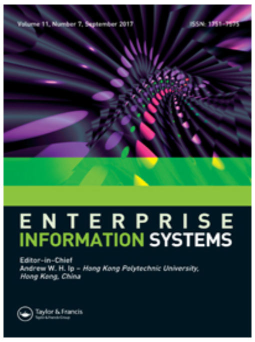

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A cloud-based production system for information and service integration: an internet of things case study on waste electronics

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ABSTRACT
Cloud computing is the new enabling technology that offers centralised computing, flexible data storage and scalable services. In the manufacturing context, it is possible to utilise the Cloud technology to integrate and provide industrial resources and capabilities in terms of Cloud services. In this paper, a function block-based integration mechanism is developed to connect various types of production resources. A Cloud-based architecture is also deployed to offer a service pool which maintains these resources as production services. The proposed system provides a flexible and integrated information environment for the Cloud-based production system. As a specific type of manufacturing, Waste Electrical and Electronic Equipment (WEEE) remanufacturing experiences difficulties in system integration, information exchange and resource management. In this research, WEEE is selected as the example of Internet of Things to demonstrate how the obstacles and bottlenecks are overcome with the help of Cloud-based informatics approach. In the case studies, the WEEE recycle/recovery capabilities are also integrated and deployed as flexible Cloud services. Supporting mechanisms and technologies are presented and evaluated towards the end of the paper.

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Cloud manufacturing; information system; industrial informatics; IoT; WEEE; waste electronics

1. Introduction

In the computing sector, Cloud systems and applications have gained huge market success globally. Cloud offers new business models and opportunities to establish advanced IT solutions and resources to improve current information systems. The Cloud provides flexible, scalable and customised computing service and storage service with lower entry barriers and less cost. Instead of investing on costly IT equipment or software licences as a whole, the Cloud users are able to pay for the exact amount of software or hardware usage. It is also known as pay-as-you-go principle. The Cloud solution is especially helpful for Small and Medium-sized Enterprises (SMEs) that are normally short of start-up capitals for new investments or equipment.

It is thus logical and reasonable for manufacturing researchers and stakeholders to adopt Cloud into the manufacturing industry so as to improve the current production performance. As a new manufacturing paradigm, Cloud manufacturing systems are proposed worldwide in recent years (Wang and Xu 2013a; Li et al. 2010; Meier, Seidelmann, and Mezgár 2010; Rauschecker et al. 2011). Different definitions of Cloud manufacturing have been proposed by numerous scholars. Some of them aimed to change the definition of Cloud resources from computing to manufacturing (Xu 2012; Wang and Xu 2013b), while others focused on the connectivity issues for digital and physical resources (Wang, Gao, and Ragai 2014). Despite different definitions and perspectives, the Cloud manufacturing research can be categorised into two types in general:

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- deploying manufacturing applications (software, data storage, computing tasks etc.) on the computing Cloud and
- providing manufacturing resources (machine tools, robots, monitors etc.) in terms of Cloud service.

However, production resources are conducted by different vendors using various standards, platforms and communication protocols/interfaces, thus forming a heterogeneous environment which experiences interaction and integration difficulties for Industrial Informatics (II). Compared with Cloud Computing systems, one of the biggest challenges for Cloud manufacturing is involving numerous types of physical resources. Therefore, our research work in this paper focuses on the integration methods that are capable of coordinating various manufacturing resources in an interoperable and flexible environment.

In parallel, waste electronics are identified as an important area of manufacturing and remanufacturing. Waste Electrical and Electronic Equipment (WEEE) indicates discarded electrical and electronic goods that either stopped services or are no longer needed. In Europe, WEEE Directive sets targets for collection, recycling and recovery, while Restriction of Hazardous Substances Directive (RoHS Directive) restricts the hazardous material content of new electronic equipment placed to the market (European Parliament 2011, 2012). Even though these directives have effectively entered into force to combat the fast increasing waste, the global environment still faces huge pressure of WEEE generation and recovery. In the United States, 3.42 million tons of consumer electronics were mixed with the municipal waste stream in 2012, which had increased by almost 79% in the past 12 years (EPA 2012). However, only 29.2% among the huge amount of WEEE was properly recovered. That means more than 2.42 million tons of WEEE in America are directly discarded every year without proper treatment. These wastes contain complex ingredients of materials and hazardous substances, which leads to numerous environmental damages/risks. On the other hand, the recovery percentage is even lower in developing countries like China, India and Brazil, due to the high growth rate of new Electrical and Electronic Equipment (EEE) generations.

There are multiple reasons for the rapid increase of WEEE generation. In practice, the fast-changing technology brings new products to the market with new functionalities and improved performance. It has to be admitted that refurbishment and upgrading not only enhance the product performance but also achieve better user experience. Yet, new products also push the current products to the end of lifecycle earlier than expected (also known as precycling). For example, Blu-ray disc players replace the old video products, e.g. tapes, VCD and DVD players. Related storage products like discs or videocassettes are also substituted. Quick replacement driven by new products not only brings additional value and huge profits to electronics manufacturers, but also adds significant amount of WEEE to the waste flow. These WEEE outputs result in multiple environmental issues, e.g. soil, sediment, water and air pollution, plus complex human and wildlife health damages.

To meet the challenges mentioned above, it is feasible to establish an information system with the help of Cloud environment. Thus, a Cloud-based system is developed and deployed for WEEE recycling and remanufacturing. In this research, WEEE is utilised as an example of the Internet of Things, which are connected to the Cloud via smart devices and methods.

