Future Directions of Power Sources for Ambulatory ECG Monitors

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Abstract

There exists a technology gap between portable diagnostic healthcare devices and the energy sources that power them. Battery technology has been developing more slowly than microprocessor, wireless, and data storage technologies, yet is fundamental to every nomadic healthcare device. Without either considerable battery development or a new approach to portable power the full impact of long-term portable ECG will be forever limited.

This paper presents empirical measurements for a number of commercially available ambulatory ECG monitors and considers potential solutions to the aforementioned technology gap for the next generation of healthcare devices.

1. Introduction

Battery technology as the limiting parameter in portable equipment is not a new phenomenon and it has been recognised that there is a genuine need for the energy requirements of roaming devices to be addressed [1]. As portable technology proliferates the market the need for energy solutions grows ever stronger. This is despite the fact that much work has been done to mitigate the shortcomings of battery technology, and indeed battery technology itself has experienced considerable research and development [2].

Mobile health monitors are an area of increasing interest, with remote healthcare and long-term monitoring of chronic conditions becoming a reality [3-5]. For such devices the importance of power in mobile health monitors is well recognised [6, 7], with recent global workshops organised by the IEEE to address theme of safe mobile power [1].

There have been undertakings to develop portable medical devices which use less energy in an attempt to extend run-times, such as [8] who developed ECG hardware and algorithms specifically targeted at frugal battery usage. A predominant school of thought is that if batteries are the problem then another way to provide energy to the portable device must be developed, such as energy harvesting technology. The current academic literature reveals the work undertaken in this area, with [9] presenting a battery-less system-in-a-patch ECG monitoring unit, [10] demonstrating wireless energy harvesting for ECG and BCG applications, [11] reporting on a battery-less energy harvesting body sensor node, and [12] who displayed an energy-harvesting healthcare network based on ECG and physical-activity sensors. Some progress has been made in using the body as an energy source [15, 11], although it is argued that this has little application for bed-bound patient monitoring. Furthermore, some novel approaches have been taken to the problem with [14] unveiling a system powered by the user's own urine.

It is envisaged that the next generation of healthcare monitors will be implantable, and power supplies for subcutaneous devices cannot be frequently charged via a traditional wall socket, so it is most advantageous to address the energy supply needs of such devices now using the wearable devices platform. To address the energy supply for ambulatory monitoring devices we must quantity the status of the current commercial situation.

Therefore, this paper presents empirical results from a measurement campaign designed to quantify the power requirements for modern ambulatory ECG monitors which utilize various power-saving schemes. From this vantage point it is thus possible to critique existing battery technology and consider alternative power paradigms for future devices.

2. Equipment

It is difficult to fairly compare various ambulatory ECG devices as most use different microprocessors, wireless technologies, reporting strategies, etc. Also, some record only ECG while others also measure heart rate, respiration rate, skin temperature, SpO2, etc. Despite this however, the fundamental parameter to which they must be measured by is indeed their basic useful operating time between charges. Regardless of what they measure and how they transfer their data, the activity of charging the device results in a break in monitoring and that occasional ECG abnormality of particular interest is as likely to occur during uptime as it is during the lengthy charging downtime.

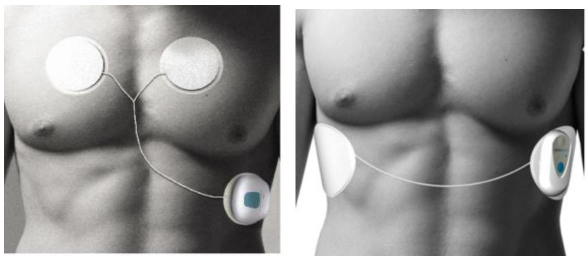

Figure 1. Ambulatory healthcare monitors under test. (A) Aingeal monitor. (B) zensor monitor.

Specifically selected commercially available ambulatory ECG monitoring devices were chosen as a testbed for investigation, these were the Aingeal device (Fig. 1A) and the zensor device (Fig. 1B) from Intelesens (www.intelesens.com). The Aingeal system is a real time respiration and diagnostic quality ECG (modified Lead II) monitor and is suitable for hospital monitoring using wireless data transmission to the hospital's Wi-Fi system. The zensor system facilitates real time respiration and diagnostic quality ECG (3-lead ECG) monitoring and is suitable for home or remote monitoring with wireless transmission using a standard Wi-Fi or mobile hotspot, or recording data to the on-board memory. Both systems are powered by contemporary battery technology of re-chargeable 1000mAh lithium-polymer packs, with the zensor offering battery replacement in situ. Both devices are commercially available and were not altered from standard factory settings for testing purposes. Operational modes for the devices include –recording specific cardiac event data to an SD card or via a wireless link; sending data periodically (pre-scheduled) via an RF connection; and streaming live data continuously.

