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IOT-BASED PROTOTYPE OF SMART FACTORY EQUIPMENT IN THE STEEL YARD

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Abstract. *The Internet of Things (IoT) is crucial for the smart factory realization by connecting things/objects with wireless and wired network. The IoT ecosystem is composed of IoT enabling technology, IoT viable marketplace and IoT applications desirable to users. Among the three areas, more research is needed in the third area, which deals with practical application cases. The purpose of this research is to develop IoT-based prototype of smart factory equipment in the steel yard. A sensor networked overhead crane with autonomous navigation system is devised and implemented with lab-level prototype.*
Keywords: Internet of Things (IoT), Wireless sensor network, Smart factory equipment, IoT prototype

1. **Introduction.** The Internet of Things (IoT) has been identified as one of the emerging technologies for the success of future manufacturing and production environment. The IoT describes a system where objects, sensors and software are connected to the Internet via wireless and wired network. It enables added value and service by exchanging data with the manufacturer, operator and/or other connected devices.

The IoT generates a paradigm where everything is interconnected and redefines the way people interface with machines and the way they interact with the environments. Many types of architecture are proposed for the IoT system. They are three-tier architecture, gateway-mediated edge connectivity, edge-to-cloud, distributed analytics and Lamda architecture [1]. The three-tier architecture consists of edge, platform and enterprise tiers. They are connected by access, proximity and service networks.

Previous researches in the IoT application areas are prototype implementation in smart factory [2], review research [1] and future directions [3]. The IoT ecosystem is composed of IoT enabling technology, IoT viable marketplace and IoT applications desirable to users and stakeholders [4]. Research trends on smart factory have been reviewed and surveyed based on the analysis of 2488 international research papers [5]. In this review paper, the smart factory research trends have been analyzed based on research framework, data collection, data preprocessing, topic extraction and topic-based trend.

Considering all these previous research works as mentioned above, IoT-based practical applications in the smart factory environment are not reported satisfactorily. Thus, a practical application framework in manufacturing environment for IoT-based smart factory is needed in this area.

The purpose of this research is to develop IoT-based prototype of smart factory equipment in the steel yard. In the most smart factory environment, overhead crane is indispensable equipment. It is equipped with autonomous navigation with IoT sensors and network capability. In the steel yard domain, steel is stocked in several layers due to limited space constraints. The overhead crane equipped with inertial navigation system,

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wireless sensors and networking can monitor the steel location correctly and ubiquitously. Section 2 describes the problem domain. Section 3 describes the methodologies and implementation. Section 4 presents the prototype implementation of the proposed research. Section 5 summarizes conclusions and future research directions.

2. **Background of Problem Domain.** In the working environment of steel yard, steel such as steel board or coil is stocked as pile by classifying their characteristics. When the yard is wide enough, as the steel can be stocked as a single layer, their efficiency of pickup and stocking process can be very high. In the practical situation, as the yard is limited, the steel is stocked as a multi-layer as shown in Figure 1.

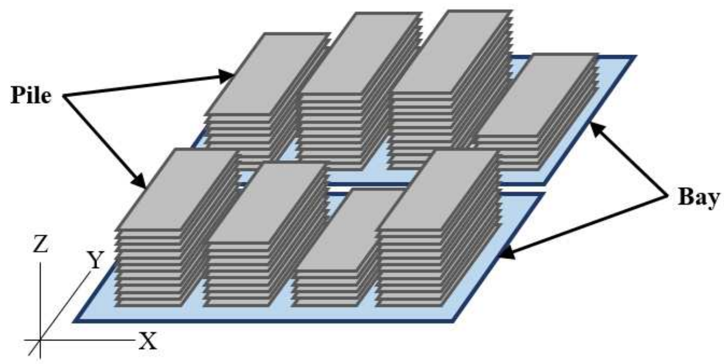


FIGURE 1. Steel board piling in the steel yard

When the multi-layer stocking is adopted, decision making criteria are location and re-handling during pick-up and loading process. In this case, the objective is to minimize the movement of steel in the upper layer in order to pick up the steel in the lower layer [6]. The idea of steel board piling in the steel yard is shown in Figure 1.