2. Literature review

From integration's perspective, different approaches are considered to adopt manufacturing applications into the Cloud. Much recent research efforts (Li et al. 2010; Zhang et al. 2010; Ren et al. 2013; Tao et al. 2011a, 2011b, 2014) have been devoted to the Cloud Computing services for the production industry. It can be considered as the first type of manufacturing Cloud. In their system, software applications are integrated and promoted in the computing Cloud, e.g. schedule, test, management and so forth, which provides a software-as-a-service model. On the other hand, Houshmand and Valilai (2012) improved their previous research work by introducing Cloud computing in a new framework (Valilai and Houshmand 2013). In their research, different product data were maintained in the STEP standard and then interpreted into XML. The approach can be considered as an integrated interpreter software application offering multiple threads on the computing Cloud, which also works at the software-as-a-service level. In addition, some researchers move manufacturing resources data on the Cloud to achieve a centralised II environment (Wei et al. 2013; Putnik 2012; Wu and Yang 2010; Wu 2011; Park and Jeong 2013; Hu et al. 2012; Zhu, Zhao, and Wang 2013; Liu, Gao, and Lou 2011; Kawa 2012; Wang, Törngren, and Onori 2015; Wu et al. 2015). However, there is still a lack of a feasible mechanism that is capable of hardware integration.

Some researchers (Rauschecker et al. 2011) suggested connectors between ManuCloud and production sites, despite it is unclear about how the production resources can be integrated and harmonised. In fact, Function Block (FB) technologies can be utilised to support the integration method. The FB is the open IEC standard (2004) for distributed control and automation. Besides advantages such as robustness and modularity, an FB provides explicit event-driven models for control and automation. An FB can be controlled by its event and data input/output, which is specifically suitable for the distributed and heterogeneous environment-like Cloud Manufacturing. Wang (2013) developed a system that enabling Cloud-based monitoring and process planning via the FB. In his research, FBs are capable of streaming machine availability information, which is combined with process planning and decision-making afterwards.

Traditionally, the WEEE recovery process focuses on the valuable content at the material level, e.g. gold, silver, aluminium, plastic etc. Streicher-Porte et al. (2005) conducted a case study in India and analysed the recycling process of drivers on personal computers. In average, there are 4 g of gold contained in a personal computer, which leads to strong incentives to recover this material fraction. In order to be separated, WEEE is suggested to be shredded to small even fine-sized particles with the help of mechanical separation (Cui and Forssberg 2003). Dalrymple et al. (2007) reviewed numerous supporting technologies that were relevant to material recycling from WEEE. However, in most cases, a big number of components inside the discarded equipment are still functioning. It is thus possible and reasonable to recover WEEE at the component level as well and organise remanufacturing processes accordingly. Babu, Parande and Basha (2007) presented a deep discussion on the WEEE waste stream in the perspective of material and component recovery. It is suggested that WEEE needs to be well characterised and understood, and the worldwide flow of WEEE needs to be projected. Better understanding is necessary for the dynamics of WEEE generation and market needs. Spengler and Schröter (Spengler and Marcus 2003) proposed closed-loop supply chains for component recovery. The information management and communication platform are identified as the key essentials for the strategic management (Figure 1).

Basdere and Seliger (2003) developed a Life Cycle Unit concept, which was conducted by sensor, marking, Life Cycle Board and actuator modules. The method utilised in their works is similar to closed-loop production. In their approach, economical fulfilments were analysed for new legal requirements, considering the disassembly and reassembly processes at the operation level. For product disassembly, a cognitive robotics-based system was proposed (Vongbunyong, Kara, and Pagnucco 2013). With the help of cognitive functions, the system is able to process different

Figure 1. A Typical WEEE Information System (Adapted from Spengler and Schröter 2003).

products without prior information. At the II level, ontology can also be utilised as the knowledge representation method for the disassembly processes (Merdan et al. 2010). Based on the knowledge maintained in the vision system, disassembly processes can be scheduled and executed by closed-loop control of robots/tools.

An automatic PC disassembly system is proposed by Torres et al. (2004) for component recovery. Recognition and localisation methods are also deployed based on a vision system. A dynamic model for the product and its components is also developed, which links product design with liberation modelling (Van Schaik and Reuter 2010). The mass and material information is available and deliverable from the early stage of product design. Thus, in the recycling phase of a product, the recyclate quality and toxicity can be predicted and related processes can be configured accordingly. At the beginning of product lifecycle, a collaborative design platform was developed by Kuo (2010) supporting WEEE recycling analysis from the Bill of Materials' perspective. Information systems throughout the product lifecycle, i.e. computer-aided design, product lifecycle management and enterprise resource planning applications, are included to offer product data at the component level. Thus, the manufacturer's eco-friendly design can be utilised directly by disassemblers and recyclers in the future. To better design and recover the products, Hendrickson et al. (2010) suggested new design rules for future recovery including design for reuse and servicing, disassembly, product and component remanufacturing and material recovery.

From the business point of view, Kim and Goyal (2011) worked on the optimisation issue for the profitability of closed-loop supply chain. In their research, the consumption flow and recovery flow are merged and integrated, which leads the optimal recovery method to a profit maximisation problem. In parallel, Chancerel and Rotter (2009) reported an investigation on the WEEE properties for small appliances. Detailed data of individual appliances are utilised to calculate the rates of recovery. It is concluded that the composition of WEEE has strong impact on the performance of recycling afterwards. It is also recommended that systematic approach is needed to support recycling process, based on recycling-oriented characterisation.

To recap, despite multiple Cloud approaches have been proposed in recent years, the current systems focus on specific technical challenges in limited scopes. There is still a lack of an integrated information and service system for WEEE remanufacturing. Thus, in this paper, FB is utilised as the integration methodology for multiple manufacturing resources. An FB-based method is developed to provide a distributed and standardised integration mechanism for the Cloud manufacturing, which offers an intelligent, interoperable and collaborative recovery environment.

