Autoclave Sterilization Powered Medical IoT Sensor Systems

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Abstract. The purpose of this study is to explore the possibilities of harvesting the thermal energy from steam sterilization process to power the IoT sensor node. Thermoelectrical generators based heat recovering have been used for powering IoT sensor nodes. The design process of the TEG based energy harvesting application is described in details. All vital parts of the system like choosing the suitable TEG module, heat storage material, power storage device, a power management system as well as insulation material to create the temperature gradient across the TEG were precisely described. The temperature-voltage characteristics of the module are analyzed within the test setup of standard steam sterilization. Power consumption of a CC2650 Bluetooth module is analyzed and optimized to maximize the power efficiency and the lifetime. During this study self powered Bluetooth IoT sensor node was developed. Power consumption software optimization have been applied resulting in the lifetime of over 10 days after single sterilization cycle.

Keywords: Energy harvesting · Steam sterilization · Sensors · IoT

1 Digitalization and Common Issues with Powering Surgical Tools

Digital healthcare is a very fast growing area of medical industry with a huge potential of delivering secure and high-quality patient care as well as driving greater business efficiency. Many reports suggest that digitalization is becoming a new business opportunity for healthcare industry involving Internet of (Medical) Things, Big Data and automatization. This could allow the connection between patients, healthcare professionals, manufacturers and providers [1,2]. There are strong indications that bringing the idea of traceable and connected devices to the operating room can improve significantly the efficiency and safety of surgical procedures [3,4]. Moreover, some papers highlight the direction towards digitalization in hospitals management systems to create so-called “Smart Connected

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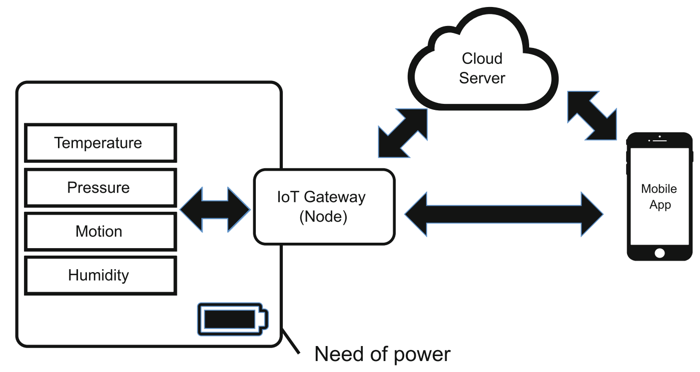

Fig. 1. Idea diagram of typical IoT architecture

Hospitals" with sensor nodes and tracking systems. To make this possible many different technologies are suggested for medical IoT, like RFID, ZigBee, Narrow Band Bluetooth, Bluetooth-Low-Energy [5]. Medical and surgical tools incomparably differ from other IoT enabled devices for consumer markets due to the need of sterilization. However, each of these devices and technologies require a power source. In the case of surgical tools and containers the power source needs to stand multiple steam sterilizations.

1.1 IoT Node

We can describe the Internet of Things as a network of physical devices embedded with electronics, sensors, software and connectivity which allows data exchange between these objects. Each object has its own unique identifier and is able to inter-operate within the existing internet infrastructure. The scheme of IoT system is shown in the Fig. 1. IoT node (gateway) equipped with a given set of sensors can communicate with cloud server with Wi-Fi connectivity or with the smartphone App with Bluetooth-Low-Energy. The data are then stored on the cloud server and synchronized among the all connected apps and devices. In this work we have used a SensorTag2 from Texas Instruments as a IoT node platform with Bluetooth-Low-Energy connectivity.

1.2 Steam Sterilization

In hospital environment there is an emphasis on clean, sterile environment. Special case in here is an operating room, where the sterile zone is needed for the patient safety. Every single medical instrument used during the surgical procedure needs to be maintained and sterilized according to the standards. Steam sterilization, described in detail in ISO:17665 standards, involves instrument exposure on the temperatures ranging from 30 to 140 °C and the pressure from −1 to 3 Bars. The temperature inside the sterilization chamber is shown in the Fig. 2. During the sterilization process, the temperature reaches the maximum of 135 °C for 7 min. At the same time the pressure reaches its maximum at 3,1 Bar. These two factors causes the chamber environment to be very harsh for any electronic devices and power sources. Thus it was crucial to make a review on possible high temperature energy storage technologies, and find a new method to power the electronics and charge the energy storage during the steam sterilization.

