An IoT-based Telemedicine System for the Rural People of Bangladesh

Raqibul Hasan
Department of Software Engineering
Halic University, Istanbul, Turkey
Email: raqibulhasan@halic.edu.tr

Md. Tamzidul Islam
Department of Computer Science and Engineering
Ahsanullah University of Science and Technology, Bangladesh
Email: 180104123@aust.edu

Md. Mubayer Rahman
Department of Computer Science and Engineering
Ahsanullah University of Science and Technology, Bangladesh
Email: 180104144@aust.edu

Abstract: IoT devices can enable low cost and interactive health care services. In this paper we have proposed an affordable telemedicine system to bring healthcare services within the reach of the rural people of Bangladesh. Proposed system enables transmission of patient's body parameters in real-time to a remote doctor. The proposed system also has real-time patient monitoring capability which is based on ECG signal classification. A feed-forward neural network is used for ECG signal classification on an embedded ARM processor. For low power operation, we have utilized fixed-point (integer) arithmetic instead of floating-point arithmetic for the ECG signal classification task. Proposed fixed-point implementation is **1.06x faster** than floating-point implementation and requires **50% less memory** to store the neural network model parameters without loss in the classification accuracy.

1. Introduction

Bangladesh is a developing country in the southeast Asia with about 160 million population. 60% of the total population lives in the rural area. Annual per capita income in the rural area is about $658 [1]. Developing countries like Bangladesh suffer from inadequate healthcare and medical services. Lack of healthcare professionals and infrastructure contribute to this problem making it more difficult to deliver healthcare to people in rural and remote communities. Particularly, there is a severe shortage of specialist doctors in the villages of Bangladesh [2,3]. The doctors prefer to live in the cities because of better living, and better earnings.

Telemedicine is a rapidly growing field that has the potential to transform healthcare delivery. Wireless communication advancements and IoT devices have paved the path for more convenient and high-quality healthcare services [4,5]. Telemedicine uses a variety of technologies, such as video conferencing, remote monitoring, and mobile health applications, to connect patients and healthcare providers across distances. This can be especially beneficial for patients who live in rural or remote areas, as it can provide access to healthcare services that would otherwise be difficult to obtain. Telemedicine can be used for a wide range of medical services, including consultation with specialist doctors, remote monitoring of chronic conditions, and mental health services. It can also be used to provide medical education and training to healthcare providers in remote areas. This technology also significantly lowers the cost of healthcare solutions. TytoCare is a remote patient examination device [6]. This device costs about $300 which is not affordable to many people living in the rural areas of Bangladesh.

Several research efforts identified the challenged of implementing a telemedicine solution in Bangladesh [7,8,9]. In the rural areas of Bangladesh, internet connectivity is not easily accessible. The rural people are not financially solvent enough to afford expensive telemedicine device like TytoCare. Most of the existing telemedicine solution in Bangladesh is limited to voice consultation over phone [7,10]. Work in [11] described a telemedicine system for the rural people which requires a personal computer. This system lacks several important body sensors such as: heartbeat sensor, pulse rate sensor. Work in [12] analyzed the current situation and challenges of IoT based smart healthcare services for rural unprivileged people in Bangladesh. The authors only described the high-level idea using a very few sensors such as: pulse rate sensor. No detailed design or implementation was examined. In [13] a system has been proposed combining IoT, GSM, and mobile application. A real-time database was introduced which will provide information about the location of the patient, pharmacy, ambulance, and hospital. No body sensor was integrated into the system. In [14] an event-driven IoT architecture is presented for data analysis of reliable healthcare applications, including context, event, and service layers.

In this work, we used IoT devices and biomedical sensors to collect, analyze a patient’s health data/parameters. These data are also transmitted to a remote doctor in real-time. The patient and doctor could be far away from each other. This telemedicine platform will bring health care benefits within the reach of the rural people where it is difficult to find a specialist doctor for consultation. It will alleviate the long travel of a patient from village to city where specialist doctors are usually located. Hence the proposed system will save people’s time, energy, and healthcare cost. Single patient unit of the proposed system will cost about $50 which is significantly less compared to a TytoCare system [6].