3. A cloud-based production system for information and service integration

In practice, the Cloud manufacturing paradigm distinguishes significantly from Cloud computing. In Cloud computing, the storage space, computing units and software tools are delivered directly via the network. The Cloud service can be achieved at the data and information level. Nevertheless, the production service in manufacturing industry involves physical resources like machines, materials and tools, which cannot be provided over the network directly. Thus, as an extension of the Internet of Things, a feasible mechanism is required to connect physical resources together and integrate them on the Cloud. *Things* mean manufacturing resources in the production environment, which lead to the concept of Internet of Manufacturing Things (IoMT). These *manufacturing things* are currently developed by different vendors based on different standards in different systems. The data and resource exchanged over the IoMT are organised in different formats and forms. Hence, a uniformed integration method is needed to support the II and server exchange among multiple service stakeholders.

3.1. *From device to cloud service: the FB mechanism*

At the shopfloor level, physical resources can be considered as the core of conventional production activities. Manufacturing processes are generated based on the hardware functionalities and

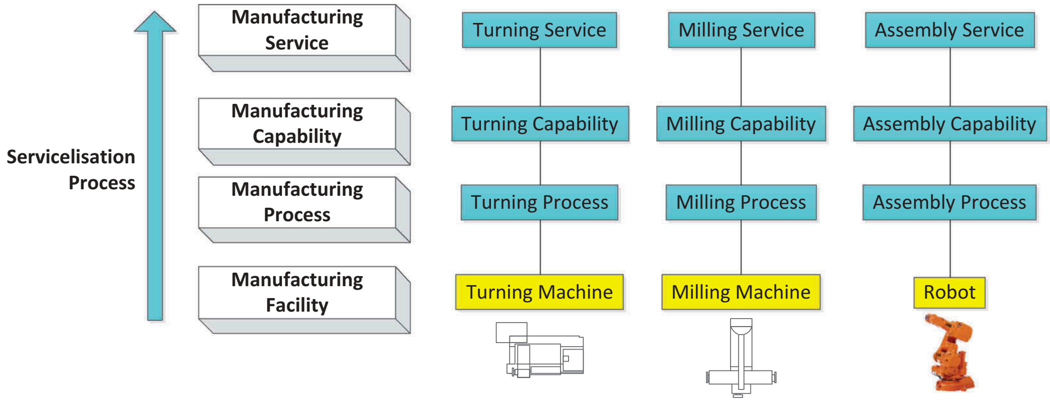

Figure 2. Servicelisation process.

specifications (Figure 2). Note that one physical resource is able to provide multiple production processes by means of functions and utilisations. Thus, at the process level, process planning engineers are able to map the production tasks to the available manufacturing processes and then to generate feasible process plans and production schedules. Typical computer-aided manufacturing, process planning and simulation systems mainly operate at this level. However, it is important to point out that when hardware is invested or utilised, the actual objective or target is the manufacturing capability of achieving production goals (e.g. turning capability of lathes and assembly capability of robots). In parallel, the resource provision itself can be considered as a specific type of service offering the resources in terms of services, e.g. Hardware-as-a-Service, Software-as-a-Service and Data-as-a-Service.

As mentioned above, the actual objective of resource investment is the manufacturing capability lying inside the devices. These capabilities can be further packaged in terms of service and provided in the shared Cloud service pool. In this research, an integration mechanism is therefore developed to promote the capabilities as Cloud services, which is defined as *servicelisation* mechanism in Figure 2. The manufacturing resources, both hardware and software, are first presented by the processes they are able to deliver. Next, these processes are described as the provider's capabilities in standardised schemas. The capabilities are then broadcasted and maintained in the manufacturing Cloud in terms of cloud services that interact with Cloud users. Hence, the production resource is integrated from shopfloor to Cloud level.

The *servicelisation* process involves both cyber and physical sectors. At the cyber level, manufacturing processes are extracted as the production capabilities and documented in standardised and uniformed models. These models are developed based on current ISO standard series and then packaged as Cloud services. The service description methods focus on the machine-readable specifications for different service packages. In this manner, the manufacturing resources, e.g. turning, milling, assembly devices and their functionalities are described in standardised models and then offered on the Cloud. More details of these models and their management mechanism can be found in Wang and Xu (2013a, 2013b), Wang (2014), Xia et al. (2015).

As the second sector of servicelisation process, physical resources can be connected and servicelised on the manufacturing Cloud via FBs. Similar to the agent technology (Genesereth and Ketchpel 1994), there are three typical approaches to develop an FB-based integration mechanism, i.e. transducer, wrapper and rewriter as shown in Figure 3. A transducer FB works between an existing application and other FBs. The transducer FB receives messages and commands from the Cloud and then interprets them into the hardware or application native data format or communication protocol before streaming them to the related resources. Vice versa, the

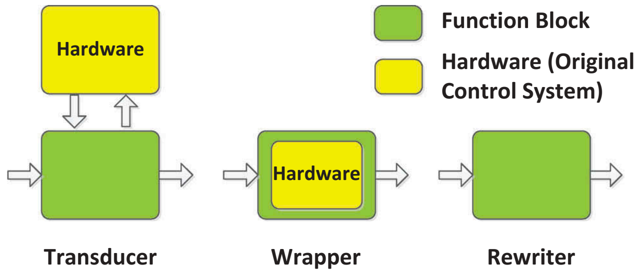

Figure 3. Three types of FB integration.

hardware's responses and communications are handled by the transducer FB and then pushed to the Cloud at higher level or other FBs. One advantage of the proposed approach is that no pre-knowledge of the application is needed except the communication protocols. This is especially valuable in practice since the source code of commercial applications is normally not available, e.g. firmware in CNC and robot controllers. Meanwhile, this approach is also feasible for special types of resources, e.g. human resource and documentations. The FB algorithms are potentially capable of interpreting the standardised semantics and connecting them to required functionalities.

