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Implementation of the Battery Monitoring and Control System Using Edge-Cloud Computing

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ABSTRACT

Battery monitoring and control are the key parts of a battery management system and are integrated on purely edge-based applications. However, purely edge-based applications face issues such as 1) difficulty in integrating methods with high computational power and complexity, 2) low speed and accuracy, and 3) limited data storage capability. Despite of those issues, previous studies only focus on battery monitoring system without considering battery control. In contrast, few studies about battery control systems still lack in control during battery discharging. In this paper, edge is integrated to cloud, performing both battery monitoring and controlling of charge and discharge states. Integrating the edge to cloud resolves the aforementioned challenges and keeps the battery within its safe operating area. In addition, a web user-interface is developed to monitor and control the battery's state remotely. To measure the performance of the proposed system, a prototype is also developed. Using the prototype, battery control commands are sent to edge for 50 trials each without any errors encountered. Also, results shows that data transmission from edge to cloud does not skip or missed any data from 0 to 18,000 seconds and achieved the appropriate sampling time of 0.1s. Therefore, accurate and complete storing of historical data of the battery pack is achieved.

Key Words : Battery control system, battery monitoring system, charge-discharge control, cloud, edge

Ⅰ. Introduction

The world now is facing global warming due to the emission of dangerous greenhouse gases from using petrol and diesel in vehicles[1,2]. To reduce and avoid the concentration of greenhouse gases, people were encouraged to use electric vehicles (EVs) to replace conventional vehicles[3-5]. To power an EV, a battery is extensively needed. One type of battery used in EV is Lithium-ion (Li-ion) battery. Li-ion batteries are highly in-demand due to its important advantages over other energy storage technologies especially in EVs. Some of its advantages compared to other batteries in the industry are: less expensive, higher energy and power density, better performance on high temperatures, longer lifespan, low self-discharge rate, and safer battery storage facility[4-6]. Li-ion batteries having high energy and power density allows it to hold a lot of energy for its weight. Less battery weight means an EV can travel further on a single charge, which is vital for EVs. Due to those aforementioned advantages, Li-ion batteries became popular in recent years, showing promise as an energy storage in EVs. Although Li-ion batteries are more efficient and safer to use than other types, accidents due to

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battery fault were still reported causing public concern[6]. In order to avoid battery-related accidents and improve battery operation, a battery management system (BMS) is needed.

The BMS is designed to monitor and control a battery unit for proper operation. In complex applications like in EVs, the BMS must fulfill more complicated tasks to restrict the batteries within its safe operating area only[7]. In [8], the BMS includes two main modules: BMS-Slave and BMS-Master. The BMS-Slave is responsible for monitoring the battery cells with signal acquisition and filtering. On the other hand, BMS-Master executes a model-based battery diagnostic algorithms, which require high computational power and data storage. These two main modules can be combined in one embedded system or designed as two separate systems with wiring communication[7,8]. However, their system structure has issues regarding computational cost, reliability, and data storage. To solve these issues, one of the key parts of BMS called battery monitoring system (BMoS) is optimized. BMoS monitors the overall battery operation such as its charge and discharge state, battery data acquisition, and diagnosis. To enhance the performance of the whole BMS, the BMoS can be restructured into a cloud-based system[9].