The previous researches in this area focus on the mathematical algorithm to minimize the re-handling cost of steel movement [7]. A computer software which is equipped with minimizing re-handling cost is off-the-shelf in the market. This software assumes that the location in the database and in the actual stocking storage is the same. However, in real situation, as two locations do not coincide, the software cannot work efficiently as intended.

The reason why two locations do not agree is that the worker does not update in the computer software after he moves the steel in the yard. In order to tackle this issue, RFID (Radio Frequency Identification) has been tried to be attached in the steel. Even this method was not successful due to a tag price and the inconvenience of tag attach/detach problem. Even when RFID is adopted, the steel can be recognized uniquely. However, it is not feasible to monitor the location when a worker has moved its location arbitrarily.

3. **IoT-Based Location Recognition System.**

3.1. **Steel identification system.** Inertial navigation technology utilizes accelerator sensor and Gyro sensor to measure the location of moving objects, which is connected with GPS (Global Positioning System). In case of moving to the pre-determined location, the acceleration and angular velocity can be calculated without GPS information [8]. In daily life, the distance of moving object can be calculated using Gyro sensor. In the smart cellular phone, Gyro sensor is equipped to detect the user motion. There is a Gyro-equipped app to be used as a measuring device. Figure 2 shows the moving distance of the user with smart phone app equipped with a Gyro sensor.

Figure 3 shows the structure of overhead crane for transferring a heavy material in the steel yard. The shape of 'hook' varies according to the steel type. When a steel board is transferred, an electromagnet is attached in the hook. In case of a steel coil, a chain is attached in the hook. The load cell can be mounted on the hook, which can be used to measure the weight of the pile using a load cell and compare it to the weight of the pile to be worked on in the database to verify that the pile to store or retrieve is correct. Through this identification system, the re-handling work can be reduced through the early identification of the wrong task. If the work mandatory is correct, operate the wired remote control or board directly and move the crane to the work position. The steel cranes can only move in three axes, the crane can move along the "Runway beam", the "Trolley" can run on the "Girder", and the pile can be moved up or down by winding or unwinding the wire by the "Hoist".

