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Design and Implementation of an End-of-Life Vehicle Recycling Center based on IoT (Internet of Things) in Korea

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Abstract

It is important to monitor the dismantling process in recycling centers for end-of-life vehicles (ELVs) to facilitate estimation of the practical recycling rate. ELVs are valuable resources in urban mining, and a 95% ELV recovery rate will be required by law. In this research, a smart dismantling monitoring system and smart trolley system have been developed for an ELV recycling center. The smart trolley handles each ELV and is equipped with a weighing load cell, RFID tag for ELV identification, and Zigbee wireless communication device. When a trolley is loaded with a target ELV to be dismantled, the trolley is registered with the ELV. When arriving at a workstation, the trolley is identified by the station's RFID reader and delivers the current ELV weight via the Zigbee device. The required dismantling instructions are displayed on the station's PC monitor based on the corresponding vehicle part database. The developed system was implemented at a recycling center in central Korea. It facilitates remote real-time monitoring via Internet of each workstation's dismantling status and of vehicles currently being processed. The part dismantling results are stored in a computer server for future verification.

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Keywords: ELV (end-of-life vehicles); IoT (Internet of Things); dismantling; monitoring

1. Introduction

Industrialization has caused environmental problems such as global warming and exhaustion of energy and resources. Various environmental regulations have been imposed in various countries, including ELVs (end-of-life vehicles), RoHS (restriction of hazardous substances), WEEE (waste electrical and electronic equipment) [1], and REACH (registration, evaluation, authorization and restriction of chemicals). For vehicles, governments are tightening controls on automobile gas emissions and are regulating the recovery rate of ELVs to control harmful materials and collect valuable resources.

EU (European Union) Directive 2000/53/EC [2] and Commission Decision 2005/293/EC [3] have imposed a basic guideline for monitoring the recycling and recycling rate of ELVs. Korea's Ministry of Environment passed regulatory requirements for ELV recycling through the 'Act on resources recycling of electric & electronic equipment and vehicles.' The regulations will result in law enforcement of reasonable treatment and recycling [4]. Regulatory requirements will eventually require a 95% recycling rate, including 10% energy recovery by 2015 [2]. The need for a higher recycling rate is growing. Accordingly, many European and Asian countries have investigated and assessed ELV treatment processes to improve material recovery techniques, including Italy [5], the Netherlands [6], Germany [7], Denmark [8], Japan, and Taiwan [9, 10].

It is an important issue to properly recycle ELVs, which are composed of various kinds of materials, such as ferrous and non-ferrous metals, plastics, glass, and rubber. Roughly 75% of an ELV by weight consists of metallic material, so ELVs should be recycled as much as possible. It was reported that on average, 670,000 waste vehicles per year were dismantled during the period of 2008 to 2010 in Korea [11]. However, many scrapped vehicles in Korea are not treated in

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an eco-friendly way, mainly due to the small scale of dismantling businesses. ELVs contain various recyclable parts and materials, but over one million tons of resources are wasted in the treatment process per year.

Ways to satisfy the high recycling rate requirements legally and technologically include vehicle design for disassembly and dismantling [5, 12], efficient recycling technologies to yield greater material returns, and EPR (extended producer responsibility) regulation. For more material recovery, the treatment of ASR (automobile shredder residue), from which ferrous and non-ferrous metals can be recovered, has steadily been studied [5, 13-16]. In addition, a practical and effective recycle monitoring system should be designed and implemented to check whether the dismantled parts are properly recycled and to collect recycling data (e.g., recyclers, materials, weight, etc.) for the verification of ELV recycling. For the recycling of WEEE, the reporting tool WF-RepTool [17] is used to track all part fractions of WEEE [1] until their final use or final disposal. The tool allows the recycling and recovery rates to be calculated. However, such an integrated and systematic data collecting application is rare for ELV recycling.

An efficient data-gathering method is proposed to facilitate monitoring of dismantling processes for a line-type dismantling plant in accordance with regulations. Data stored on a computer server via IoT (Internet of Things), such as sensor and network data, are used to monitor dismantling results, for work proof submitted to managing agencies, or for later use to trace further recycling activity. Remote monitoring of dismantling processes is also provided for real-time visualization.

2. Status of ELV Recycling Process and Recycling Rate

The dismantling and recycling flow for an ELV can be summarized as follows. A waste vehicle starts the recycling process at a dismantling plant. It is required by law for the dismantler to separate designated parts such as refrigerants, fuel, fluid oil, lubricants, tires, airbags, bumper covers, fuel tanks, catalysts, and batteries from the ELV. Then, reusable parts are separated for sale and reuse, and reusable core parts of a component are retreated for use as main parts of new components through remanufacturing. Other detached metallic parts are collected and sent to steel mills (ferrous metal) or smelters (non-ferrous metal) for material recycling. The vehicle shell (hulk) is then shredded, and materials are separated by proper methods, where ASR is further recycled for energy recovery and sent to a landfill (see Figure 1) [18].

