. Twigg, and S.-Y. Peng, "A fully reconfigurable low-noise biopotential sensing amplifier with 1.96 noise efficiency factor," IEEE Trans. Biomed. Circuits Syst., vol. 8, no. 3, pp. 411–422, Jun. 2014.

[58] R. Mohan et al., "A 0.6-V, 0.015-mm2, time-based ECG readout for ambulatory applications in 40-nm CMOS," IEEE J. Solid-State Circuits, vol. 52, no. 1, pp. 298–308, Jan. 2017.

[59] X. Zhang, Z. Zhang, Y. Li, C. Liu, Y. X. Guo, and Y. Lian, "A 2.89-μW clockless wireless dry-electrode ECG SoC for wearable sensors," in Proc. IEEE Asian Solid-State Circuits Conf., 2015, pp. 1–4.

[60] "Peace of mind," AliveCor. [Online]. Available: https://www.alivecor. com/?gclid=EAIaIQobChMI8u2iz_fw1gIVEIJpCh2HOwkT EAAYAS ABEgLdv_D_BwE.

[61] "Smart Wearable ECG EKG Monitor—QardioCore," Qardio. [Online]. Available: https://www.getqardio.com/qardiocore-wearable-ecg-ekg-monitor-iphone/.

[62] "AfibAlert—Heart rhythm monitor with instant atrial fibrillation detection," Lohman Technol. [Online]. Available: http://www. lohmantech.com/.

[63] "CARDIO-B PALM ECG," Gima, articoli medicali, apparecchi per medicina, elettromedicali, endoscopi, misuratori medicali, arredo ambulatorio, elettrobisturi, articoli per il pronto soccorso, articoli per la sterilizzazione. [Online]. Available: http://www.gimaitaly.com/prodotti. asp?sku=33261&dept_selected=580&dept_id=5800.

[64] "The HeartCheck PEN handheld ECG device," CardioComm Solutions Inc., North York, ON, Canada. [Online]. Available: http://www. cardiocommsolutions.com/QTStudy/.

[65] "PHYSICIANS," The Heart Check. [Online]. Available: http://www. theheartcheck.com/physician.html.

[66] "Home - ECG Check | iPhone & Android heart monitor," Home - ECG Check | iPhone & Android heart monitor. [Online]. Available: http://cardiacdesigns.com/.

[67] "Color Portable ECG Recorder Dicare m1CC,"

Portable ECG Recorder, Cardiac Monitor, Ambulatory ECG, Dimetek Digital Medical Technologies, Ltd. [Online]. Available: http://www.dimetekus.com/ Color-Portable-ECG-Recorder-Dicare-m1CC_p234.html.

[68] "Handheld ECG Monitor [Online]. Available: http://www.choicemmed. com/info.aspx?m=photo&id=447#.

[69] "Handheld ECG Monitor [Online]. Available: http://www.choicemmed. Com/info.aspx?m=photo&id=537#.

[70] "Easy ECG Monitor—PC-80A (Bluetooth 4.0)," Easy ECG Monitor – PC-80A (Bluetooth 4.0)-Portable ECG Monitors-Heal Force Biomeditech Holdings Limited. [Online]. Available: http://www.healforce. com/en/index.php?ac=article&at=read&did=176.

[71] "H3+," Mortara Instrument. [Online]. Available: https://www.mortara. com/products/healthcare/holter-monitoring/h3/.

[72] W. Einthoven, "Un nouveau galvonometre," Nat. Arch Neerl Sci Exactes, vol. 6, pp. 623–33, 1901.

[73] [Online] available: MAX30003 Ultra-Low Power, Single-Channel Integrated Biopotential (ECG, R to R Detection) AFE | Maxim Integrated.

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