3. Methods

A random sample of four of the commercially available "Aingeal" ambulatory ECG monitoring devices were selected for testing. An in-depth study was performed on the various devices based around observable power consumption rates for assorted modes of operation. Each of the devices were charged to their maximum capacity (fully charged) and commissioned at the same time. Of particular interest was the effect of the different pre-scheduled fixed reporting frequencies used to transfer data to the hospital patient information system. Typically this is a key parameter set by clinicians and previous observations indicated that the chosen reporting mode had a notable impact on battery life.

Furthermore, the Aingeal devices are designed to issue software-generated alarms at various remaining runtime estimates (low power alarms). Alarms were observed for 120mins, 30 minutes, and 15 minutes runtime remaining, with total runtime (0 minutes) also recorded. Devices were tested at room temperature in an operational clinical environment.

In addition to these tests the other device ("zensor") was tested as a comparison to investigate how other similar devices compare with respect to run time for the same reporting frequency. Additionally we investigate how using the zensor device in holter mode (RF module disabled and on-board data storage only) affects the total run time.

4. Results

4.1. Aingeal devices

The measurement campaign highlighted the power consumption requirements for the various ambulatory ECG monitors. Pre-scheduled reporting using various fixed reporting frequencies yielded the following results for the 1000mAh cells using Wi-Fi wireless links.

Table 1. Time to alarms (in hours) and run time (in hours) for various reporting frequencies for Aingeal device.

Reporting Freq.	Device	Time to 120min Alarm	Time to 30min Alarm	Time to 15min Alarm	Total Run Time
1 Hour	1	30.52	32.05	32.28	32.53
	2	31.81	33.31	33.54	33.79
	3	32.33	33.84	34.07	34.32
	4	32.55	34.05	34.31	34.56
30 Minutes	1	30.58	32.09	32.36	32.61
	2	30.70	32.25	32.46	32.71
	3	32.59	34.10	34.34	34.59
	4	35.48	37.00	37.25	37.50
15 Minutes	1	32.98	34.49	34.72	34.97
	2	30.89	32.39	32.63	32.88
	3	30.04	31.53	31.79	32.04
	4	36.08	37.59	37.86	38.11
5 Minutes	1	32.91	34.43	34.66	34.91
	2	32.07	33.58	33.84	34.09
	3	34.68	36.18	36.45	36.70
	4	36.30	37.80	38.05	38.30
1 Minutes	1	26.43	27.95	28.19	28.44
	2	29.56	31.07	31.30	31.55
	3	26.54	28.02	28.30	28.55
	4	28.38	29.88	30.15	30.40

Table 2. Average time to alarms (in hours) versus reporting frequency for Aingeal device.

Reporting Freq.	120min Alarm time (hours)	30min Alarm time (hours)	15min Alarm time (hours)	Total Time (hours)
60 min	31.80 ± 0.91	33.31 ± 0.90	33.55 ± 0.90	33.80 ± 0.90
30 min	32.34 ± 2.29	33.86 ± 2.28	34.10 ± 2.29	34.35 ± 2.29
15 min	32.50 ± 2.69	34.00 ± 2.70	34.25 ± 2.70	34.50 ± 2.70
5 min	33.99 ± 1.88	35.50 ± 1.88	35.75 ± 1.88	36.00 ± 1.88
1 min	27.73 ± 1.51	29.23 ± 1.52	29.48 ± 1.51	29.73 ± 1.51

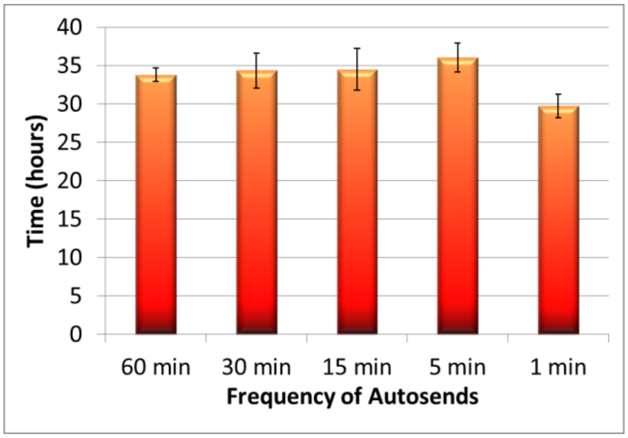

Figure 2. Average maximum run time of Aingeal devices for various reporting frequencies.

Table 1 reports on the time to the various preset alarms for each device with respect to the set reporting frequency (the 15 minute alarm is called the critical alarm to warn users to recharge immediately), while table 2 presents the mean time to alarms for each reporting frequency and the standard deviation about the mean. Figure 2 displays the averaged maximum battery life for the Aingeal devices with respect to the various reporting frequencies.

It is observed that at reporting time of 5 minutes yields the best battery life and 1 minute reporting time the worst. Reporting times of 60, 30, and 15 minutes each delivered similar battery lives. As part of a mechanism to ensure that the device remains within Wi-Fi coverage and the hospital server is still contactable, it tries to establish a connection at least every 2 minutes by sending a short data packet; this is regardless of the reporting frequency the device. This procedure appears to have a limited effect on all reporting times except for 1 minute frequency as such regular wireless connections acts as a more rapid drain on the battery.