Figure 2. Example Gyro app for distance measure

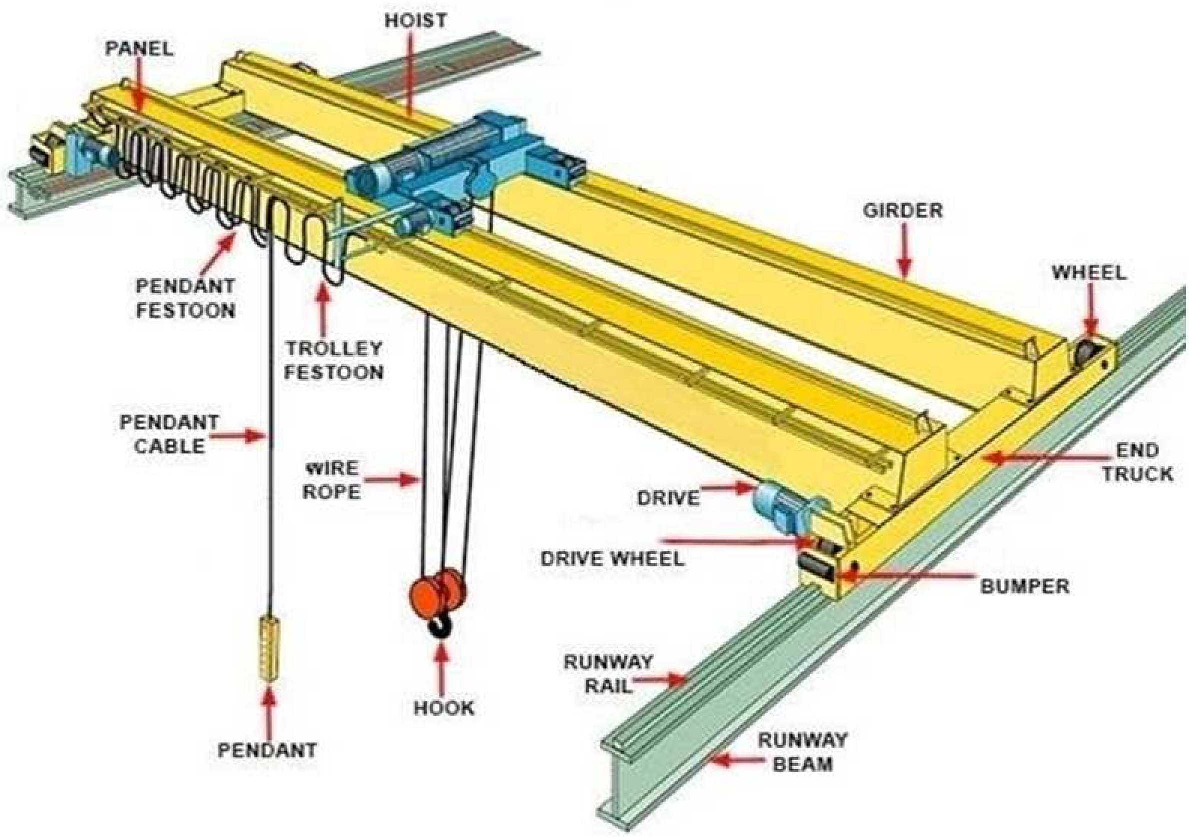


Figure 3. Structure of overhead crane in the steel yard

In the figure, the structure and operating procedure of the overhead crane are installed at the steel stocking place. Since the movement of the crane is relatively slow and the direction in which it can move can be limited, the sensor can be used to accurately recognize the position of the crane. If the position of the crane can be accurately recognized, it is possible to control the "Drive" and the "Trolley" to autonomously travel at the designated coordinates.

In this study, a 9-axis gyro sensor (3-axis angular velocity, 3-axis acceleration, 3-axis geomagnetism) is attached to a hook for the development of an autonomous overhead crane. Based on the above 9-axis architecture, the method of calculating the position of the crane is shown in Figure 4.

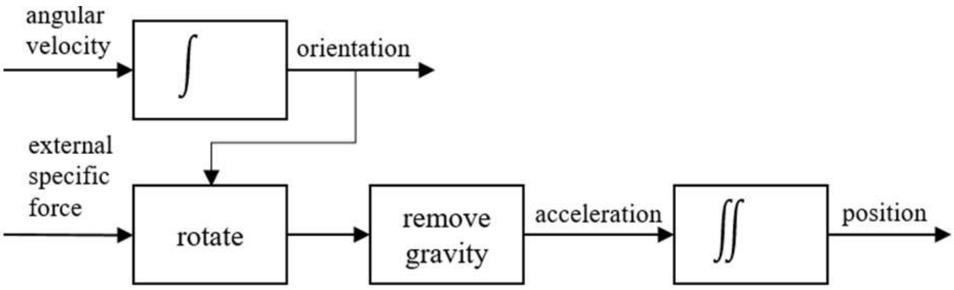


FIGURE 4. Method of calculating the position of the crane

In the steel yard, the location where the overhead crane starts is always the same position. If acceleration sensor and Gyro sensor are equipped in the hook, the acceleration and angular speed from crane movement can be measured automatically, and the location of crane can be identified by integral calculus. Thus, the real stocking location of a steel can be monitored correctly even the worker has transferred the steel arbitrarily. Figure 5 shows the modeling scheme of re-handling problem in the steel yard. 'Withdraw' implies the transfer of steel in one location to another, and 'deposit' means to stock steel at a predetermined position.

