Qualitative framework based on intelligent robotics for safe and efficient disassembly of battery modules for recycling purposes

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Abstract
In next 5-10 years, there will be 5-8 million tons of spent batteries accumulated as waste. There exists methods for recovery of materials from a battery for reuse or remanufacturing purposes. The research question arises on how about the recycling of batteries stacked in the battery modules in series or parallel configurations. This paper shall propose the qualitative framework based on intelligent robots for safer and efficient disassembly of battery modules for recycling. The framework combines the battery pack's automatic removal procedure with the battery's intelligent sorting program to recycle the reusable batteries. It has higher degree of automation and higher recycling efficiency than the existing frameworks. This also includes a smart battery information collection system (machine vision based information reading), an intelligent robot based battery disassembly system and a smart battery classification system. In addition, the framework also includes AI model based programming of robot so that it can sort out the batteries in ascending order of their remaining life.

Keywords: electric vehicles; intelligent robots; recycling; qualitative framework

1. Introduction
Lithium-ion batteries are used in many electronic applications such as mobiles phones, electric cars, mobile watches, etc. The lithium-ion battery is mainly composed of a battery core and a casing. The battery has a separator, a positive and a negative electrode. The positive electrode active material has a carbon black conductive agent, a lithium cobaltate powder and an organic binder, and these materials are directly coated on the collector portion of the aluminum sheet material; the anode active material The main component is carbon powder, in addition to the lesser binder, the material is applied to the copper sheet current collector. After a plurality of charge and discharge activities, the lithium battery may have a decrease in capacity and an expansion of the electrode, and eventually it is scrapped. The advantages of lithium batteries make it an ideal secondary energy source for human development in the 21st century. In the past five years, lithium batteries have developed rapidly in the downstream consumer goods field, among which notebooks and mobile phones are the two major applications of lithium batteries. In the long run, with the support of the state for the new energy industry, electric vehicles have gradually become the largest demand industry for lithium batteries.
From 2008 to 2018, there were more than 3,000 research papers related to lithium ion battery recycling. In summary, the recycling process comprises of the two phases. The first stage is a mechanical cycle process. Second phase is the recycling of precious metals and raw materials. R. Golmohammadzadeh [1] has proposed a process for recovering lithium and cobalt from single spent lithium-ion batteries using organic acids. GP Nayaka et al. [2] proposed to replace inorganic acids with aqueous mixtures of weak organic acids to recover valuable metal ions from spent lithium ion batteries. Q. Meng et al.[2] proposed the use of glucose as a reducing agent to recover Co from spent lithium ion batteries. The main purpose of these studies is to recover useful materials and elements from waste batteries [3-5]. Most of the research contents are based on a single battery, and few mention the process of recycling of large systems in form of packs/stacks.

How to deal with recycling of large scale lithium-ion batteries embedded in packs/stacks is a serious challenge. [6-9] Lithium-ion batteries are hundreds or even more in number in battery pack. In addition, recycling materials from the battery pack is critical to ensuring the advancement and sustainability of the electric vehicle market. Mechanical processes include battery-to-module disassembly [10], module-to-battery disassembly, and crushing of individual lithium-ion batteries and material sorting. The researchers did not focus on the recycling of the entire battery pack/battery modules systems. In the process of recycling waste batteries, there are many repetitive jobs in the mechanical and chemical parts of the process. It consumes lot of time and expensive to finish the process manually, and the operators may have some hidden safety risks when disassembling these batteries. These dangerous jobs can be taken over by robots.

The present work illustrates the qualitative framework based on intelligent robotics which is of positive significance for the recycling and utilization of large quantities of electric vehicle waste batteries. Section 2 discusses research problem undertaken in our work. Section 3 discusses the proposed framework. Section 4 discusses research directions with future aspects. Finally, Section 5 makes a brief conclusion of full paper.

2. Research Problem Undertaken
This section illustrates the research problem on recycling of a battery pack. Due to the complex composition of battery pack, power battery recycling and reuse faces many limitations and higher technical thresholds. Figure 1 illustrates the internal structure of the battery after disassembly.

![Figure 1. Decomposition of battery pack showing its components.](image-url)
The recycling of the current battery pack difficulties can be subdivided into the following three sub-problems as follows:

2.1 The process of dismantling of batteries
The disassembly of the battery is an extremely complicated process and has potential hazards. In addition, there are no uniform rules for the size and structure of the battery. The design of various battery systems is completely different, so the same set of disassembly lines cannot be used, resulting in battery disassembly. The solution is extremely inconvenient. At the same time, the disassembly of battery modules of different sizes and shapes places high demands on the flexibility of the production line, resulting in excessive disposal costs. At present, most factories basically relies on manual dismantling, and the skill level of workers directly affects the efficiency of the battery recycling process. At the same time, due to the high energy of the battery pack itself, various safety problems such as short circuit and liquid leakage may occur, which may cause fire or explosion.

2.2 Residual energy detection system for batteries classification
Sorting of batteries in the dismantled battery pack (manual) is a difficult problem. Many batteries are embedded in series of parallel configurations. For the battery module, the remaining battery capacity of each battery is different. It is necessary to disassemble the battery pack into a single battery, and then develop residual energy detection system for each battery to classify and recycle the battery.