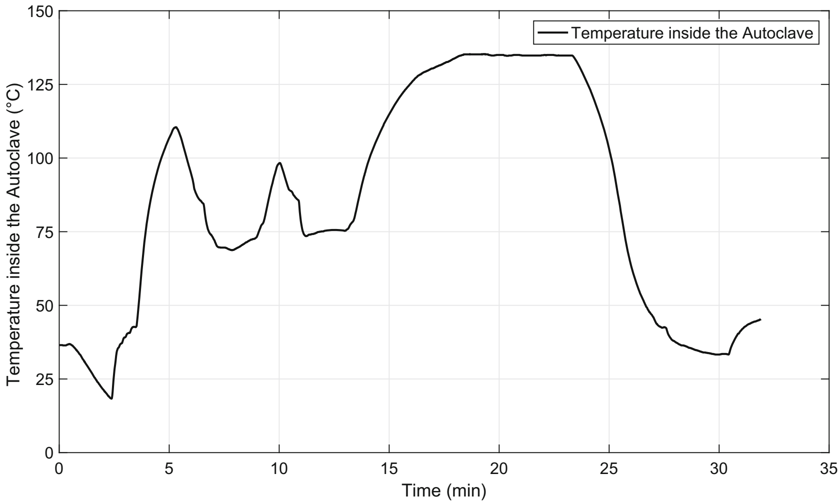

Fig. 2. Typical changes of the temperature inside the autoclave during steam sterilization

1.3 High Temperature Power Sources

High temperature inside the autoclave narrows significantly the choice of technologies for energy storage. In general, we can distinguish following energy storage systems (ESS) available on the market:

– Lithium primary cells
– Lithium secondary cells
– Supercapacitors
– Lithium-ion supercapacitors
– Energy harvesting systems

Lithium based batteries are known as a good and reliable power storage for consumer electronics with operating temperature range from −20 to 60 °C. Some of the lithium-ion chemistries can handle the temperatures of up to 150 °C, like

$Li-SOCl_2$ or $Li-CuO$ [6], however they are non-rechargeable and their energy density of 500 and 300 $Whkg^{-1}$ respectively determines very low maximum constant current and fast drain after working in high temperature environment. The secondary lithium-based cells in general cannot withstand the temperatures of a steam sterilization. When a cell is heated above 130 °C, and the heat cannot be dissipated by the cell, the exothermic processes will proceed causing rapid temperature rise which usually leads to gas release and explosion of the cell [7,8]. This process is called thermal runaway. Hammami et al. suggests, that thermal runaway can occur spontaneously after the cell reaches the temperature of 80 °C [9]. Recent advances in battery manufacturing processes led to development of small factor cylindrical cells with stable chemistry which prevents them from thermal runaway. However, the capacitance is limited to 3 mAh.

The second common type of ESS are electrolytic double layer capacitors (EDLC) which can also form supercapacitors. Supercapacitors usually employ acetonitrile or an organic carbonate solvent as the electrolytes. However, the boiling point of acetonitrile is only 82 °C and reaching this temperature causes the evaporation of the solvent and increase of the internal cell pressure which can lead to explosion. Recently, FastCAP Systems revealed a new technology of supercapacitors with an operational temperature up to 150 °C [10], however the cost effectiveness of this solution for the IoT node remains disputable. The other issue which needs to be taken into consideration is a self-discharge rate which can be high in the case of thermally stressed supercapacitors.

The special case of energy storage device is a lithium-ion supercapacitor, which is a hybrid of an EDLC and a lithium-ion battery. It is composed of a negative electrode doped with lithium ions (typical battery material), an activated-carbon positive electrode (typical capacitor material), and an organic electrolyte containing a lithium salt. Recent research shows that the exotermic reactions inside the Li-Ion supercapacitor begin at 90 °C leading to thermal runaway at 175 °C [11].