According to the patterns in Figure 5, we can get the information of steel movement and transfer. When any change occurs in the stocking location, this information is updated in the database, and thus the steel stocking location can be maintained correctly.

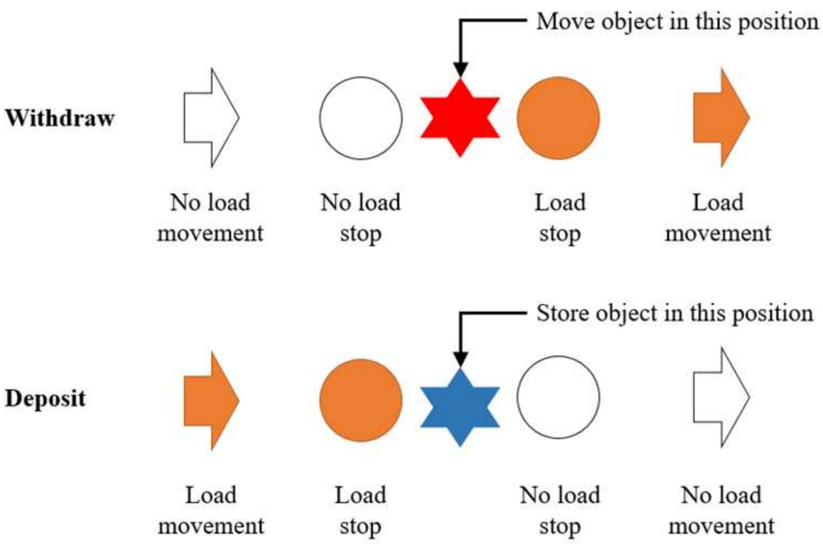


FIGURE 5. The re-handling process in the steel yard

Figure 6 shows an example of a stockyard management system that can be linked to an autonomous traveling crane developed in this study. When the autonomous traveling crane proposed in this study is applied to a steel stockyard management system, it is possible to maintain the consistency of the steel storage location information even if the operator moves the steel at an arbitrary position, thereby greatly improving the inefficiency caused by the inconsistency of the storage location.

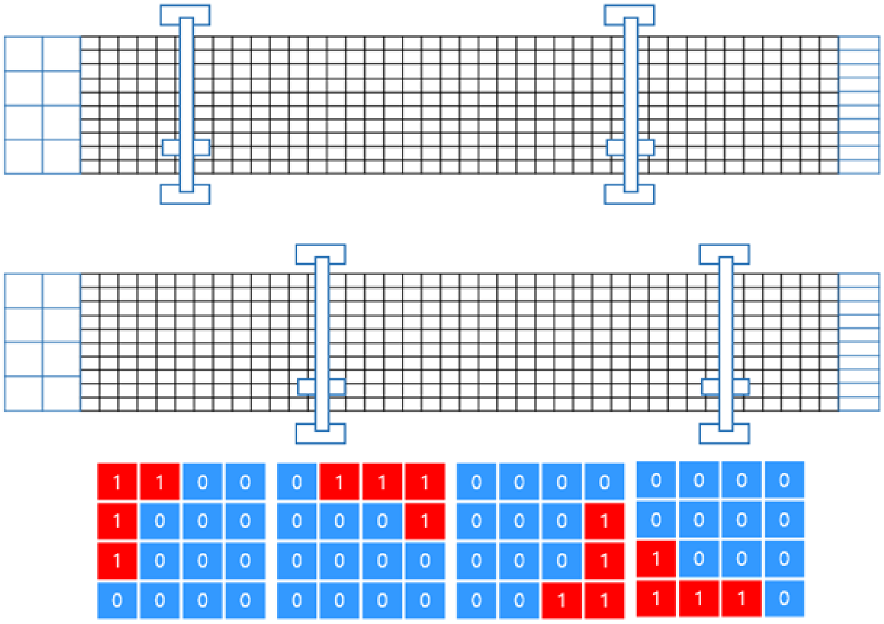


FIGURE 6. Database structure for stocking steel block

3.2. **IoT-based factory crane monitoring system.** The factory crane monitoring system is composed of three sub systems. They are physical crane, IoT sensors with loadcell and positon sensor, cyber monitoring system with crane terminal and IoT receiver. In the overhead crane, a crane terminal is equipped, and this terminal communicates with a host computer via a wifi network. The communication between sensor and crane terminal occurs through Zigbee. This system structure is shown in Figure 7.