This research focuses on the dismantling plant (the ELV recycling center), which plays an important role in the first stage of recycling. An ELV recycling center may have line-type workstations or a single workstation, depending on the number of vehicles treated. The dismantling process is divided into cost-effective and non-cost-effective operations. The cost-effective operations detach parts or materials for profitable sale, while the other operations are not profitable, or even require additional cost for further treatment. Laws require the dismantling and recycling results to be reported, because economically infeasible dismantling processes are not expected to be eco-friendly. In Korea, there is a web-based reporting system, EcoAS (Electrical and electronic Equipment and Vehicle ECO-Assurance System in Korea) [19], where recyclers must manually input their recycling data. The managing agency has tried various ways of monitoring, but there have been no effective and practical methods.

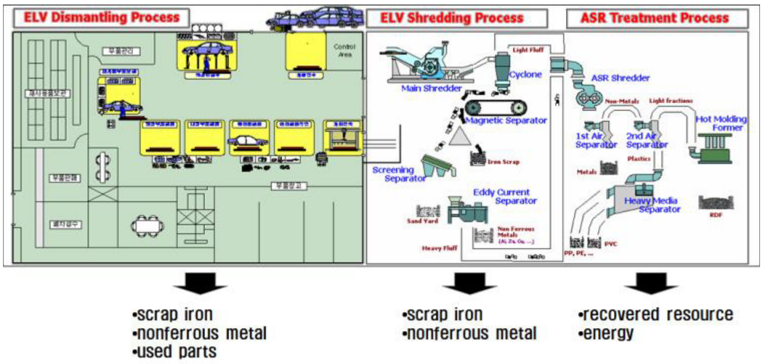

Fig. 1 .The overall ELV recycling process [19]

ELV recycling rate regulations can be categorized into those that enhance vehicle design for higher recycling rate and those that enhance dismantling and recycling processes. As an example of vehicle design regulation, auto manufacturers in Europe must be qualified to achieve a target recycling rate for approval of a new vehicle model. However, regulations on recycling processes are not yet mandatory in most countries. Moreover, it is not easy to strictly regulate the on-site recycling process, since many recyclers are involved, and recycling procedures are divided into separate stages, such as dismantling, shredding, ASR recycling, and energy recovery.

Various ways to enhance environmentally friendly recycling activities are utilized in some countries. In Japan, for example, auto recyclers are paid for environmentally friendly recycling expenses with a prepaid amount of money from when a car was sold. Also, many nations legally regulate materials that affect the environment, which include Freon and various liquid waste that remains in the vehicle. As for Europe, there are large deviations in ELV recycling rates reported in a few European countries [21]. Also the real recycling rates are expected to be much lower than the depicted values since they are mostly based on recyclers' reports. In Korea, the government legally requires auto recycling centers to report treatment results using the web-based database system (EcoAS). Additionally, authorized agencies irregularly perform on-the-spot inspections of illegal treatments.

Therefore, it is important to design and implement ELV recycling centers and dismantling plants to facilitate efficient monitoring of dismantling and further recycling. The line-type system developed based on IoT to enable real-time on-site communication collects and stores dismantling results on a PC server, which are later utilized to trace further treatment of the ELV parts.

3. Line-type ELV recycling system based on IoT

3.1. IoT

The term IoT was first used by Kevin Ashton of the MIT Auto-ID Center in 1999. Daniel Giusto defined it as a concept that enables a goal to be achieved by organic communications among various things or devices around us [22]. The requirements for IoT are as follows: ID (identification) for independent recognition, sensors to collect necessary information, network connections to deliver the collected information to an external device, and additional functions to control the device or to utilize the information remotely. The first three elements are mandatory, while the last one is an important requirement to activate IoT, but it may either be restricted or infeasible to implement.

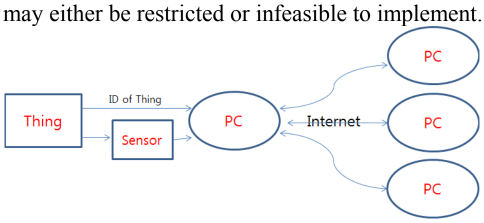

Fig. 2 Structure of IoT

'Things' in IoT may include various monitoring devices: heart monitoring implants, vehicle sensors, supporting devices for fire fighter rescue operations, and so on. The monitoring function is not restricted to the human body and convers many fields. Since various types of regulations are provided to protect the environment, it is necessary to monitor compliance with the regulations. The ELV recycling center should be a proper area that requires monitoring of recycling operations.