The proposed system also has real-time patient monitoring capability. It is used for patient emergency situation detection [15]. The patient monitoring system is based on ECG (electrocardiogram) signal classification. We are classifying ECG signal on an embedded ARM processor in real-time. An embedded system has several constraints such as limited memory, slower clock frequency [16]. In a patient monitoring system, the embedded processor is battery powered. Hence an algorithm implemented on an embedded processor needs to be energy efficient. Work in [17] classifies ECG signal in real-time using deep learning algorithm on an embedded GPU. Embedded GPUs are more power consuming and expensive than an embedded ARM processor. Most of the existing ECG signal classification systems utilize floating-point operation [18].

Floating-point numbers provide more precision than integer numbers. But floating-point data storage requires more memory space than integer data. Furthermore, floating-point operations are slower and more energy consuming than integer operations [19]. Energy consuming operations will drain the battery quickly. In the proposed work, we implemented a feed-forward neural network (FNN) for ECG signal classification on an embedded ARM processor using integer (fixed-point) operations. This is another novel contribution of the proposed work.

The rest of the paper is organized as follows: section 2 describes the proposed telemedicine system. Section 3 describes the real-time patient monitoring system. Section 4 describes the prototype design and presents the experimental result. Finally, in section 5 we conclude our work.

2. Proposed Telemedicine System

In this work, we used IoT and biomedical sensors to collect, analyze, and transmit a patient's health data/parameters in real-time to a remote doctor. Body sensors collect a patient's vital signs, such as heart rate, blood pressure, and oxygen levels. These parameters allow healthcare providers to assess a patient's health and detect any changes or anomalies that may require intervention. Figure 1 shows the overall architecture of the proposed telemedicine system.

A doctor heavily relies on a stethoscope signal for his/her initial examination of a patient. In the proposed system, a digital stethoscope is inserted directly into the cell phone's 3.5mm headphone jack. The cell phone capture patient's heart and lung sound from the electric stethoscope and transmit the signal to the remote doctor's end in real-time. The system also has biomedical sensors such as pulse rate sensor, temperature sensor (LM35), SpO2 sensor for oxygen level measurement, blood pressure sensor and ECG sensor. These sensors are interfaced to a microcontroller. From the microcontroller these sensor data are transmitted to the cell phone using Bluetooth. The body sensor data are transmitted to the healthcare providers from the cell phone using the internet connectivity. The data are also displayed on the mobile screen through an app. A patient will be able to access his/her test report produced by a diagnostic center through the app. In the proposed system the patient, doctor, hospital, and diagnostic center are interconnected through the internet.