In conclusion, high temperature ESS are still in an early stage of development and suffer from limited thermal, chemical, and electrochemical stability at increased temperatures, resulting in their short lifetimes [6]. To prevent this, the energy storage in the sterilizable IoT node needs to be insulated from the high temperature and the self-discharge needs to be compensated in sterile, maintenance-free way. One way to recharge ESS is to use the energy harvesting techniques and recover the energy from the sterilization process itself.

1.4 Energy Harvesting

Waste heat recovery became recently an important topic causing rapid development in energy harvesting solutions.

The heat can come also from the steam sterilization process inside the autoclave. One of the most robust and reliable method of recovering the energy from the heat is using thermoelectrical generators (TEGs). Each TEG module is then composed of pairs of TE couples connected together electrically in series and thermally in parallel, which directly convert a thermal energy that passes through them into electricity based on Seebeck's effect. This is shown in Fig. 3.

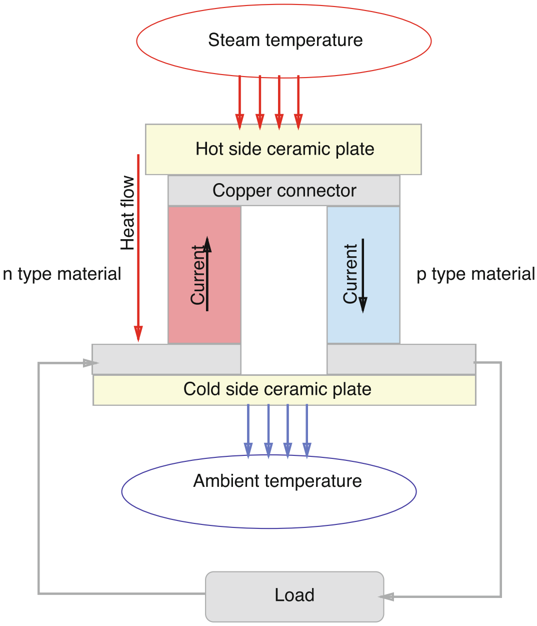

Fig. 3. Scheme of a single thermoelectric pair. It comprises of n-type and p-type semiconductors. Heat flows from hot side to cold side and electrical current is flowing from n-type to p-type material due to temperature gradient

The efficiency of TEGs is usually relatively low. Studies shows an average efficiency of 8.45% of the TEG modules available on the market [12]. However, newest technologies can improve the efficiency up to 20% [13]. One way to do this, is to apply the oscilating temperature on the hot side of the TEG as some authors suggest [14]. This can be the case where the oscilating temperature of steam sterilization can improve the energy harvesting efficiency. Despite their robustness, TEGs are limited to the applications in extreme environments like space exploration, automotive industry, aircraft, military, and heavy industry. This was caused mainly by their relatively low efficiency and high cost of the modules [13]. During the last years an increased need of self-powered sensors is observed. Not only for industrial applications but as well for IoT nodes, wearables, surveillance systems, and everywhere where there is a need for stable, compact and maintenance-free energy source. Despite this fact applications of thermal energy harvesting in medical industry are still in their early infancy and are mainly focused on implantable or wearable devices [15,16]. One of the most important factors affecting the energy harvesting efficiency is matching the TEG to the working environment. In the case of the autoclave the temperatures varies from 20 to 140 °C, with the maximum temperature gradient of 70 °C. Usually TEG modules are optimized for the high ambient temperatures as well as high gradients. For instance, low cost Bi_2Te_3 based modules are usually working with temperature gradients up to 300 °C. Thus, the steam sterilization environment needs to be considered as a low gradient conditions. Literature shows that in such a conditions it is possible to use thermoelectrical coolers as a TEG [17]. To choose the optimal TEG for given application thermal resistance of the heatsink and thermal resistance of the TEG needs to be known. The thermal resistance of the heatsink is taken usually from the producer specifications or material datasheet. However, the thermal resistance of the TEG needs to be calculated, and the most fitting TEG module needs to be chosen. The thermal resistance of the TEG can be estimated from the parameters given by the TEG manufacturer and in general is described as:

$$\theta_m = \theta_k \sqrt{1 + ZT_1}$$

where: θ_k - Thermal resistance of the heatsink

Z - figure of merit of the thermoelectric materials of the generator

T_1 - Temperature of the heat source

Matching these parameters with appropriate TEG ensures the thermal resistance match between TEG and heatsink and maximum power generation in given environmental conditions [18].