The second approach dealing with legacy hardware is to implement a wrapper, i.e. injecting code, inside the hardware control system to enable its communication in a neutral programming language. The wrapper is able to directly examine and modify the data structure of the hardware. The merit of this approach lies in its greater efficiency compared with the transduction approach. It is also feasible for scenarios in which inter-process communication with the legacy hardware is not feasible. However, it partially requires the availability of the local system's source code, e.g. extension tools and user application protocol interfaces for extendable objects.

Last but not least, the third approach, as the most drastic one integrating legacy hardware, is to overwrite or reinvent the original system. Rewriting the applications based on the same kernel and format provides strong system robustness and reliability to the environment. Implementing a proprietary format is called data-centric interoperability solutions. The deployment of applications within one organisation may be feasible, but when it comes to multiple tiers of suppliers, contractors and retailers on the Cloud, it is not realistic to force all the stakeholders to use new tools in the same kernel. The wrapper FB provides attractive advantages, e.g. fast response and high efficiency. However, it requires the source code from hardware programmes to build internal connections between the hardware and the FB, which is against both the expectation and intellectual property rules of the hardware vendors. The transducer approach thus provides a feasible solution with high flexibility and easy implementation. Hence, it is necessary to develop a transducer FB with some of the wrapper FB's features, without interference with the hardware systems.

In this research, the integration framework is illustrated in Figure 4. In the Cloud manufacturing system, the user connects to the manufacturing Cloud via network and interacts with the coordinating mechanism at the Manufacturing Cloud layer to request Cloud manufacturing services. As previously mentioned, at the information level, the coordinating mechanism analyses and manages the digitised service images in a standardised manner.

At the physical layer, each service package maps to a specific FB deployed on the shopfloor. The FB is connected to the manufacturing resources onsite and directly controlled by the manufacturing Cloud via network. As aforementioned, an FB is capable of automatic control and remote supervision. In this approach, the internal algorithms and variables are predefined within an FB before it is deployed on the shopfloor. The coordination mechanism is thus able to launch, manage and terminate manufacturing services by controlling the data/event flows through FBs.

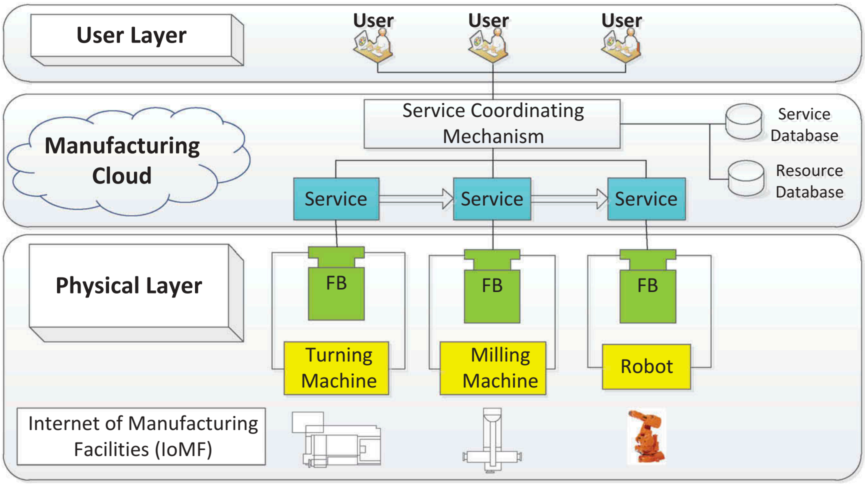

Figure 4. Function block-based integration framework.

Regarding standardisation and communications, the Cloud-based FB mechanism is able to play as a universal interface for different physical resources. The manufacturing Cloud communicates with FBs on the shopfloor via standardised protocols, while internally different wrapper FBs are developed to carry out specific service tasks. The internal communication between wrapper FBs and hardware is established based on the native protocol or data format. In spite of different protocols or proprietary communications methods inside FB modules, a standardised data/event exchange method is achieved between the physical layer and the manufacturing Cloud. Note that instead of conventional one-to-one integration model, each FB maps to one production process presented in Figure 2. As a result, physical resources are able to provide multiple Cloud service packages with the help of multiple FBs on the shopfloor. It thereby offers a many-to-many integration methodology for different manufacturing hardware.

The FB is one of a series of published IEC standards which aims at modularised and event-driven control and automation (IEC 2005). The internal algorithms and functionalities inside an FB are driven by the data and event flow through them. Therefore, this research makes use of the modularity of FBs. FBs have previously been utilised to model and control other mechanical systems. The modularity and interconnection properties of virtual FBs allow rapid integration of manufacturing resource in the Cloud manufacturing environment.

The service integration flow is summarised in Figure 5. In the service integration phase, the manufacturing hardware is wrapped by an FB. For the wrapper FB, the input variables are

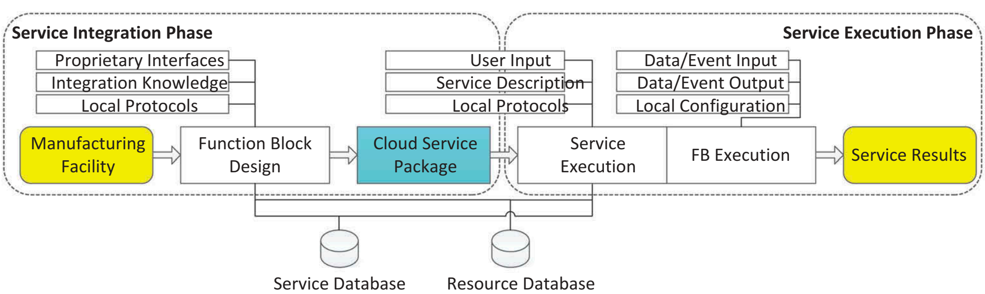

Figure 5. Service integration flow.

compliant with the unified Cloud interfaces, and the output matches to proprietary interfaces towards local hardware. In the behaviour sessions of FBs, control methods can be implemented at different levels. For example, for conventional control, an FB is able to launch, pause, stop hardware and manipulate the date flow including input/output files and monitoring data from sensors. For open systems with rich user application protocol interfaces, an FB is also able to fulfil more complex and detailed tasks, e.g. machine control, process planning etc. Eventually, the manufacturing resources are wrapped by the FB and established as Cloud service package on the manufacturing Cloud.