3.2. Concept of dismantling system

Figure 3 depicts an overall view of the developed line-type dismantling system, which can be applied to a large-scale line-type system with a series of workstations. Each workstation is equipped with a PC that can receive work instructions and transmit work results via interactive communication with a server. The first workstation where an ELV initially arrives allows an operator to store vehicle information (e.g., ID, photos) on the server using of a smart pad with a dedicated application. The next workstation collects liquid waste by type, and the drained liquid is collected at each tank and weighed with a scale.

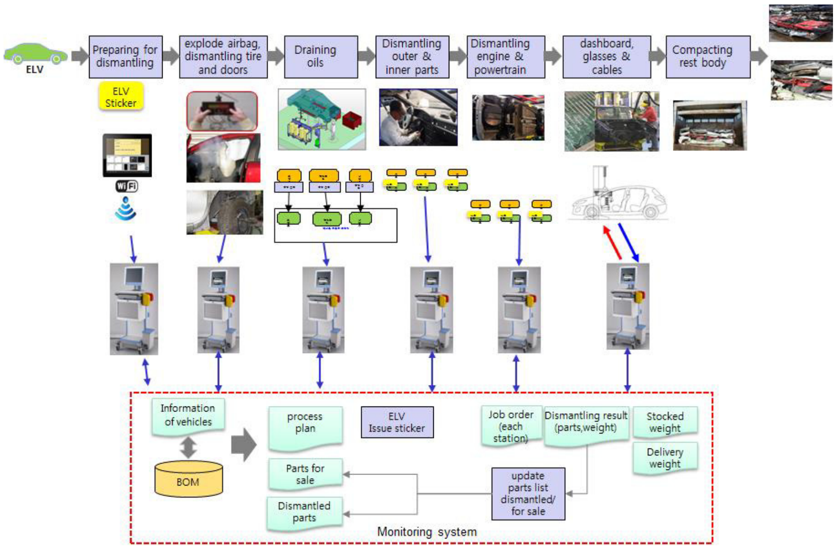

Fig. 3 Schematic diagram of the developed ELV recycling center

The smart trolley is equipped with an RFID sensory system and a load cell. The trolley enables identification of the input ELV by recognizing its ID data and measuring the ELV's weight. Each workstation communicates with the server via Zigbee communication, sending weight data and dismantling results to the server and receiving work instructions from the server. Dismantled parts for reuse or remanufacture are attached with printed barcode sheets at each workstation. All part-dismantling results are stored in the server and automatically transferred to a remote monitoring system if required.

3.3. PC-KIOSK for Korean ELV-recycling center

Most ELV dismantling systems in Korea collect recycling data by manual input (e.g., part name, weight), and they give little consideration to dismantling plant work conditions such as temperature and humidity. Uneducated operators may not be expected to input complete dismantling data as well. The PC (personal computer) at a dismantling site may not boot up on cold winter days, since the work floor is not warm enough, which is not appropriate for applications in Korea. The PC-KIOSK in the developed system has an automatic timed heating function to solve this problem.

An air-circulating heater is installed inside of the KIOSK to cope with cold weather (e.g., –20 degrees Celsius). The airflow in the KIOSK should be carefully designed to effectively cool down the PC. So, a digital timer is installed to automatically start the heater on cold days. The KIOSK is also equipped with electric outlets and pneumatic and hydraulic couplers for connecting operating tools. The KIOSK has a barcode tag printer for managing reusable parts, a scanning device to obtain input ELV information, a 900MHz RFID reader for identifying a vehicle, and a Zigbee device for wireless communication with the cart. Pneumatic or hydraulic machine tools can be controlled via the PC interface of the KIOSK.

3.4. Vehicle and part database

When a recycling center purchases an ELV, the first step is registration for dismantling. Vehicle information such as vehicle type is input, and reusable parts in the vehicle are selected based on the market condition, the vehicle type, and model year. The parts for reuse (for used parts or remanufacture) are designated on the vehicle's dismantling worksheet. A smart pad is utilized to input the vehicle data. The pad is portable and enables real-time transferring of vehicle photos for sales purposes. Some remarks or reusable part information of the registered ELV are input in the server and can be printed on the worksheet.