Integrating the BMoS to the cloud exponentially increases its computational power and data storage capability[10]. By distributing the workload of the BMoS such as battery analysis and diagnosis to a cloud platform, its computational power increases. To provide a data storage capable of handling data throughout a battery's lifespan, cloud servers were used. Different cloud-based systems are implemented nowadays in different areas and industries. In [11], a cloud-based ageing monitoring for IoT devices is developed. The system adopted a cloud-based method to monitor the status of an IoT device remotely and continuously. Then, through data analysis in a cloud server, more accurate prediction was achieved. In [12], a cloud-based battery condition monitoring platform for Li-ion batteries using IoT is presented. The high-performance computing resources of cloud in their platform allows accurate health condition monitoring of battery cells. However, [11] and [12] still lacks methods to control and protect the battery and/or the device when it falls outside the safe operating area. Furthermore, the technical details of their user controls are rarely introduced. In [13], a Li-ion BMS for electric bicycle based on the cloud and IoT for rental battery packs is designed. The battery and location information are transmitted to the cloud platform in real-time to ensure safety operating status of the rental battery packs. Although their system can perform BMoS remotely, it still lacks battery control strategies to protect the battery. In [14], a smart active battery charger for prototypal electric scooter is developed. The system focuses on battery control strategies: fast charging mode, voltage equalization mode, and protection mode. To ensure battery charging safety, the proposed control strategies are automatically performed during charging times. Then, the user can monitor the battery remotely through cloud for current conditions. However, their system is only applicable during charging times. Furthermore, the BCS is only active when using the battery charger itself. The aforementioned cloud-based BMS focuses on / also lose its capacity. To protect the batteries from overcharging or deep discharging, it is required to implement BCS. It would be highly beneficial to the battery¯s lifespan and operating conditions to integrate battery control strategies. Therefore, BMS should not only focus in BMoS, but also in BCS.

In this paper, the proposed BMS aims to perform both battery monitoring and controlling tasks through cloud in real-time. First, by restructuring the BMoS part into a cloud-based system, the data storage and high computational cost problems are resolved. Then, the BCS part protects and controls the battery of the EV not only while charging, but also when discharging. The proposed system consists of three parts: (1) edge, (2) cloud, and (3) user interface. The first part collects all the battery information needed – battery voltage, current, and temperature. After that, the edge device will be connected to a cloud server where all the data are stored. Then, the current state and information of the battery is displayed in a user interface. On the BCS part, both charging and discharging states are controlled. To protect the battery from overcharging or deep discharging, an automated charge-discharge control (CDC) is implemented. The user is notified through sending alerts when the battery reaches a certain threshold. Since the system is integrated in cloud, the user is able to control the EV⁻s battery states without the need of physical contact to the EV.

The remainder of this paper is organized as follows: Section II introduces the related works of BMS. Section III is the overall representation of the BMS and the cloud-based implementation which is the focus of this work. Section IV presents the experimental setup and results. Section V concludes the paper for the proposed edge to cloud-based BMS.

Ⅱ. Related Works

The overall system representation of the proposed edge to cloud BMS is shown in Fig. 1. The proposed BMS consists of the integration of BMoS and BCS to the cloud. This section highlights the existing approaches of the two important parts of the proposed system: the BMoS and BCS. Then, the comparison between offline-based and cloud-based BMS is discussed.

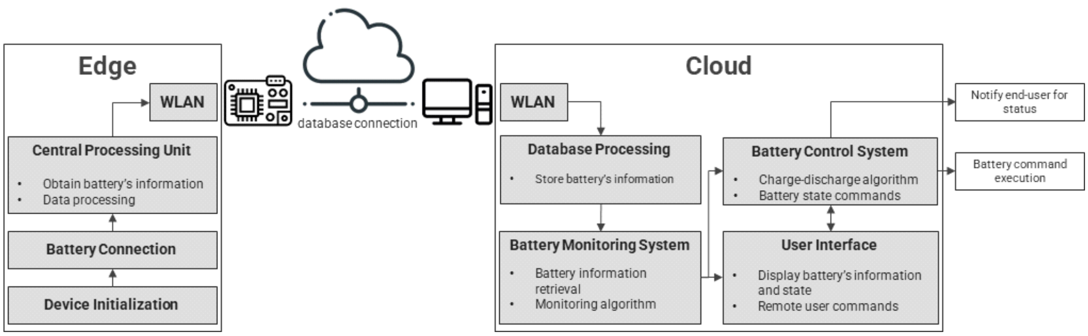


Fig. 1. Overall system representation of the proposed edge to cloud BMS.

2.1 Existing BMoS & BCS

The role of BMoS is to monitor the overall battery operations such as its charge and discharge state, battery data acquisition, and diagnosis. Without an efficient and reliable BMoS, BCS can't perform its role effectively. On the other hand, BMoS alone is not enough to manage the battery unit for proper operation.