2.3 Application scenarios for recycling batteries based on residual energy
Once the batteries are sorted based on residual energy, the next task is to make expert decision whether to recover materials from batteries or use for secondary applications. If no residual energy (health) is left in the battery, then the materials (Li, Cobalt, etc,) are recovered. If batteries have residual energy remaining, then they can be used for secondary applications such as the mobile, the watches, the electric bike, etc. The batteries can be divided into a detachable battery (without residual power) and a secondary battery (with residual power) depending on the remaining battery power. The detachable battery enters the crushing and disassembling process to recover precious metals such as cobalt and lithium and raw materials. The secondary utilization battery is subjected to gradient utilization depending on the performance.

3. Qualitative framework based on Intelligent Robotics
The current mechanical disassembly process for small-scale battery packs is mostly done manually. The reason may be that in the past few decades, research on large-scale electric vehicle battery packs has not received much attention, the demand for electric vehicle batteries is very small, and manual removal will consume a lot of manpower, materials and time, and will no longer be safe. To solve this problem, authors propose a qualitative framework based on intelligent robots (Figure 2). In this framework, the six-degree-of-freedom UR5 industrial robot and different end-effectors for different functions was chosen. The entire framework is divided into three parts, namely digitization process, Intelligent robot process, and mechanical disassembly process.

(a) Information reading process: The robot uses a hand-eye system with a camera at the end of the arm to provide real-time progress feedback. Through the conversion between the camera coordinate system and the robot world coordinate system, the battery position and attitude information in the three-dimensional space is decided by the computer, and the data is transmitted to the intelligent robot, so that the intelligent robot performs subsequent fine operations.

(b) Intelligent disassembly process: After collecting images through the camera and processing the data through the information reading process, making the motion planning of the intelligent robot based on the vision system, so that it can be disassembled and sorted by the two-armed cooperation. The main task is to reduce the time it takes to complete these tasks, and to be able to repeat work and ensure the safety. The
robot can theoretically reach any position of the target object (battery) and achieve the job. This has an irreplaceable role in modern intelligent production lines.

(c) **Battery classification process**: This process is to test the cells by using a testing machine. After the loop test, the measured data is passed to the sorting robot controller. The robot sorts according to the state and performance of the battery and the collecting machine is used for recycling.

**Figure 2.** Proposed recycling framework based on intelligent robotics.

### 4. Research directions with future aspects

Based on literature and analysis, the following research directions are proposed.

#### 4.1 Solving the complex and security issues of the dismantling process of batteries

Since electric vehicle batteries do not have uniform specifications in size and structure, the design of the battery system is various, so it is impossible to use the same disassembly process for all battery packs and modules, resulting in extremely inconvenient battery disassembly. If large-scale automatic disassembly is required, battery packs and modules of different sizes and shapes will require a high degree of flexibility in the production line, resulting in high processing costs. At present, recycling is mainly manual disassembly. The skill level of workers directly affects the efficiency of the battery recycling process. At the same time, due to the high energy of the battery pack itself, various safety problems such as short circuit and liquid leakage may occur, which may cause fire or explosion.

#### 4.2 Solving the problem of poor product consistency

After the used batteries are recycled, they need to be reclassified (including safety assessment, cycle life test, etc.). When the classified batteries are reused, the used electric vehicle batteries must undergo quality inspection. However, if these batteries do not have a complete data record during the inspection process, the accuracy of the battery life prediction may be reduced, the battery consistency may not be guaranteed. Due to the internal resistance of different batteries, the electrochemical and thermal properties are not the same, and the consistency and reliability of the battery may not be guaranteed. If some problematic batteries are not tested during the screening process, they will be used again. Increase the security risk of the entire battery system. Therefore, in this case, how to achieve fast, non-destructive and accurate detection is the key to recycling.

#### 4.3 Establish a more scientific and efficient battery recycling standard system for electric vehicles

In the case of disassembling the battery, a flexible fit between the various processes is required, and the disassembly process is segmented and optimized. For different battery packs, it is necessary to reuse existing assembly lines and equipment (including intelligent robots) as much as possible during the construction and disassembly operation. Improve productivity and reduce duplication of investment. At the
same time, it is necessary to completely record the operating data of the battery during the use period, and the life model of the battery module can be established based on the data.

5. Conclusions
This paper proposes a qualitative framework based on intelligent robots (Figure 2). In this framework, the six-degree-of-freedom, UR5 industrial robot and different end-effectors for different functions was chosen. The framework combines the battery pack's automatic removal procedure with the battery's intelligent sorting program to recycle the reusable batteries. It has higher degree of automation and higher recycling efficiency than the existing frameworks. This also includes a smart battery information collection system (machine vision based information reading), an intelligent robot based battery disassembly system and a smart battery classification system. At present, the lithium battery market has not yet established a complete recycling specification. The manufacture of lithium-ion batteries seldom considers the factors for subsequent battery recycling which brings certain difficulties to the automatic recycling of the battery. Further works can explore more complex artificial intelligence methods [11-12], such as machine learning, computer vision, etc., to develop a smarter and fully automated robotic recycling framework.

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