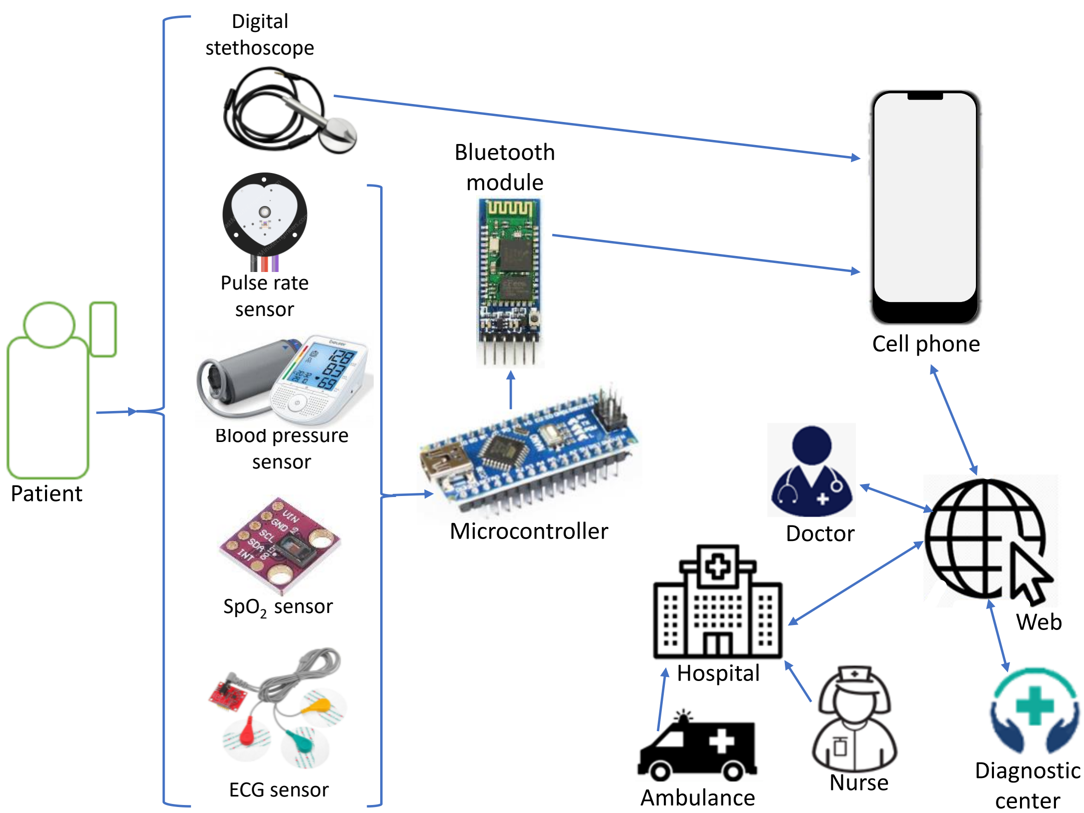
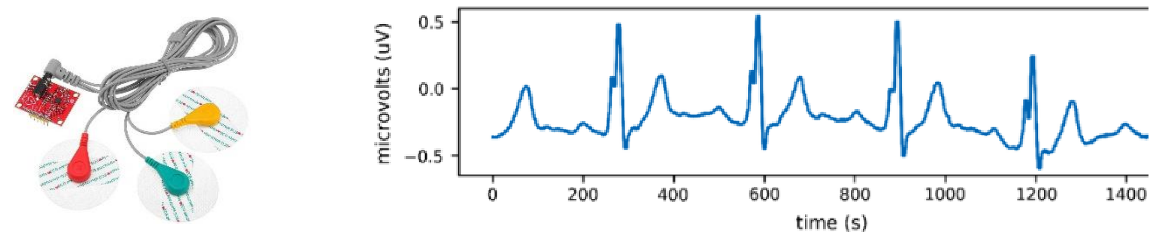


Figure 1: Overall system diagram of the proposed telemedicine model.

3. Real-time Patient Monitoring

Patient monitoring is a very important feature in a healthcare system. It allows healthcare providers to monitor patients who have been discharged from the hospital or who are recovering from surgery. An IoT based remote patient monitoring system ensures that patients receive timely and appropriate care, regardless of their location or mobility. Furthermore, it can also be used for patient emergency situation detection [15].

The proposed system implements remote patient monitoring feature based on ECG signal classification. Figure 2 shows the real-time ECG signal classification system. As the system is battery powered, we need to use an embedded processor for the ECG signal classification task. Algorithm implementation on an embedded processor needs to be memory efficient as these systems have limited memory. Floating-point numbers provide more precision than integer numbers. But floating-point data storage requires more memory space than integer data. Furthermore, floating-point operations are slower and more energy consuming than integer operations [19]. In this work, we implemented a feed-forward neural network (FNN) for ECG signal classification on an embedded ARM processor using integer (fixed-point) operations.



(a) (b)

Figure 2: (a) ECG signal classification system. (b) a sample ECG signal.

Arrhythmia dataset [20] from UCI Machine Learning repository was used in this work to train the FNN. The dataset has total 452 instances (number of samples), 279 attributes each instance, and 16 classes (normal and 15 unusual classes). We used a FNN of configuration: 279->20->16 for the ECG signal classification task. The network has 20 neurons in the hidden layer and 16 neurons in the output layer. In the FNN the sigmoid activation function was used. Figure 3 shows the block diagram of the FNN. We used Keras Deep Learning tool [21] for training the FNN. Figure 4 shows the FNN training graph.