Challenges on existing onboard BMoS includes the difficulty of integrating methods that requires high computational power and complexity, expensive components, low speed and accuracy, limited data storage capability, and so on[4,7,8,15]. To overcome these challenges, many researches have focused and improved the BMoS. Several model-based methods were integrated to accurately determine the condition of the battery[7,8]. However, high computational load is not suitable for pure edge-based systems in real-time applications. In [4], many different monitoring methods are compared. Some focused on reducing computational cost and complexity, high speed and accuracy, and improving other methods. Although the edge-based monitoring methods were able to improve in each way, there's still some disadvantages. As an example, in [16], a direct method for battery cell estimation is discussed. This is a simple yet an effective method to measure different associated parameters of the battery (e.g., voltage, current, temperature). However, high estimation accuracy is difficult to obtain. In [17], a capacity degradation-based model for Li-ion batteries is implemented. Their method provides high accuracy due its deep understanding of battery's mechanism. However, it is associated with high computational complexity level that is difficult to integrate in edge-based systems. Although edge-based BMoS methods are improving, data storage capability problem is still a concern.

In order to prevent battery-related problems, various battery control strategies are implemented along with the BMoS. Many researchers focused on battery charging methods such as coordinated, uncoordinated, delayed, off-peak, fast charging, and so on[5,14,18]. Coordinated charging is performed where an EV should be charged for a specific time in the day i.e., particular period during low electricity demand. In uncoordinated charging, EV's battery will start getting charged as they park i.e., charging is done irrespective of the peak hours and price. Delayed charging is done at home wherein charging is delayed until after a certain time. And on the other hand, off-peak charging is done at home but is under a direct command of a utility company. The study in [18], proves that coordinated charging is the most proficient and valuable method due to its optimal scheduling approach in real-time. In order to improve other charging methods, combining two different methods are considered[16]. Aside from charging state, discharging must also be controlled. However, it is not considered in most of the studies.

The BMS is designed to monitor and control a battery unit for proper operation. In order to achieve an effective and reliable BMS, optimizing both BMoS and BCS is necessary. In this paper, the proposed BMS aims to perform both battery monitoring and controlling tasks of charge and discharge states in real-time.

2.2 Offline-based vs. Cloud-based BMS

One of the advantages of offline-based BMS is that it doesn't require internet access to manage a battery unit. However, problems requiring high computational power, complexity, and data storage capability is associated[8]. To accurately estimate and predict battery's states, complex model-based algorithms are integrated which requires high computational power and data storage capability[4]. Furthermore, new functionalities such as lifetime prognostics and optimization of different strategies are difficult to be integrated onboard. Also, the reliability and cost of wiring communication becomes challenging with the increase in the number of battery cells and the scale of the battery systems. To overcome these challenges, the BMS can be restructured into a cloud-based system[9].

Compared with the offline-based BMS, cloud-based application has advantages in both hardware and software as shown in Table 1. Cloud-based system offers cloud services which has a high system reliability and computational power[10,20]. Furthermore, cloud servers are used as a data storage capable of storing historical data throughout a battery's lifespan[10,11]. These features further support the application of advanced and complex methods of BMS. On the other hand, existing onboard BMS methods[4,10,11] can be further improved with more advanced methods in the cloud. Additionally, new functionalities such as historical data-based lifetime prognostics and system optimization can be implemented on cloud easily.

Different cloud-based systems are implemented nowadays in different areas showing its advantages over offline-based systems. Cloud-based methods can monitor the status of an IoT device remotely and continuously – achieving more accurate prediction due to integration of complex algorithms. In [12], a cloud-based battery condition monitoring platform for Li-ion batteries using IoT is presented. The high-performance computing resources of cloud in their platform allows accurate health condition monitoring of battery cells. With cloud integration, enormous data storage capability and implementation

Table 1. Advantages of cloud-based application in BMS.

	Advantages
Hardware	Data storage capable of storing historical data throughout a battery's lifespan
	Reliable system structure
	High computational power
	Reduces workload of hardware components
Software	Able to perform advanced and complex methods of monitoring and control tasks for more accurate and reliable results
	Optimization and new functionalities are easier to integrate

of complex methods are met. The system application in [12], proved that cloud resolves the challenges in offline-based monitor and control tasks and in [9], a BMoS based on IoT for batteries in a microgrid system is proposed. Their system shown several concepts and benefits of applying cloud in a BMS. However, the technical details of their user controls and strategies are rarely introduced. Therefore, their systems didn't provide enough information on their BCS performance.