The work principle of TEG implies a need to generate a heat flow across the TEG in the environment with set ambient temperature. For this the heatsink made of aluminium can be thermally coupled with TEG on the hot side and a heat storage material on the cold side. Many different materials were reviewed according their parameters, heat accumulation, heat transfer and the cost effectiveness. Recently there are numerous heat storage materials available on the market, including phase changing materials with great thermal accumulation properties [19]. However, according to the dynamical changes of the temperature inside the autoclave within the cycle, it was essential to choose the material with not only high specific heat but also with high heat conductivity.

1.5 Power Conditioning Circuits

The energy from heat recovery of the TEG is linked to the energy storage usually via a DC-DC converter. Currently available state-of-the-art DC-DC converters can be divided in two categories: actively controlled with single inductor and passively switched coupled inductors without active control circuit. The single inductor circuits, due to their active control circuits, can match the input impedance and boost-up ratio dynamically to allow so called maximum power point tracking (MPPT). MPPT checks the output of the TEG module, compares it to energy storage voltage then fixes what is the best power that TEG module can produce to charge the storage and converts it to the best voltage to get maximum current into energy storage [20]. The disadvantage of single inductor architecture is relatively high minimum input voltage of 100 mV and a cold start input voltage of 330 mV due to the poweing additional passive cold-start voltage converter. A market example of such an architecture is bq25504 from Texas Instruments.

Table 1. Comparison of bq25504 and LTC3108

Parameter	bq25504	LTC3108
Switching control	Active feedback control	Passively controlled switch
Startup voltage	330 mV	Down to 20 mV
Min. input voltage	100 mV	Down to 20 mV
Max. input voltage	3 V	Down to 400 mV
Efficiency	Up to 85%	Up to 50%
Voltage regulation	Controlled boost ratio	Linear drop-out

On the other hand, the coupled inductors based, fully passive circuit, DC-DC converter has a very small input startup voltage of 20 mV. The disadvantage of this topology is lower efficiency. This is caused by two main factors. Firstly the inefficiencies of passive switching circuits, inductor couplings and rectification required after the boosting stage. Secondly, using the fixed boost ratio defined by coupled inductors results in a boosted voltage which is much higher than the energy storage voltage for higher input voltages. Thus, a passively controlled low-dropout regulator is used, which causes linear efficiency decrease for higher input voltages. A market example of such an architecture is LTC3108 by *Linear Technology*. The comparison of these two chips are presented in Table 1.

As literature shows, the advantage of the bq25504 single inductor based solution is its ability to dynamic adaptation of MPPT algorithms resulting in higher efficiency, the tradeoff however is that it needs higher startup voltage to power up active circuit elements [21]. For this project the efficiency and wide input voltage was critical therefore the bq25504 has been chosen for further development.

2 Materials and Methods

The aim of this research was to design a maintenance-free, sterilizable IoT sensor node using energy harvesting from sterilization cycles. The whole system is composed from TEG module, DC-DC boost-converter, power control circuit, energy storage device, communication module and sensors serving as a load. The architecture diagram of the system is shown in the Fig. 4. The output of the TEG is connected to the boost converter and power management system. This allows to feed the load with sufficient power or to store it in a power buffer. As a sensor module Texas Instruments SensorTag2 with CC2650 Bluetooth chip has been used. Small Murata UMAC040130A003TA01 hybrid li-ion battery served as power buffer. In the experimental part of this work, the power generation from the steam sterilization and software optimizations of IoT module were examined.