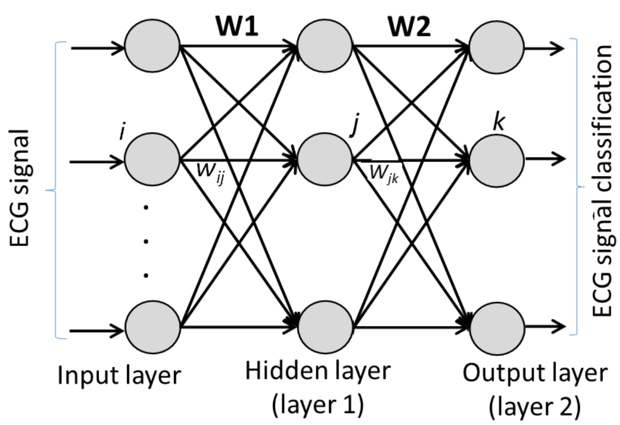


Figure 3: Block diagram of the FNN.

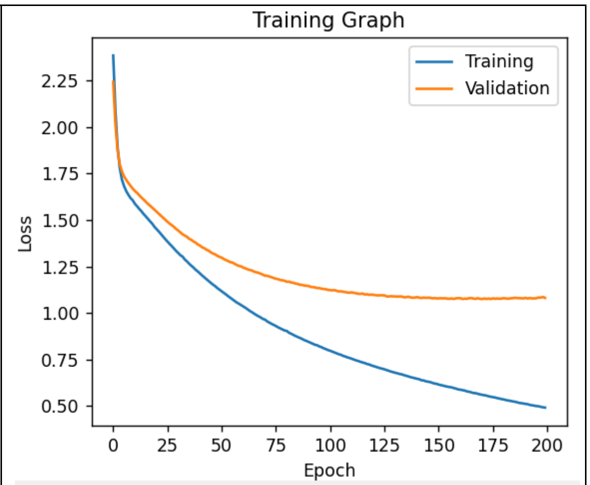


Figure 4: Training Graph (after 200 epoch the classification error was significantly reduced).

Figure 5 shows the methodology used in the proposed work for the implementation of the FNN on an ARM processor. For the fixed-point representation of the FNN weights, we considered 8 bits before the decimal point and 8 bits after the decimal point. Thus, one weight will require 2 bytes in this representation. The nonlinear sigmoid activation was implemented using a lookup table. The size of the lookup table is 512 byte (256 rows).

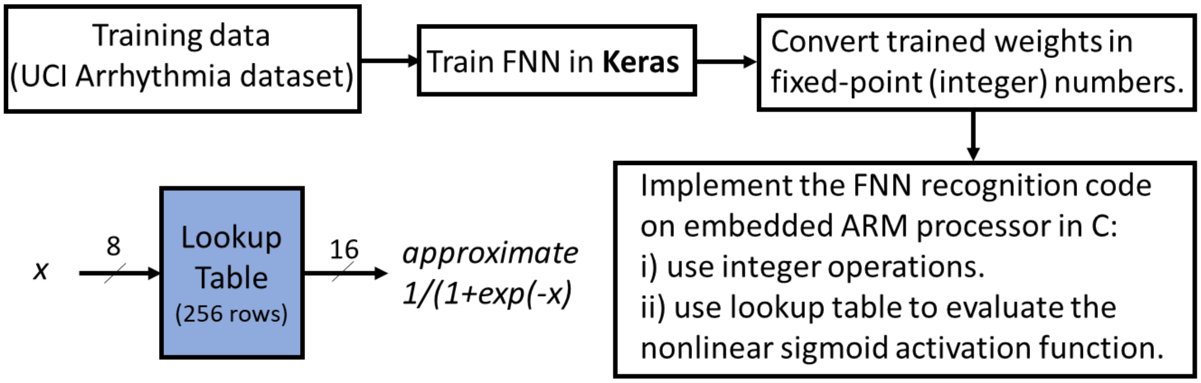


Figure 5: The methodology used for the fixed-point implementation of the FNN.