In this paper, cloud is integrated to overcome the challenges of offline-based BMS. Therefore, the proposed edge to cloud-based BMS performs both battery monitoring and controlling tasks in real-time effectively. Rather than implementing battery control strategies only during charging, the proposed system controls both battery charging and discharging states. Additionally, automated battery control method and notification is implemented. The technical details of each subsystem will be discussed further in this paper.

Ⅲ. System Overview

In this section, the overview of the proposed edge to cloud-based battery monitoring and control of Li-ion batteries is discussed. Moreover, the benefits, operation flow, and technical details are introduced.

3.1 Operational flow of subsystems

In this section, the details of each subsystem of the proposed cloud-based BMS is introduced. The subsystems include: (1) data acquisition, (2) cloud platform, (3) data monitoring, and (4) visualization and control commands.

3.1.1 Data Acquisition

The main role of data acquisition is to measure the battery voltage, current, and temperature using data sensors. Then, the measured battery data is transmitted to an edge device via Serial Peripheral Interface (SPI) protocol and connects with the internet through Wi-Fi. Therefore, a reliable and stable internet connection is required for a stable real-time data transmission. To perform battery monitoring and controlling tasks, the edge device communicates and interacts with other components and subsystems. In this paper, the main component for data sensing is the LTC6803. The LTC6803 is a battery monitoring IC that includes a 12-bit ADC, a precision voltage reference, a high voltage input multiplexer, and a serial interface. Each LTC6803 can measure up to 12 battery cells connected in series having a 0.25% maximum total measurement error. For the edge device, there are many options to consider: Arduino-based boards, Texas Instruments boards, Raspberry Pi, and so on. The only requirement is to reliably receive and transmit data from sensors to cloud platform.

3.1.2 Cloud Platform

Edge devices usually have limited data storage, computational capabilities, and complex process or methods are hard to integrate. Compared with edge devices, cloud platform has an enormous data storage capability, higher computational power, and higher system reliability. With these features associated in cloud, advanced and complex methods are easier to integrate. Therefore, the existing onboard BMS functions can be further improved in cloud. Moreover, new system functionalities or optimizations which are difficult to be implemented in onboard BMS are easier to integrate in cloud.

3.1.3 Data Monitoring

As a part of the edge to cloud-based BMS, data monitoring automatically controls the battery's state based on the monitored data from battery cells in real-time. Its main role is to protect the battery from overcharging or deep discharging. During charging, the system will automatically stop charging when the battery reaches a certain threshold. Afterwards, the user is notified through sending alerts for battery status update. On the other hand, when discharging, the system will only send alert to the user before the battery gets deep discharged. This is due to the fact that the EV will stop running if discharging is automatically stopped. Therefore, this will help the user to be aware of the current battery status and plan strategies beforehand. Moreover, the user can prevent battery-related accidents and prolong the battery's life.

3.1.4 Visualization and Control Commands

Another feature of the proposed edge to cloud-based BMS is the remote data visualization and user-controlled commands. The web-based user interface of the proposed system provides real-time visualization of the battery's states and user-controlled commands. This provides the opportunity for the user to control and monitor the current state of the battery remotely. Furthermore, the commands are user-controlled which will depend on the user's demand. After a command is identified, the cloud communicates with the edge device to execute the command to the battery pack. In this way, the user can conveniently monitor and control the battery anytime, as long as internet is accessible.