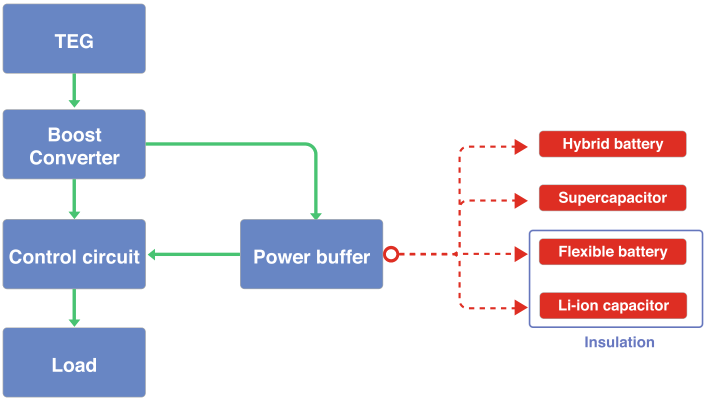

Fig. 4. Block diagram of the prototype

Two main challenges of the prototype design were to overcome. First of all to protect the electronics and energy storage from high temperatures, and to maximize the efficiency of thermal energy conversion among the TEG. The other issue was to optimize the energy consumption of Bluetooth-Low-Energy according to the average use-case of surgical containers. The module should be charged after the single steam sterilization cycle and work for at least 5 days after the sterilization. The cross-section of the first prototype is shown in Fig. 5. In this study, two *Ferrotec Nord TMG-127-0.4-1.6* connected in series have been used. The whole module was insulated using aerogel-based materials which provides extremely low heat conductance as 0.02 [W/m*K]. The output of the energy harvesting module is connected to the bq25504 Boost-up converter with MPPT algorithm and power storage maintenance control circuits. The bluetooth module based on CC2560 chip and temperature sensors are connected to the power buffer through the control circuit.

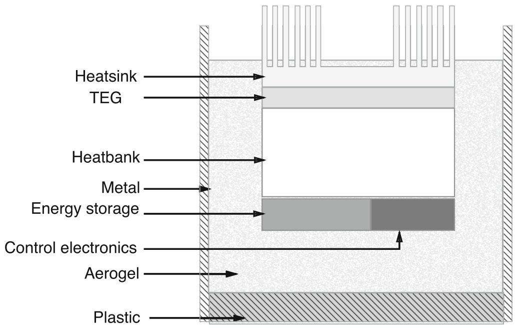

Fig. 5. Cross-section of the prototype of the self powered IoT node

2.1 Software Optimization

The lifetime of a Bluetooth-Low-Energy device is determine how much power the device's components consume. Thats why it was essential to evaluate and to choose the optimum device hardware setup regarding the microprocessor, radio and the sensors.

In the case of Bluetooth-Low-Energy devices the counter-intuitive rule of low-power communication is that listening for data is much more expensive in the case of energy than sending data. This is because of longer intervals when the radio needs to be turned on. In this case, the optimization was to find out the appropriate interval on advertising wake-up packets which tells the receiving device that it is a time to receive the data. This technique, described in [22], is called sampled listening. The other optimization is made by periodically wake-ups of the device from the stand-by mode to check if there is any pending connection requests. If so, it starts to do sampled listening, but only for a short while. The last two improvements were regarding the data rate and the responsiveness. The data rate is a parameter indicating how often the data will be sent by the Bluetooth module and responsiveness tells about how often the module needs to respond to the commands.

2.2 Test Setup

We have examined the prototype regarding efficiency of power generation, power consumption and estimated lifetime of the IoT node after single sterilization cycle. During the efficiency tests the module was placed inside the climate chamber which have simulated the temperature changes during the steam sterilization. The temperature on the module surface as well as inside the module and the voltage on the TEG was measured. The power consumption tests involved the measurement of a power consumption of CC2650 chip with different sensors attached to it and in different operating modes. The module was powered with the single coin cell battery and the measurements were performed by taking the current characteristic in several operating modes. Finally, the optimizations of the chip software was made to maximize the power efficiency and to extend the lifetime of the whole IoT node after single sterilization. The power consumption before and after the optimizations was compared.