At the service execution stage, the user provides service descriptions and uploads supporting documents to the Cloud, e.g. product design, process planning document, technical specifications etc. Based on these inputs, the service package enters service integration phase, and the wrapper FB is launched. In practice, users' inputs and specifications are interpreted as data and event variables that are readable for FBs. These inputs are then streamed to the FBs on the shopfloor, which is triggered to initiate the service process. According to the variables and behaviour definitions pre-implemented inside FBs, the service goals are achieved step by step. As a result, digital service outputs can be directly transferred back to the Cloud over the network, e.g. simulation results, monitoring data etc.; while physical outputs (finished product and example workpieces) can be transported by logistic or transportation services allocated on the Cloud.

3.2. *WRCloud: a specified cloud implementation on WEEE remanufacturing*

As a specific type of service, WEEE remanufacturing operations can also be integrated on the manufacturing Cloud in form of services (Wang and Wang 2014; Wang et al. 2014; Wang, Lopez, et al. 2015). As mentioned above, in most cases, discarded electrical and electronic products contain numerous functioning parts at the component level. To recover these functions, the WEEE management system can be deployed at the Cloud level, which provides a distributed information system with high connectivity and flexibility. As shown in Figure 6, with the help of smart tags and devices, normal WEEE can be integrated to the information system in terms of IoMT. Together with manufacturing and remanufacturing devices, it forms a Cloud-based information environment connecting Internet of Smart Things.

Thus, the WEEE Remanufacturing Cloud (WRCloud) is developed as an integrated system to manage and control the remanufacturing processes and offer them as Cloud services in this research. A generalised WEEE processing flow in WRCloud can be found in Figure 7.

After the pre-sorting process, WEEE can be recovered at both material level and component level (options 1 and 2). The components are disassembled and reutilised with new warranty conditions, e.g. screen, battery, cable, PWB, motor etc. Then, the unrecoverable substances are discarded. As a result, it is necessary to coordinate both the component recovery and material

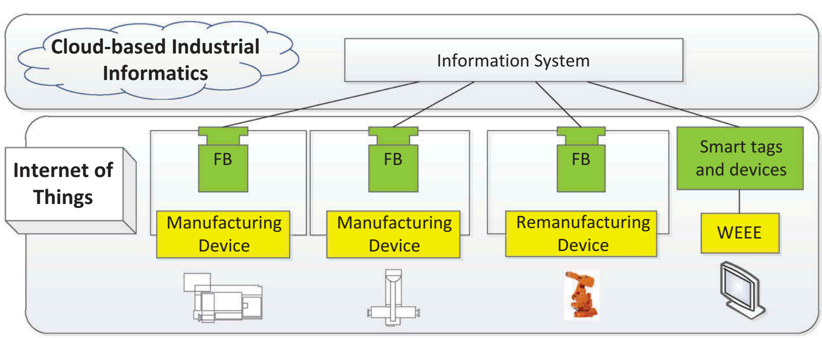

Figure 6. Cloud-based industrial informatics for WEEE.

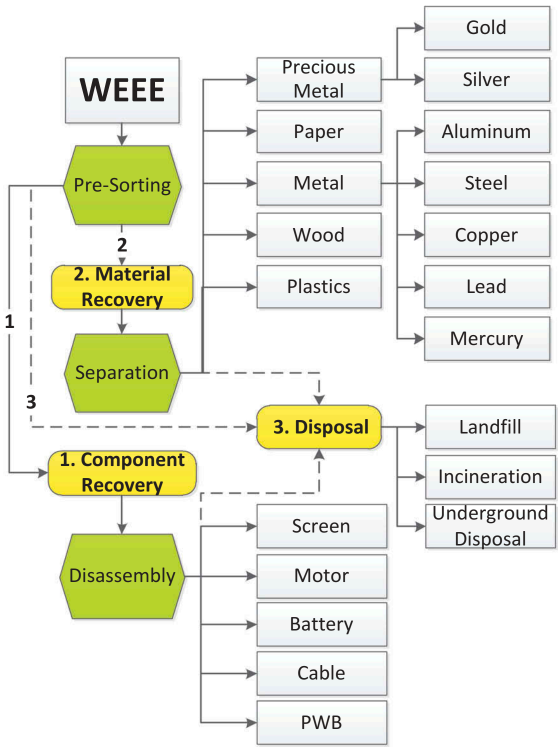

Figure 7. Generalised WEEE process flow.