3.2 The proposed cloud-based BMS

This paper focuses more on how to integrate edge on cloud and the process of monitoring and controlling the battery pack remotely through cloud. Our proposed edge-cloud based BMS consists of a Li-ion battery pack, data sensor (LTC6803), three microcontroller units (ATMEGA, C2000, CC3220SF) which serves as the main communication and control units in the prototype, and a virtual cloud server. The operational flow of subsystems that were introduced and discussed in Section III.1 are all applied in our implementation which explains the role of each part. By restructuring the BMS into a cloud-based system, we can obtain the advantages of cloud as summarized in Table 1. Compared with onboard BMS, cloud-based BMS has higher computational power, enormous data storage capability, and higher system reliability. With these features associated in cloud, advanced and complex algorithms can be easier to integrate. Therefore, the existing onboard BMS functions can be further improved in cloud. Furthermore, new system functionalities or optimizations which are difficult to be implemented in onboard BMS are easier to integrate in cloud. In this section, operation flow of the cloud-based BMS and the functionalities of the subsystems are introduced.

The proposed edge to cloud-based BMS aims to perform both monitoring and controlling tasks in real-time. The proposed system consists of three parts: (1) the edge, (2) cloud, and (3) user interface as depicted in Fig. 2. The edge part collects all the battery information needed – battery voltage, current, and temperature by using LTC6803 as data sensors. The sensor measurements will be processed and transmitted to the ATMEGA device via a synchronous communication protocol – SPI. Then, the ATMEGA connects to the cloud via wireless communication protocol, specifically, Wi-Fi. ATMEGA, LTC6803, and the Wi-Fi module work together to perform two functions: (1) to determine the state of the battery, and (2) execute battery control commands to ensure that the state of the battery is within its safe operating area. The LTC6803 works as a data acquisition module, the ATMEGA is the main controller on the edge while the Wi-Fi module serves as the bridge between the

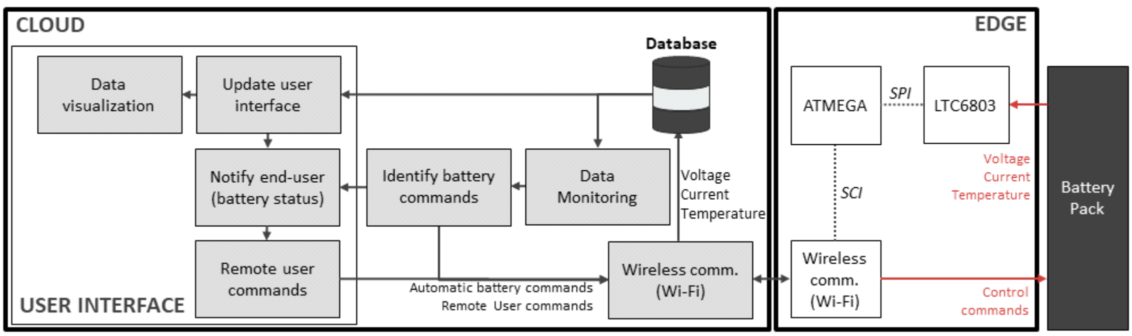


Fig. 2. Overall process diagram of the proposed edge to cloud-based BMS.

edge and the cloud. In this paper, we used libraries provided by Linear Technology and Texas Instruments to manually build the system which will meet the design requirements. The ATMEGA and the Wi-Fi modules communicates via Serial Communication Interface – SCI. There are two types of data being exchanged between the BMS and battery pack: sensor values and control command, as shown in Fig. 2. All data transmitted from the edge to cloud will be stored in a database system powered by the cloud server. These stored data will be used for two separate processes: (1) automatic battery monitoring and controlling tasks and (2) remote user-controlled commands. In automatic battery monitoring and controlling tasks, the real-time process flow chart is shown in Fig. 3. First, the battery data is retrieved from the database repeatedly until the CDC threshold is reached. Once the threshold is reached, the system will identify two states: charging or discharging. When the battery is charging, the system will automatically send a command to stop the battery from charging. This will prevent the battery from being overcharged. Afterwards, an alert or notification will be sent to the user for status update. On the other hand, during discharging, the user will receive alerts to notify them before reaching deep discharge status. Therefore, this will help the user to be aware of the current battery status and plan strategies beforehand. The system will only notify during discharging due to the fact that the EV will stop running if discharging is automatically stopped. In remote user-controlled commands, the system flow chart is shown in Fig. 4. The user interface keeps updated in real-time by retrieving battery data from the database. Also, the user interface will display the current battery status and user-controlled battery commands. Once a command from the user is received, the system will identify the command. In this paper, four user-controlled commands are set: (1) restrict battery charging, (2) remove battery charging restriction, (3) restrict battery discharging, and (4) remove battery discharging restriction. The availability of use of battery commands depends on the status of the battery. If the battery is charging, command (1) is available to use. This command will restrict the battery from charging itself using any