3 Results

3.1 Power Generation

Power generation tests results are shown in the Fig. 6. The temperature in the climate chamber simulated the steam sterilization process (red line) and reaches 135 °C after 20 min. At that time the voltage of the TEG reaches its maximum of 2.3V (green line). The temperature inside the module reaches 80 °C (blue line). Next, the chamber is being opened, which is visible on the diagram as a sudden drop of the temperature inside the chamber. The heatflow changes its

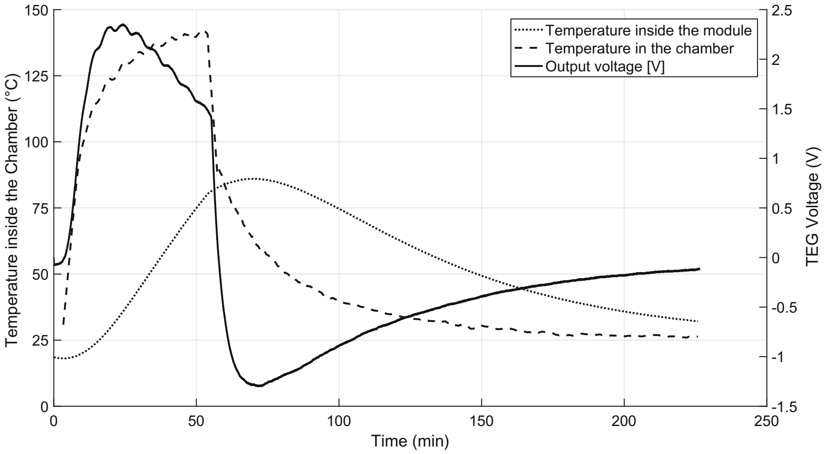

Fig. 6. Temperature and pressure data of steam steriliation process

direction and it goes from heatbank to the outside of the module causing the TEG to change its polarity and reach the −1.4 V. After that the module is cooling down for the next 140 min and the voltage generated on the output of TEG is slowly decreasing until it reaches the value of 0.08V which is the terminal test condition as the boost converter stops working. Using the low power rectification and conditioning circuit allows to charge the ESS even when the voltage of TEG is negative.

3.2 Power Consumption

The power consumption (in mA) of the CC2650 varies depending on the current operating mode and sensors. The several different measurements have been taken, as it is shown in Table 2. All of the measurements were taken using standard demo-software available from *Texas Instruments*. It is worth to mention, that this software was not optimized on power consumption, and its main aim is to demonstrate all of the features of the *CC2650 SensorTag*. Thus the average power consumption during the tests was 6.12 mA, caused mainly by the motion sensor. There was significant power consumption during the startup of the module, thus it is not recommended to switch it to the off state.

As it is shown in Table 2, the power consumption without any optimizations is unacceptable in the case of maintenance-free energy harvesting based application. The standard average is a state when the SensorTag2 with CC2650 is operating with a standard software and with standard sensor setup.

3.3 Power Optimization

After the optimizations described in Sect. 2.1, the power consumption has been lowered more than over 95% to 0.3mA. Reducing the advertisinig time interval

Table 2. Power consumption of evaluated CC2650 SensorTag

Mode	Power consumption (mA)
Powering On	12
Standby	0.24
Discovery	2.0
All sensors off	0.24
Temperature sensor	0.80
Barometric sensor	0.50
Motion sensor	4.16
Standard average	6.12

improved the power efficiency the most, lowering the energy consumption to 0.4 mA. Awaking the device periodically to check the connection request instead of constant monitoring allowed to fall below 0.05 mA of average current consumption. The last two optimizations lowered the power power consumption to the level of 0.03 mA. This prolonged the lifetime of the module after a single sterilization to over 10 days, which exceeded the first assumptions of this project and is enough to power the IoT node in during the sterilization cycles interval.