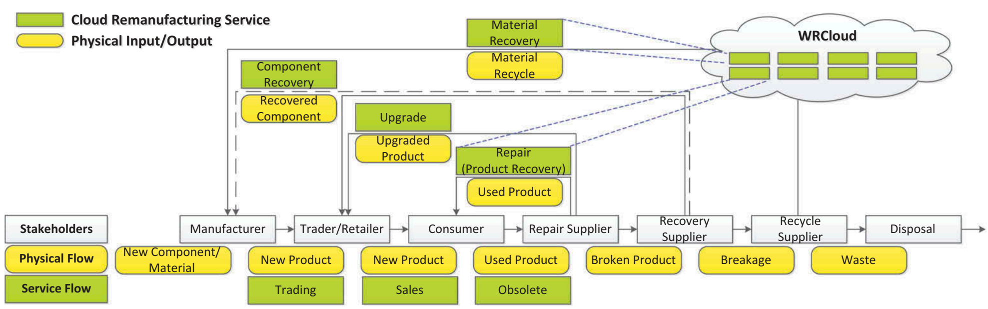

Figure 8. WRCloud closed-loop service chain.

recycling operations. With the help of manufacturing Cloud, it is possible to integrate these processes at the global level and provide a collaborative environment.

The WRCloud closed-loop service chain is illustrated in Figure 8. The users of the services include all participants throughout the product lifecycle, e.g. manufacturer, retailer, consumer and remanufacturer. The production-related processes are first registered as Cloud services in the WRCloud. These services are maintained in the service repository which is available for users to search and query. For example, when a customer needs to repair or upgrade a product, he or she is able to interact with the Cloud- and organise-related services accordingly. Based on the rich service pool on the Cloud, the queries from the user can be analysed and matched by multiple candidate solutions. These candidate solutions can be further optimised based on user's preferences, e.g. cost, time and quality factors. To the end, the user describes the required remanufacturing services, and the WRCloud responds with optimal service solutions that can be executed quickly and directly.

Most importantly, these repair or upgrade service records in the Cloud database can be utilised for future recovery process, which is one of the major advantages of Cloud-based approach, compared with conventional systems. Nowadays, the original hazardous substance and component details are maintained by equipment manufacturers, as required in directives, regulations and regional laws. However, after a new product is sold to a consumer, the product management is interrupted. It is difficult to track the product and record/update the changes, for instance, new components during upgrading and replacement. With the help of the integrated environment in WRCloud, all dynamic changes of product are documented as the output of manufacturing services. After the product is terminated, the component and material recovery processes can be organised based on the service history. The trust-worthy product specifications are particularly valuable for disassembly process planning and recovery scheduling in the future.

As a result of the recovery service, recycled components or materials can be utilised for a new product lifecycle, thus forming a Cloud-based closed-loop manufacturing/remanufacturing service chain. In WRCloud, the original manufacturer, retailer, repair supplier, recycle supplier and customer are all able to share the information and knowledge in the same environment and to generate optimal recovery solutions/strategies. To support the product and service management on the Cloud, a WEEE data model is developed based on the extended ISO standard series (Figure 9) (ISO 1994, 2004, 2002).

The core of the proposed data model is WEEE entity. It is directly connected to the EEE model which maintains its original product specifications as a new device. Besides general specifications, e.g. unique ID, model name, size and weight, the WEEE data model records the specifications of the components and materials. Note that one WEEE may have multiple component and material entities, which means that all the information of recoverable substances are documented in the data model. Such information can be utilised as individual components or sub-products for future recovery processes. Related process details are kept in the Cloud_Service model, which is also an

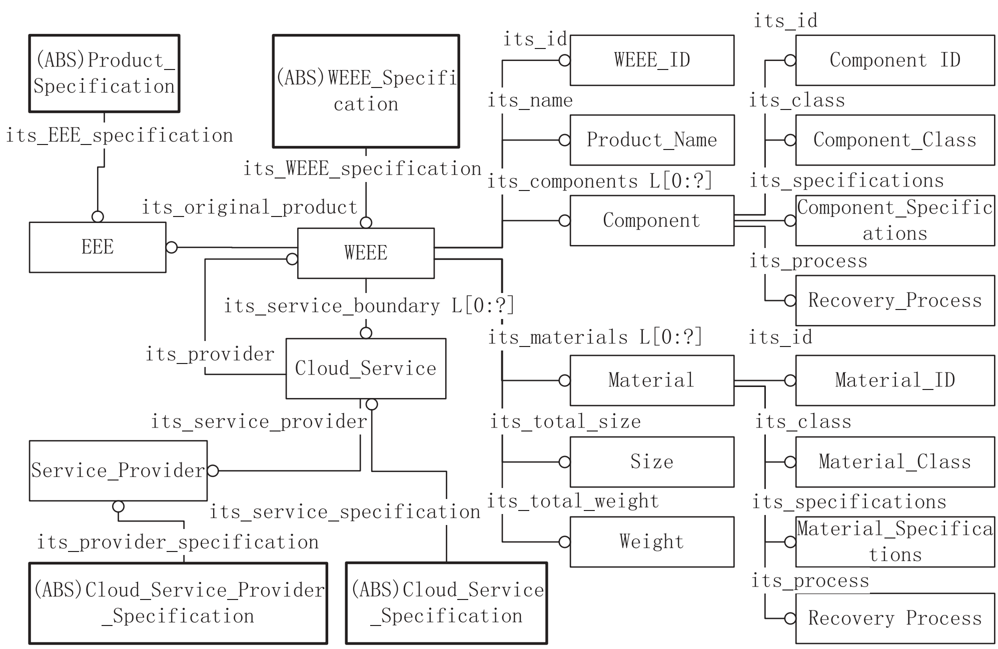

Figure 9. A standardised WEEE description data model.