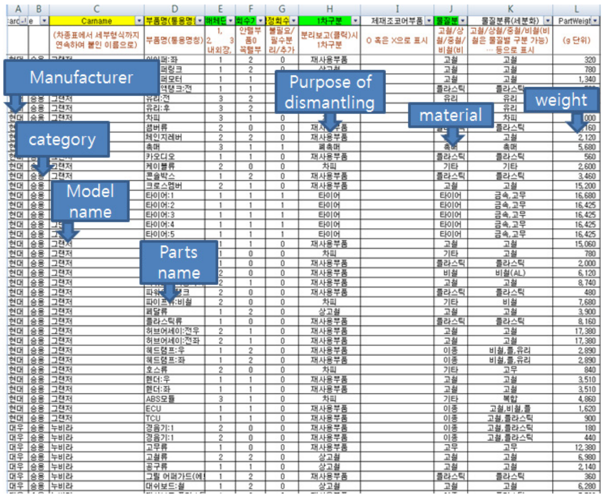

Fig.4 Standard parts and weight database (partial)

The parts constitution of an ELV may differ depending on the vehicle type and model year. It is ideal for each detached part to be weighed and for the dismantling result to be input to the server. However, it is practically infeasible to do so in most Korean recycling centers, because most parts are not detached individually, and weighing every part is economically infeasible. Therefore, a standard parts database for most vehicle types has been constructed on the operating server of the recycling center. The database has to be updated, and the developed system enables standard parts databases of the client sever to be updated through an administrative server. Figure 4 depicts a partial list of standard parts and weights for a passenger car.

3.5. ELV cart

In the line-type dismantling system, the vehicle to be dismantled should be sequentially transferred from station to station. An efficient method is required to identify the ELV at each workstation. Two different identifying numbers of each vehicle may be available: a number plate and a VIN (vehicle identification number). Number plates are unavailable after legal disposal paperwork, while the VIN is still available but difficult read, and it is rarely identified by an external sensor. The developed system matches an RFID-tagged vehicle cart with the ELV, which allows each workstation to identify the incoming cart (with the loaded ELV on it). In addition, each vehicle cart is equipped with a load cell that transfers the ELV weight value to the workstation PC via Zigbee communication [23]. Figures 5 to 7 depict schematic diagrams of the developed ELV cart system.

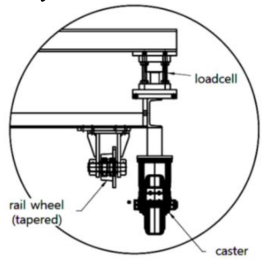

Fig.5 Schematic diagram of ELV cart

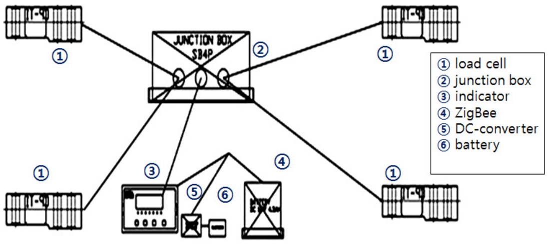

Fig.6 Electric wiring diagram for cart

Fig.7 Load cell and Zigbee wireless communicating device

3.6. Implementation of recycling center

The overall ELV dismantling process that is currently implemented in Yeoju, Korea, is divided into seven stages: matching cart and vehicle, pretreatment, glasses removal, dashboard removal, inner part removal, engine and powertrain removal, and vehicle shell compression (see Figure 8).

The cart and guided rail system have been developed for transferring an ELV from station to station. At the pretreatment station, drained liquid is collected in separate tanks by type, weighed, and stored in the monitoring system. When a cart arrives at the workstation, an RFID reader identifies the vehicle, and the workstation PC requests a dismantling worksheet for the ELV from the server. If automatic identification fails for any reason, the on-site operator selects the corresponding vehicle to match with the cart. The whole weight of the cart and ELV is transferred to the PC via Zigbee communication upon arrival.

Fig.8 Implemented ELV dismantling stages

The dismantling worksheet is displayed on the screen, where parts are categorized into reusable parts and recycling materials. Parts for reuse require further operator selections, such as domestic/export, part condition, and detach/do not detach. Barcode tag printing is enabled for the reuse of a part if 'detach' is selected, but it is not necessary for the parts for material recycling. All of the generated data are stored in the plant server and can be automatically transferred to the remote monitoring system.

4. Remote monitoring

Most previous research may be restricted in process control in a dismantling plant. The developed system facilitates providing information via IoT, RFID, load cells, and Zigbee devices. An application of such information is a remote real-time monitoring system for dismantling processes in a plant. Figure 9 shows a main screen capture of the developed monitoring system. Note that some comments are added since the implemented language is Korean.