4. Prototype and Result

4.1 Hardware Prototype Design

We have designed a prototype of the proposed telemedicine system which is shown in Figure 6. Figure 7 shows the implemented prototype hardware. Table 1 shows the hardware components used in the prototype. The digital stethoscope used in the proposed system internally has a very sophisticated microphone sensor. It converts heart, lung, bowel sound into electrical signal which is interfaced to the cell phone through the audio jack port. The cost of a single patient unit of the proposed system is about $50.

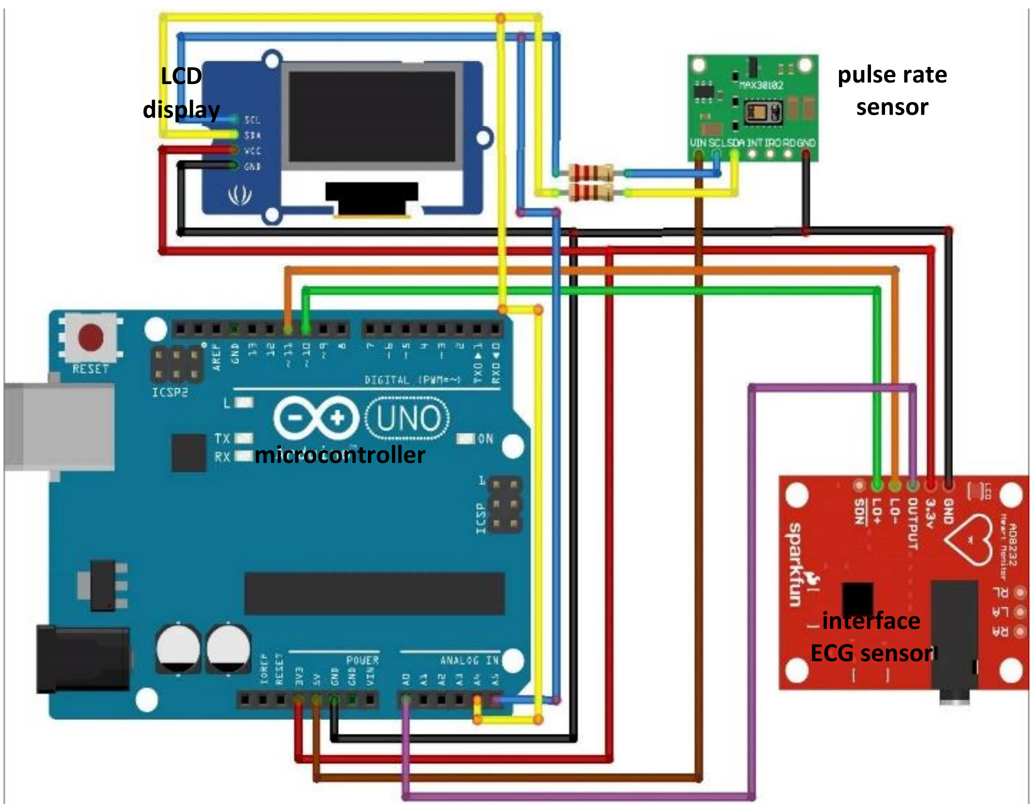


Figure 6: Prototype hardware diagram.