4 Discussion

Numerous reports, market researches and papers show that digitalization and IoT will spread through medical industry. What is most important some studies shows that hospital management information specialists are ready for adopting the IoT technology in their workplace [23]. In this study we have proved, that it is possible to power the sensor IoT nodes even in such a harsh environment as a steam sterilization. More over, it was possible to store the harvested energy in a save way. This allows us to think about the digitalization of the surgical equipment. Every single medical sterile container, medical instrument or power device needs to be sterilized on a regular basis. This opens a lot of possibilities for the applications like surveillance the sterile status of a container. Integrating ultra low-power shock sensors brings us the possibility to log the critical events during the transport. However, further design optimizations and tests of energy-harvesting modules need to be done, as well as optimization of their power efficiency. With these issues resolved, it should be possible to reduce the cost and size of the single module. These two factors plays the key role in medical and hospital logistics. The results of this work show, that implementing energy harvesting powered IoT nodes opens possibilities to increase the digitalization level in the medical facilities resulting in better management, faster logistics operations, increase in sterile safety. As an end result it could lower the cost and increase the safety of medical treatment.

5 Summary

The aim of this study was to examine the possibility of energy harvesting from steam sterilization process for medical IoT sensor nodes. The results show, that powering IoT sensor node from autoclave sterilization is possible. Choosing the right thermoelectrical generator plays a crucial role in the whole design of energy harvesting device. Together with a heat storage and insulation materials the physical dimensions and the design can be determined. As it was reviewed, power storage devices like lithium based batteries and supercapacitors needs to be insulated and connected with a TEG via DC-DC converter including power management system. Several different power management topologies have been reviewed. It was examined that it is possible to store the energy in safe way in a lithium-based safe batteries or supercapacitors protected with an aerogel-based insulation. To optimize time of life of the sensor and communication electronics several optimizations have been made according to the software of the module. It reduced the energy consumption to the average of 0.04 mA. Thus, the power generated by a single procedure is sufficient to power the Bluetooth-Low-Energy module and sensors for over 10 days.

References

1. David, A.: The Digital Future of Healthcare (2017)
2. Kanan, R., Elhassan, O.: Batteryless radio system for hospital application. In: Proceedings of 2016 SAI Computing Conference, SAI 2016, pp. 939–945 (2016). https://doi.org/10.1109/SAI.2016.7556093
3. Huang, A., et al.: The SmartOR: a distributed sensor network to improve operating room efficiency. Surgical Endoscopy Other Interv. Techn. (2017). https://doi.org/10.1007/s00464-016-5390-z
4. Mahfouz, M., To, G., Kuhn, M.: Smart instruments: wireless technology invades the operating room. In: RWW 2012—Proceedings: 2012 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems, BioWireleSS 2012 (2012). https://doi.org/10.1109/BioWireless.2012.6172743
5. Zhang, H., Li, J., Wen, B., Xun, Y., Liu, J.: Connecting Intelligent Things in Smart Hospitals using NB-IoT. IEEE Int. Things J. **4662**(c), 1–11 (2018). https://doi.org/10.1109/JIOT.2018.2792423
6. Lin, X., Salari, M., Arava, L.M.R., Ajayan, P.M., Grinstaff, M.W.: High temperature electrical energy storage: advances, challenges, and frontiers. Chem. Soc. Rev. **45**(21), 5848–5887 (2016). https://doi.org/10.1039/C6CS00012F. http://xlink.rsc.org/?DOI=C6CS00012F
7. Bandhauer, T.M., Garimella, S., Fuller, T.F.: A critical review of thermal issues in lithium-ion batteries. J. Electrochem. Soc. **158**(3), R1 (2011). https://doi.org/10.1149/1.3515880. https://doi.org/10.1149/1.3515880
8. Spotnitz, R., Franklin, J.: Abuse behavior of high-power, lithium-ion cells. J. Power Sour. **113**(1), 81–100 (2003). https://doi.org/10.1016/S0378-7753(02)00488-3
9. Hammami, A., Raymond, N., Armand, M.: Runaway risk of forming toxic compounds. Nature **424**, 635 (2003). https://doi.org/10.1038/424635b. https://doi.org/10.0414/424635b