The workstations are displayed on the screen, where an ELV image and its information for the active workstation are shown. The ELV information at a workstation includes the following data: vehicle type, VIN, registration number, ID, arrival time, arrival weight, current weight, number of parts to be dismantled at the station, and the whole number of parts to be dismantled.

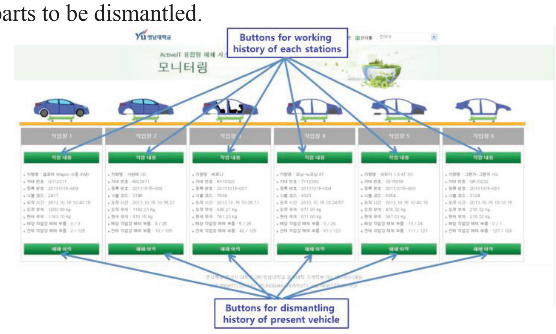

Fig.9 Image capture of main screen of remote monitoring system

The upper green button allows the operator to reference the current station's work history, while the ELV's work history is referenced with the lower button. Figure 10 depicts a sample work history of an ELV on a pop-up window that shows the time and weight at arrival, operation time, final weight, and number of detached parts as a table. Clicking the lower green button displays the target ELV's work history at each workstation: time and weight at arrival, time and weight at work completion, and number of detached parts.

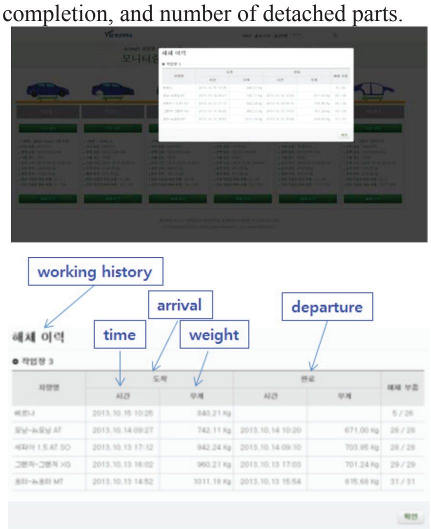

Fig.10 Image capture of screen daily work history of a workstation

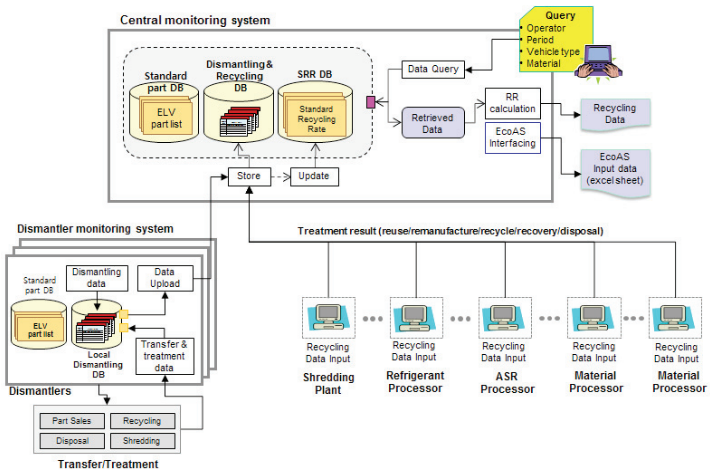

Fig.11 Schematic diagram of overall recycling monitoring system [20]

The developed system may be connected to a web-based monitoring system equipped with a central database for gathering and storing data to compute the recycling rate of dismantled ELVs (see Figure 11).

The whole system may be composed of a central monitoring system and a dismantler monitoring system. The dismantler monitoring system locally collects and uploads dismantling data to the database of the central monitoring system. Part transfer and treatment data are also uploaded. The standard part database provides an initial parts list of each vehicle type, which serves as a basis for creating a dismantling worksheet. All authorized operators in the recycling process can access the system and report their recycling results via the network or over the Internet.

5. Conclusions

A line-type dismantling system was suggested and implemented with remote real-time monitoring using IoT technology for ELV dismantling plants. An ELV's identifying data like the VIN are stored on a server, and the ELV is identified by matching it with a loading car with an RFID tag. Each workstation identifies the vehicle with an RFID reader, requests the ELV's weight via Zigbee communication from the cart, and receives the dismantling worksheet from the server. The dismantling result is displayed on a PC screen and stored in the server. The monitoring system enables an authorized user to inquire about each workstation's state and work history via Internet, as well as each ELV's work history data from the server. This research could be the basis for a more complicated monitoring system than extends to downstream recyclers such as shredding and ASR treatment.

Acknowledgements

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