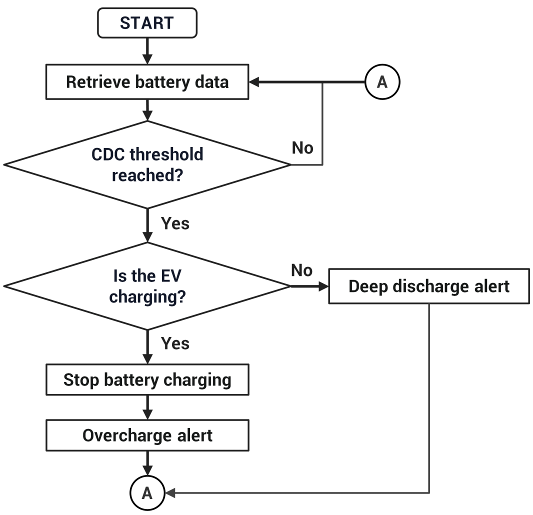


Fig. 3. Battery data monitoring and automatic charge-discharge control flow chart.

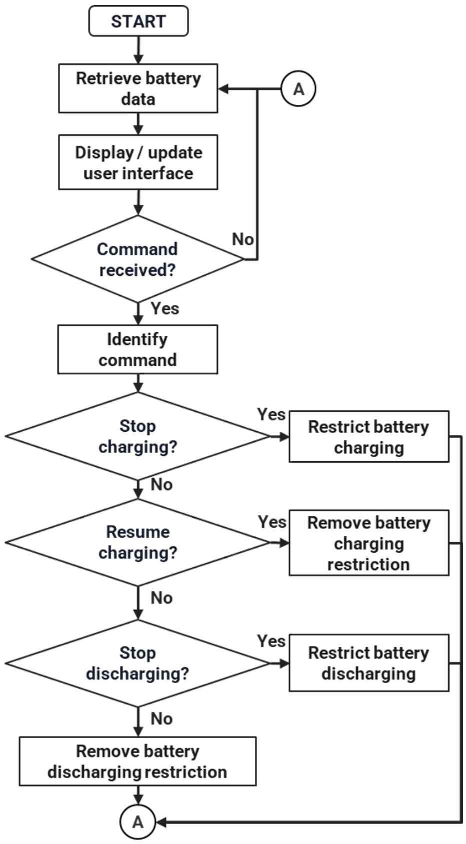
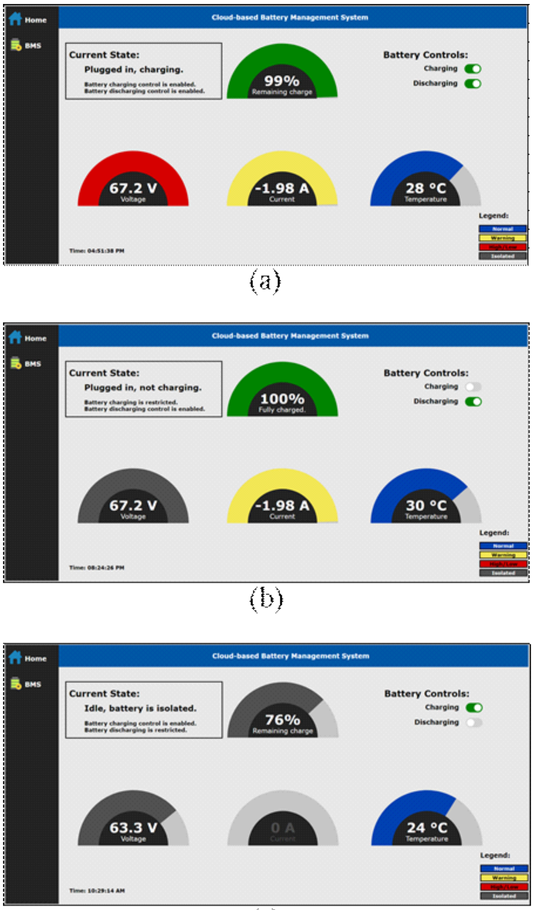


Fig. 4. Remote user interface battery commands flow chart.