The range of run times is also interesting as it is suggestive of best and worst battery lives for such devices and clearly highlights the need for frequent recharging which results in a break in monitoring.

Additionally, it was observed (although the graphs are not presented here for brevity) that the same characteristic pattern was exhibited for each of the various 120 minute, 30 minute, and 15 minute alarm run times also, that is, 5 minutes reporting time had the longest battery duration and 1 minute the shortest. This would indicate that battery usage was most likely consistent during operation.

Looking at the standard deviation values of the maximum run times it is understood that a reporting frequency of 60 minutes gives the least variation and 15 minutes the most variation between the individual devices under test (Table 2). This would suggest that selection of 60 minutes reporting frequency offers a slightly more predictive operational run time for devices in operation. In truth there are only minor variations between the performance of individual devices which one could argue is a simple result of tolerances in battery performance, sub-assemblies and usage during the tests.

4.2. Zensor/Aingeal comparison

For comparison an alternative Wi-Fi ambulatory ECG device with similar hardware and a 1000mAh cell was tested with a focus on 15 minute reporting frequency (default setting). Comparison of measured results indicate that the average run time for both sets of devices were comparable, with the average run time for the Aingeal devices being 34.5 hours and 37.6 for the Zensor devices. While this is only a small sample it clearly indicates that typical run times for such ECG devices is less than 2 days before charging is required.

4.3. Home monitoring versus hospital monitoring setup

The above zensor devices were also tested to investigate the effects disabling the RF module and only saving data to the on-board memory (SD card) has on the run time. It is typical that if an ECG ambulatory device is required to operate in an environment outside of a hospital (e.g. residential) it is utilised in “holter mode” where a Wi-Fi link cannot be guaranteed and therefore the device records all data onto the considerable on-board memory. For the non-RF tests the average run time for the zensor devices was 81.1 hours, which, when compared to the standard operational mode run time of 37.6 hours, shows how the use of wireless technology equates to a much shorter battery life. However, in a clinical setting it is necessary to transmit patient data regularly to the main system, both to save it to the patient’s record and also to highlight changing health conditions at the clinician master terminal, and thus use of wireless communications is necessary in most cases.

5. Discussions

Results from across the datasets highlight the power consumption requirements by such ECG monitors and demonstrate a distinct deficit in modern battery capability despite designers employing contemporary power supply technologies and novel power-frugal algorithms. Therefore, clearly a solution is required if such health monitors are to be capable of long-term recording in various environments. As previously mentioned, there has been much work undertaken to address these issues found in most modern portable devices. The main areas of consideration are threefold; developing better batteries, developing devices that are less power-hungry, and in employing emerging energy harvesting technologies. Portable batteries have increased in capacity in recent years but still lag well behind the pace of the technologies they are expected to power; this is unlikely to be resolved without a rapid breakthrough in the chemical technology of the batteries. Likewise, while device developers can use power-saving algorithms, place devices in regular sleep mode (not applicable for an ECG device that constantly monitors), employ various strategies to process data on the devices to reduce communication data volume (e.g. transmit only on a cardiac event or out of range detection), and employ low-power wireless communications, these alone do not add up to a winning solution. Energy-harvesting technology is a most promising technology, although current solutions struggle to offer power supplies of a few microwatts which is insufficient for modern ECG devices.

Therefore, with consideration the best future solution is likely to be a combination approach of selecting the best portable power sources, developing ultra-low power electronics, employing the best of power-frugal operating strategies and utilizing the most beneficial energy-harvesting technologies (perhaps more than one) for the application in conjunction with standard chemical batteries (hybrid approach). Other areas of potential benefit are in the use of using localized mesh networks to reduce wireless transmission distances (and thus required RF transmission power), and perhaps even charging the devices wirelessly while they are in operation by using wireless power transfer [1], although the health issues around this approach require considerable investigation. It is therefore in a multifaceted approach that we are more likely to deliver ambulatory devices that meet the demands of modern healthcare.

6. Conclusions

This paper has presented empirical results from a measurement campaign designed to quantify the power requirements for modern ambulatory ECG monitors which utilize various power-saving schemes. Commercially available ambulatory ECG monitors were investigated to understand typical battery life between charges, the effects of data reporting frequency, and use of wireless communications on device run-times. The work indicates typical run time of approximately 36 hours for wireless enabled devices and in the order of 81 hours for holter-type devices. Reporting frequency has an impact on battery life and for the devices tested it was discovered that reporting back to the network every 5 minutes was optimal. It was considered that a combination approach of the latest batteries, power-frugal electronics and operating strategies, and utilizing suitable energy-harvesting technologies offered the best option in achieving a robust power supply solution for modern ambulatory devices.

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