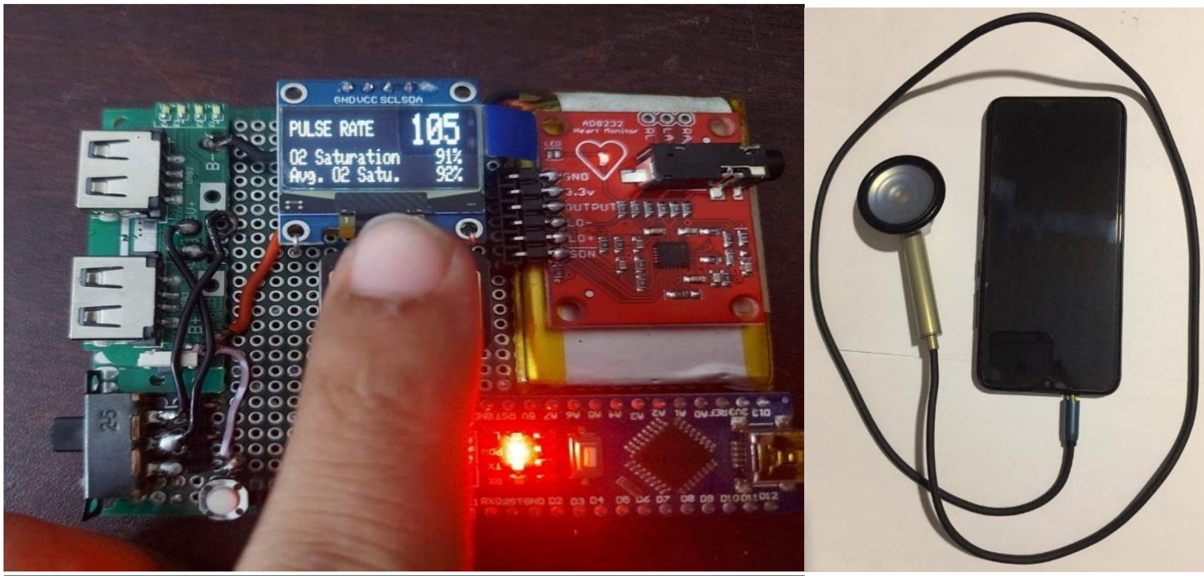


Figure 7: Prototype hardware implementation.

Table 1: Hardware components used in the prototype.

Component	**Use**
Arduino-Nano	Read body sensor data
MAX30102	Detect Pulse Rate, SpO_2
AD8232	Detect ECG signal
Bluetooth module	Send sensor data to the cell phone app
Digital stethoscope	Capture heartbeat and lung sound
Cell phone	Receive patient data through Bluetooth and headphone jack.

4.2 ECG Signal Classification Results

In this work, we used an ARM cortex-A57 processor for the fixed-point implementation of the ECG classification FNN. The operating frequency of the processor is 1.43GHz. Table 2 comparisons the floating-point and fixed-point implementation results. Floating-point model size is 23744 bytes while the integer/fixed-point model size is **11872 bytes** (50% less memory). To classify one ECG signal, the floating-point implementation takes 6.99 us while the fixed-point implementation takes 6.61 us. Hence the proposed fixed-point implementation is 1.06x faster than floating-point implementation. The low energy consumption of the proposed FNN implementation will increase the battery lifetime of the system. Classification accuracy on test dataset is 73% (for both floating-point and the proposed fixed-point implementation).

Table 2: Comparison of the floating-point and fixed-point implementation of the FNN for the ECG signal classification task.

	Floating-point implementation	**Fixed-point implementation**
Accuracy (%)	73	73
FNN model size (byte)	23744	11872
Inference time (μs)	6.99	6.61
Energy consumption for single inference (μJ)	10.485	9.915

5. Conclusion

In the rural areas of Bangladesh people suffer a lot from the lack of proper healthcare and proper medical services. This project will help people from rural areas to get a better healthcare service. Patients will get consultation of specialist doctors remotely. The doctors will be able to examine patients in real-time analyzing multiple body sensor parameters including lung and heart sound. It gives effective and low-cost medical care at home. Single patient side unit of the proposed system costs about $50. The proposed system also has real-time patient monitoring capability based on ECG signal classification. We implemented a FNN for ECG signal classification on an embedded ARM processor using fixed-point operation. To store the FNN model parameters, the proposed implementation requires half of the memory required for a floating-point implementation. In addition to that, the proposed FNN implementation is 1.06x faster than floating-point implementation. Our future work will deploy the system as a pilot project and evaluate the effectiveness of the system based on patient and doctor feedbacks.

References

[1]https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/57def76a_aa3c_46e3_9f80_53732eb94a83/2023-04-13-09-35-ee41d2a35dcc47a94a595c88328458f4.pdf.