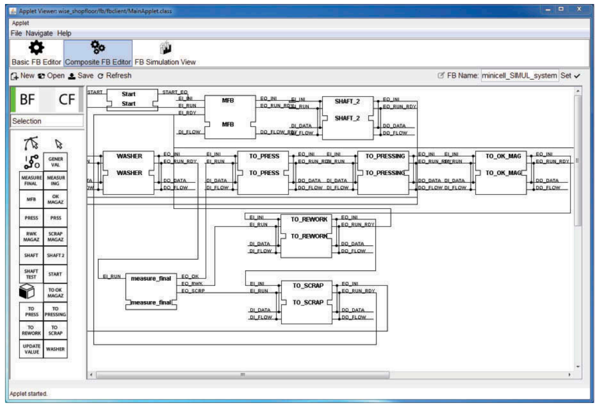

Figure 10. KTH Manufacturing Cloud environment and function block designer.

attribute of the WEEE model. It thus forms a complete data description mechanism to support the Cloud-based remanufacturing environment.

In practice, data acquisition requires contributions from all stakeholders throughout the product lifecycle, e.g. design data from manufacturers, location and status data from consumers and recovery knowledge from remanufacturers. Based on the Cloud environment and standardised data mechanism, WRCloud is able to integrate the knowledge of the product and support the recovery processes. It hence guarantees the information and knowledge exchange throughout the product lifecycle.

4. Implementations

To validate and evaluate proposed integration and information systems, the Cloud manufacturing environment is established and implemented accordingly. The Cloud environment is conducted by 24 computing cores and 64 GB memories, which is specifically suitable for a typical private Cloud structure inside an SME. Based on the OpenStack environment, the Cloud structure is able to host various operation platforms for the end user, e.g. MS Windows, Linux and UNIX family. In this layout, the stakeholders do not need to install or configure any local applications. The software/ hardware services and data management can be directly delivered at the Cloud level.

Based on previous research outputs (Wang, Jin, and Feng 2006), A Cloud-based FB designer module is deployed which refers to the service integration phase in Figure 5. It helps service developers define basic FB types that generate composite FB networks and then establish localised wrapper FBs networks. In this module, the developer means the Cloud developer or the FB expert who has the knowledge of both proprietary resource protocols and uniformed interfaces with the manufacturing Cloud. The definition of a basic FB type can be displayed in either graphical or textual forms. Once properly defined and deployed, an FB works as a fundamental control unit besides the manufacturing resource as well as during the service execution. For example, in a Cloud milling service, the user interacts with the coordination mechanism and decides the service plan. Then, the Cloud coordinator sends event and data trigger to local wrapper FB to launch the machine, input the NC code and then execute the milling processes.

Additionally, a Cloud-based FB management platform is also developed for Cloud administrators to manage and control FBs (Figure 11). It refers to the service execution phase in Figure 5. With the help of the management platform, the Cloud administrator is able to set up the network connection between Cloud and the FBs on the shopfloor. Server–socket protocols are utilised for data and event transmission. At the initialisation stage, the Cloud administrator is also able to communicate with the experts on site via the management system. As aforementioned, after properly defined

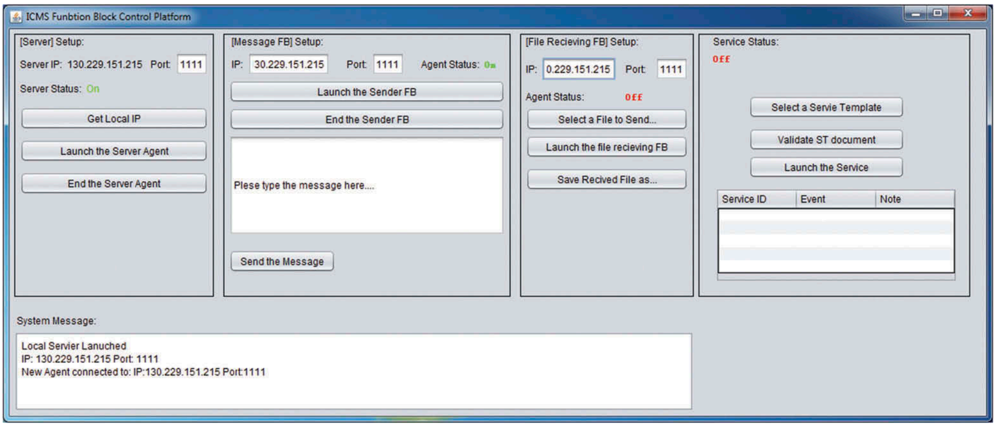

Figure 11. Function block management platform.

and configured on the shopfloor, the wrapper FB is able to work independently like a black box with minimum maintenance effort. Furthermore, service inputs and manufacturing documents can be transmitted by the management platform, including the Cloud service plans. In this way, the local FB is able to receive and interpret the service specifications and execute them accordingly.

To evaluate the system mentioned above, the WRCloud framework is also deployed in the Cloud environment. In the first case study, an LCD television is chosen as the sample product. After the product stops functioning, the user identifies the product model and unique ID with the help of the product-tracking mechanism (Wang et al. 2014) and then interacts with WRCloud over the network. Based on the unique product identifier, the original product specifications are quickly located and collected in the Cloud repository, including important component and material information inside the television (Figure 12). Additionally, previous upgrade and repair history is also documented in the Cloud in forms of Cloud service records. Eventually, the collecting and recovery services are assigned based on the dynamic and trustworthy WEEE information on the Cloud. With the help of Cloud-based tracking and management mechanisms, the LCD TV is integrated in the information system as IoMT.

In the second case study, it is assumed that the electronics industry and market statistics are integrated with WRCloud. Therefore, the physical flow of EEE and WEEE can be monitored with the help of WRCloud at high level. Additionally, relevant recycle and recovery services can be predicted at the regional and even country level. For instance, as a result of the big amount of WEEE import, related recovery services and resources shall be prepared due to the increasing amount of WEEE in the near future. As shown in Figure 13, the total number of TV sales in 2013 was maintained in the WRCloud (Statista 2014). Then, the LCD recycling resources and equipment can be organised by policy makers based on the average TV lifespan in those countries. Thus, the policy and strategy making are assisted by the rich data collection in WRCloud at the global level.