10. Cooley, J., Signorelli, R., Green, M., Sasthan, P., Deane, C., Wilhelmus, L.A.: Power system for high temperature applications with rechargeable energy storage (2012)
11. Smith, P.H., Tran, T.N., Jiang, T.L., Chung, J.: Lithium-ion capacitors: electrochemical performance and thermal behavior. J. Power Sour. **243**, 982–992 (2013). https://doi.org/10.1016/j.jpowsour.2013.06.012. https://doi.org/10.1016/j.jpowsour.2013.06.012
12. Chen, W.H., Wu, P.H., Wang, X.D., Lin, Y.L.: Power output and efficiency of a thermoelectric generator under temperature control. Energy Convers. Manag. **127**, 404–415 (2016). https://doi.org/10.1016/j.enconman.2016.09.039. https://doi.org/10.1016/j.enconman.2016.09.039
13. Champier, D.: Thermoelectric generators: a review of applications (2017). https://doi.org/10.1016/j.enconman.2017.02.070
14. Chen, W.H., Huang, S.R., Wang, X.D., Wu, P.H., Lin, Y.L.: Performance of a thermoelectric generator intensified by temperature oscillation. Energy **133**, 257–269 (2017). https://doi.org/10.1016/j.energy.2017.05.091. http://linkinghub.elsevier.com/retrieve/pii/S0360544217308460
15. Kanan, R., Bensalem, R.: Energy harvesting for wearable wireless health care systems. In: 2016 IEEE Wireless Communications and Networking Conference, vol. 2016-Septe, pp. 1–6 (2016). https://doi.org/10.1109/WCNC.2016.7565034. http://ieeexplore.ieee.org/document/7565034/
16. Lundager, K., Zeinali, B., Tohidi, M., Madsen, J., Moradi, F.: Low power design for future wearable and implantable devices. J. Low Power Electron. Appl. **6**(4) (2016). https://doi.org/10.3390/jlpea6040020
17. Buist, R.J., Lau, P.G.: Thermoelectric power generator design and selection from TE cooling module specifications. In: XVI International Conference on Thermoelectrics, 1997 Proceedings ICT 1997. (616), pp. 551–554 (1997). https://doi.org/10.1109/ICT.1997.667589
18. Lineykin, S., Ruchaevsky, I., Kuperman, A.: Analysis and optimization of TEG-heatsink waste energy harvesting system for low temperature gradients. In: 2014 16th European Conference on Power Electronics and Applications, EPE-ECCE Europe 2014 pp. 1–10 (2014). https://doi.org/10.1109/EPE.2014.6910778. http://www.scopus.com/inward/record.url?eid=2-s2.0-84923902652&partnerID=40&md5=6115ae5a48219981242ca2d3f23a1686
19. Alva, G., Liu, L., Huang, X., Fang, G.: Thermal energy storage materials and systems for solar energy applications. Renewable and Sustainable. Energy Rev. **68**, 693–706 (2017). https://doi.org/10.1016/j.rser.2016.10.021. https://doi.org/10.1016/j.rser.2016.10.021
20. Laird, I., Lu, D.C.: High step-up DC/DC topology and MPPT algorithm for use with a thermoelectric generator. IEEE Trans. Power Electron. **28**, 7 (2013). https://doi.org/10.1109/TPEL.2012.2219393
21. Thielen, M., Sigrist, L., Magno, M., Hierold, C., Benini, L.: Human body heat for powering wearable devices: from thermal energy to application. Energy Convers. Manag. **131** (2017). https://doi.org/10.1016/j.enconman.2016.11.005
22. Hui, J.W., Culler, D.E.: IPv6 in low-power wireless networks. Proc. IEEE **98**(11), 1865–1878 (2010). https://doi.org/10.1109/JPROC.2010.2065791
23. Muhammad, A.P., Akram, M.U., Khan, M.A.: Survey based analysis of internet of things based architectural framework for hospital management system. In: 2015 13th International Conference on Frontiers of Information Technology (FIT), pp. 271–276 (2015). https://doi.org/10.1109/FIT.2015.54. http://ieeexplore.ieee.org/document/7421012/