(c)

Fig. 6. Web user interface: (a) normal battery charging state, (b) restricted battery charging, and (c) restricted battery discharging.

battery charger. When battery charging is restricted, command (2) will be available. This allows the battery to remove battery charging restriction from any battery charger. During discharging, command (3) can be executed. This command allows the battery to stop self-discharging to save battery life. Then, to remove the battery discharging restriction, command (4) is used. These commands are user-controlled; therefore, the user manually selects a command depending on the user's demand. After a command is identified, the cloud communicates to the edge device and perform the battery command. In this way, the user is able to monitor and control the battery's state remotely depending on the user's demand.

Our proposed edge-cloud based BMS mainly

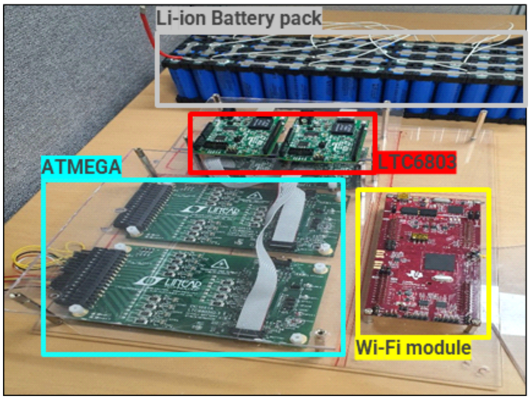


Fig. 5. Implemented prototype of the proposed BMS.

focuses on the implementation of edge to the cloud so, advanced and complex algorithms that can be applied easier in cloud were not further discussed. Thus, the importance and advantages of implementation of edge to cloud were introduced. The cloud serves as a storage capable of storing near-unlimited data and integrates more complex algorithms such as applying machine learning-based model to estimate the state of the battery easier than of non-cloud implementations. Edge-cloud computing is needed so that we can easily apply complex algorithms and methods such as machine learning-based model to predict/estimate the state of the battery. Furthermore, the cloud enables the user to monitor the state and control the battery pack remotely anytime, anywhere, as long as there is internet connectivity is available in the area.

Moreover, the cloud minimizes the workload of the edge in performing such high computational tasks that makes our edge-cloud based BMS' performance more effectively by having the edge to just transmit data and wait for any control commands from cloud to be executed. The cloud is also used to visualize data in real-time through a web-page that is running on a virtual cloud server connected to the battery with the use of the integrated Wi-Fi module. With this, the user can monitor the state of the battery connected to the cloud server and manually control the battery depending on the user's demand. Additionally, automatic battery pack monitoring and control will be executed from the cloud to the edge so that the battery pack will be restricted to perform in its safe operating area only.

Ⅳ. Experimental Setup and Results

To validate the functionalities of edge and cloud with their corresponding hardware and software components, we designed a prototype of the edge to cloud-based BMS. Fig. 5 shows the main components of the prototype setup and are connected sequentially as follows: Li-ion battery cells/pack, LTC6803, ATMEGA, TI C2000 – F28379D, TI CC3220SF, cloud server, webhost, and a device with internet access (e.g., PC or phone).