FIGURE 7. IoT-based factory crane monitoring architecture

4. **Prototype Implementation.** In order to develop the proposed system, a laboratory-level prototype is developed with physical crane, sensor and monitor.

The prototype system works as the following steps. First, the weight change is identified through the loadcell sensor, and acceleration and movement via Gyro sensor are measured. Second, this data is transferred to the crane terminal. Third, the crane terminal updates steel stocking location via a host computer and networking. Fourth, the actual location of a steel and database information always coincide through this process.

When the value generated by the gyro sensor is transmitted to the host computer through the Zigbee modem, the host computer calculates the position of the crane and determines whether it is moving based on the distance to the target position and transmits it to the controller. In order to compensate for the position error, we added a crash sensor to the prototype. The overall concept of the prototype architecture is shown in Figure 8.

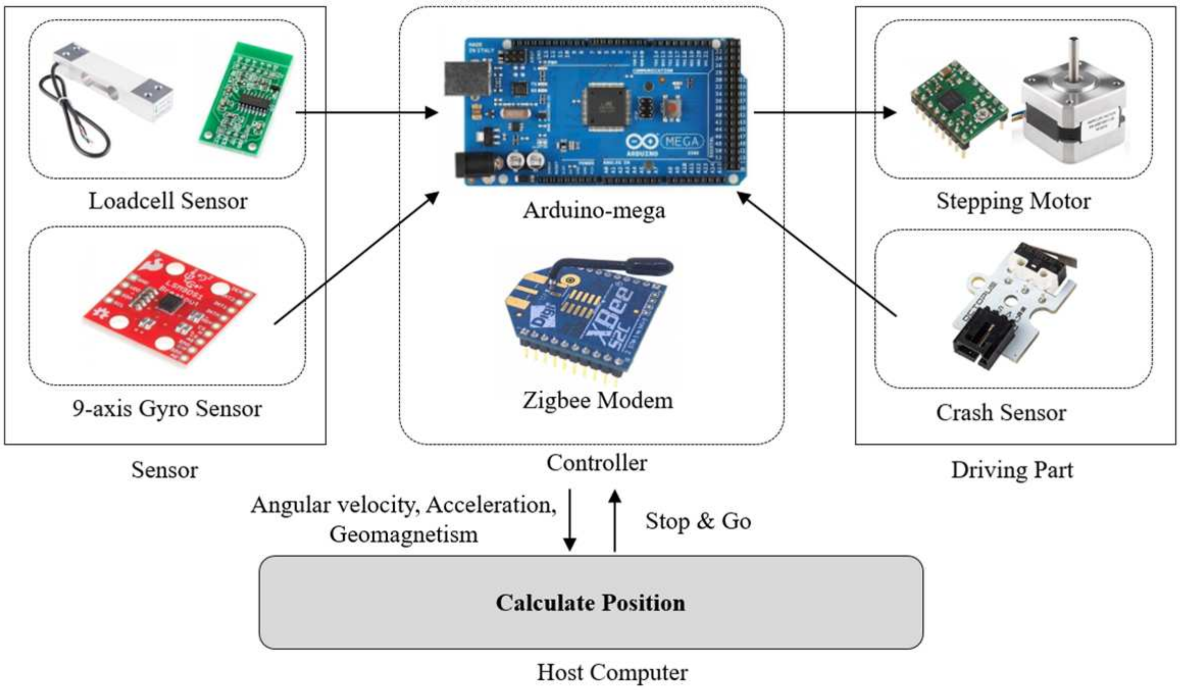
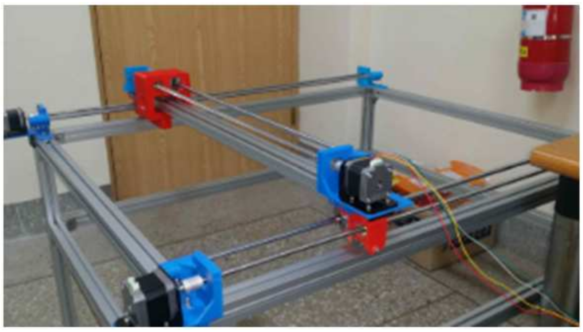