[2] Zobair, K. M., Sanzogni, L., & Sandhu, K. (2020). Telemedicine healthcare service adoption barriers in rural Bangladesh. *Australasian Journal of Information Systems*, *24*.

[3] Islam, A., & Biswas, T. (2014). Health system in Bangladesh: challenges and opportunities. American Journal of Health Research, 2(6), 366-374.

[4] Albalawi, U., & Joshi, S. (2018, February). Secure and trusted telemedicine in Internet of Things IoT. In *2018 IEEE 4th World Forum on Internet of Things (WF-IoT)* (pp. 30-34). IEEE.

[5] Garai, Á., Péntek, I., & Adamkó, A. (2019). Revolutionizing healthcare with IoT and cognitive, cloud-based telemedicine. *Acta Polytech. Hung*, *16*(2).

[6] https://www.tytocare.com.

[7] Alam, M. Z. (2018). mHealth in Bangladesh: current status and future development. *The International Technology Management Review*, *7*(2), 112-124.
[8] Zobair, K. M., Sanzogni, L., & Sandhu, K. (2020). Telemedicine healthcare service adoption barriers in rural Bangladesh. Australasian Journal of Information Systems, 24.
[9] Hakim, A. I. (2016). Expected Challenges to implement Telemedicine service in public hospitals of Bangladesh. Journal of Social and Administrative Sciences, 3(3), 231-244.
[10] Chowdhury, S. M., Kabir, M. H., Ashrafuzzaman, K., & Kwak, K. S. (2009). A telecommunication network architecture for telemedicine in Bangladesh and its applicability. International Journal of Digital Content Technology and its Applications, 3(3), 4.
[11] Siddiqua, P., & Awal, M. A. (2012, May). A portable telemedicine system in the context of rural Bangladesh. In IEEE International Conference on Informatics, Electronics & Vision (pp. 608-611).
[12] Khan, M. M. (2020, November). IoT based smart healthcare services for rural unprivileged people in Bangladesh: current situation and challenges. In Presented at 1st International Electronic Conference on Applied Sciences (Vol. 10, p. 30).
[13] Zaman, M. A. U., Sabuj, S. R., Yesmin, R., Hasan, S. S., & Ahmed, A. (2021). Toward an IoT-Based Solution for Emergency Medical System: An Approach to i-medical in Bangladesh. Sustainable and Energy Efficient Computing Paradigms for Society, 81-105.
[14] Rahmani, A. M., Babaei, Z., & Souri, A. (2021). Event-driven IoT architecture for data analysis of reliable healthcare application using complex event processing. Cluster Computing, 24, 1347-1360.
[15] Green, Michael, Mattias Ohlsson, Jakob Lundager Forberg, Jonas Björk, Lars Edenbrandt, and Ulf Ekelund. "Best leads in the standard electrocardiogram for the emergency detection of acute coronary syndrome." *Journal of electrocardiology* 40, no. 3 (2007): 251-256.
[16] Moons, Bert, Daniel Bankman, and Marian Verhelst. "Embedded deep learning." *Embedded Deep Learning* (2019).
[17] Caesarendra, W., Hishamuddin, T. A., Lai, D. T. C., Husaini, A., Nurhasanah, L., Glowacz, A., & Alfarisy, G. A. F. (2022). An embedded system using convolutional neural network model for online and real-time ECG signal classification and prediction. Diagnostics, 12(4), 795.
[18] Jeon, T., Kim, B., Jeon, M., & Lee, B. G. (2014). Implementation of a portable device for real-time ECG signal analysis. Biomedical engineering online, 13(1), 1-13.
[19] Barrois, Benjamin, and Olivier Sentieys. "Customizing fixed-point and floating-point arithmetic—a case study in K-means clustering." In *2017 IEEE International Workshop on Signal Processing Systems (SiPS)*, pp. 1-6. IEEE, 2017.
[20] https://archive.ics.uci.edu/ml/datasets/arrhythmia.
[21] https://keras.io/