After building the prototype, we performed tests to verify the reliability and efficiency of both edge, cloud, and web user interface in real-time. The test conducted is described as follows: (1) the web user interface is tested by displaying current battery state and send battery control commands to edge as intended by the user. In Fig. 6, the current battery state, measurements, and controls are being displayed and updated in real-time. Battery control commands are tested as depicted in Fig. 6(b) and 6(c). An example scenario where the battery is plugged in a battery charger is shown in Fig. 6(a) and 6(b). Fig. 6(a) shows that the battery is plugged in a battery charger and is normally charging. Fig. 6(b) shows that the battery charging has been restricted by the user to stop battery charging remotely. When the battery charging control is turned off, the battery will be isolated to the battery charger restricting it from charging. Fig. 6(c) shows that the battery is in idle status when the user turned off the battery discharging control. In this situation, the battery will slow down from discharging and eventually isolate the battery to stop operating and discharging. To validate the consistency and reliability of the user-controlled and automated battery controls, the commands are sent to edge for 50 trials each. The results listed in Table 2 shows that out of 50 trials in sending commands from the cloud to edge, no errors were encountered. Therefore, all battery control commands sent from the cloud is received by the edge and performed to the battery pack successfully. (2) To validate the consistency of data transmission from edge to cloud database, we conducted tests wherein the data measurements from battery pack to edge were stored in cloud database continuously in real-time. Battery data were measured, collected, and stored in the database every sampling time in seconds (s). First, the sampling time is set to perform data transmission from edge to cloud database every 1s then, every 0.5s, and 0.1s. Results shown in Table 3 verified that the data transmission from edge to cloud didn't skip or missed any data (voltage, current, and temperature) from 0s to 18,000s timeline. Therefore, accurate and complete historical data are stored in the cloud and can be used in more advanced and complex methods in the future. Furthermore, in real-time applications, it is appropriate to have at least 0.1s sampling rate to efficiently and effectively monitor and control a battery pack system for better management, which is achieved under this experimental setup. In this way, the user can easily manage the battery pack as it has a complete and accurate data transmission. No

Table 2. Trial and error for sending battery control commands from web user interface to edge.

Battery Controls	Response	Trials	Errors
Charging: OFF	Restrict battery charging	50	0
Charging: ON	Remove battery charging restriction	50	0
Discharging: OFF	Slow down battery discharging and eventually isolate the battery	50	0
Discharging: ON	Reconnect battery from discharging	50	0
Charging: OFF (automatic)	Restrict battery charging	50	0
Discharging: OFF (automatic)	Send alert, slow down battery discharging and eventually isolate the battery	50	0

further tests are needed on a much faster sampling rate than 0.1s due to the fact that it will only lead to much higher cost of using a really high-specification virtual cloud private server.

Within the conducted tests of our prototype system, the hardware and software components successfully validated all the functionalities of the proposed edge to cloud-based BMS. Furthermore, a reliable wireless communication between edge and cloud is needed to consistently send battery control commands to the edge, which was performed in the proposed BMS. The cloud server consistently receives all battery pack parameters from edge to cloud as fast as 0.1s sampling time without missing or skipping any data. The battery pack control commands were also sent back and executes to the edge without fail. Real-time visualization is also performed synchronously while receiving and storing data through a web-page running on our virtual cloud server.

Ⅴ. Conclusion

In this paper, an integration of edge to the cloud for battery monitoring and control of Li-ion batteries is developed. A reliable and consistent communication between edge and cloud synchronously performing real-time visualization and updates were implemented as well. Edge is integrated to the cloud to improve the computational power, speed, accuracy, and data storage capability. Also, automatic battery monitoring and control for both charging and discharging states are implemented. In this way, we can improve the battery life, performance, efficiency, and the safety of the battery and user. Furthermore, new functionalities such as historical data-based lifetime prognostics and system optimization can be implemented on cloud easily. Additionally, the user can access a web user interface to monitor and control the battery's state remotely anytime, anywhere, as long as internet is accessible. The system functionalities of both hardware and software were validated with the cloud-based BMS prototype. The results show that out of 50 trials in sending each command from the cloud to edge, no errors were encountered. Therefore, all battery control commands sent from the cloud is received by the edge and performed to the battery pack successfully. Results also verified that the data transmission from edge to cloud does not skip or missed any data from 0s to 18,000s timeline. This proves that the latency of communication between edge and cloud was minimized even as fast as 0.1s sampling time setup. Since the appropriate sampling rate of 0.1s is achieved, the user can also efficiently monitor and control the battery pack system.

Table 3. Data transmission validation from edge to cloud database.

Sampling time in (s)	Time (s)	Data	Skipped data
1.0	18,000	Voltage	0
		Current	0
		Temperature	0
0.5	18,000	Voltage	0
		Current	0
		Temperature	0
0.1	18,000	Voltage	0
		Current	0
		Temperature	0

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