Figure 8. Conceptual model of prototype architecture

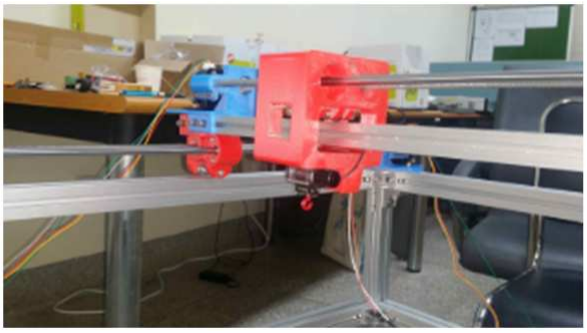
If the actual location of steel is always correct, it is possible to move the crane to the real position where the target steel is located by crane control terminal. Figure 9 displays laboratory-level prototype of IoT-based crane monitoring system with autonomous navigation. The system is composed of loadcell sensor, 9-axis Gyro sensor, Arduino, Rapsberry Pi and laboratory-level crane. The crane is designed by CAD and produced through 3D printing.

5. **Conclusions.** This research has proposed a prototype of IoT-based smart factory equipment with autonomous navigation system in the steel yard. The minimization of re-handling task is essential in the overhead crane handling a heavy material. Actually, as workers handle steel arbitrarily in the yard, a mathematical algorithm does not work properly because of gap between real location and database information. Through the IoT-based sensor networking in the overhead crane transfer, the actual control and monitoring can be possible based on the real location data from sensor information.

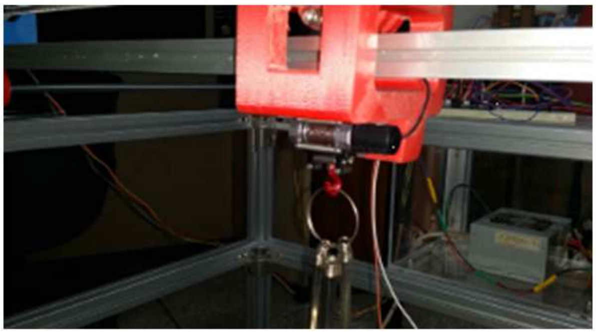
Future research directions are as follows. More test is required to verify the handling of model steel with reasonable weight. An intensive simulation is needed to verify the operation of autonomous navigation crane in the near-real environment. Also, the proposed system needs to be upgraded into a more generic methodology through more applications.



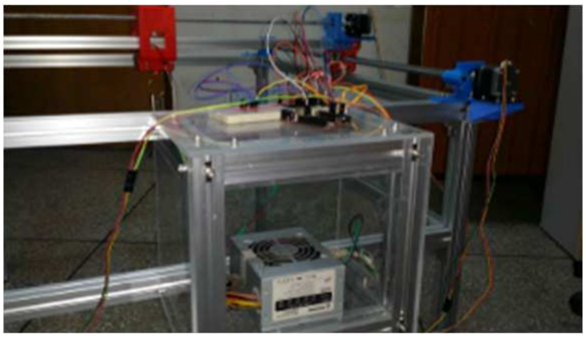
(a) Driving device



(b) Hoist crane



(c) Hook



(d) IoT device & power supply

Figure 9. Laboratory prototype of IoT-based crane monitoring system

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