5. Conclusions

Compared with the computing business, the ICT solution for manufacturing industry is much more complex since it involves material flows and numerous unpredictable variables. For Cloud computing, data storage, software application and computing tasks are executed in the cyber world by servers, computing units and hard drivers collaboratively over the network. As mentioned in the first section, there are two types of Cloud manufacturing approaches in general, i.e. Cloud Computing in manufacturing environment and Manufacturing Cloud providing production services. The second type, which can be considered as a comprehensive manufacturing Cloud, is more

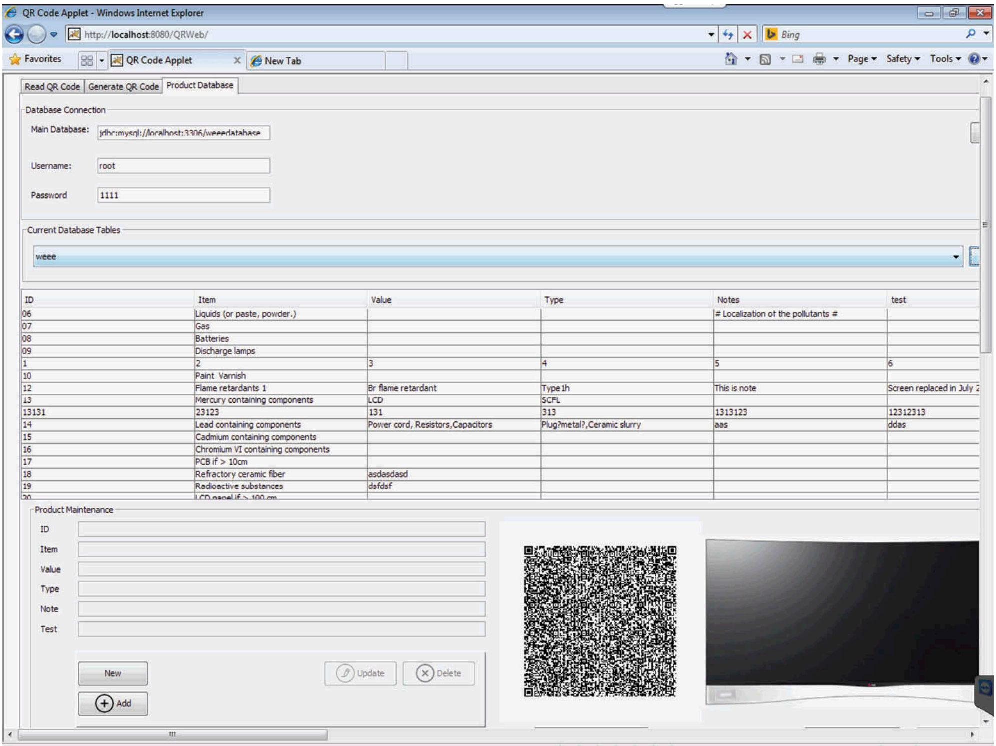

Figure 12. Cloud-based WEEE management interface.

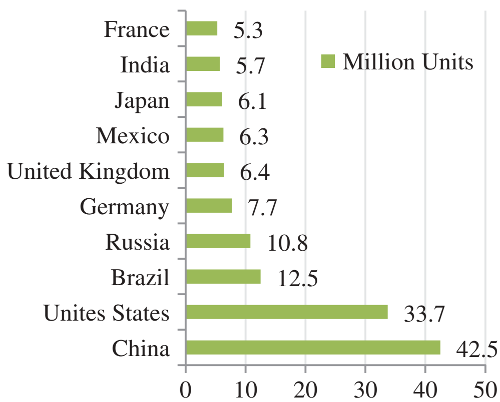

Figure 13. Worldwide TV sales to customer in 2013.

challenging since it aims to integrate the physical resources into the Cloud. In comparison with implementing manufacturing software applications in the cyber world (first type), a comprehensive manufacturing Cloud should be an advanced cyber-physical system that integrates both software and hardware applications.

In this research, a Cloud-based manufacturing system is developed aiming to create an inter-operable and uniformed environment that integrates physical manufacturing resources, e.g. CNC machine tools, robots, monitors etc. The FB technologies are utilised as the integration methodologies to connect the hardware to the manufacturing Cloud in a standardised and efficient way. In this paper, an FB-based integration framework and related mechanisms are proposed to support a distributed, flexible and adaptive production system. Meanwhile, an FB designer module and a management platform are also implemented to evaluate the proposed system. Based on the generic communication methods, users are able to develop native or machine-specific FBs to interact with the current resources on the shopfloor. The Cloud-based environment hence provides collaborative and integrated mechanisms for the II.

From the integration's perspective, the servicelisation process is a bottom-up approach that promotes localised machining resources to a higher level, in terms of process, capability and Cloud service. In contrast, the utilisation of Cloud service follows a top-down route, which enables users to identify the needed Cloud service at high level, search for suitable capabilities, allocate and localise the detailed machining process, and then execute the service on specific machines or tools. The FB-based Cloud environment thus forms a complete local–Cloud-local loop to connect shop-floor resources at low level to the manufacturing Cloud at high level.

The first three industrial revolutions came out as a result of mechanisation, electricity and IT, respectively. Currently, the ICT sector provides a new generation of technologies, e.g. Internet of Things, Big Data Management, Cloud etc. The manufacturing industry calls for new opportunities into current systems to improve the performance and enhance the competitiveness in the future global market. Cloud manufacturing can be an enabling technology that offers collaborative, scalable, flexible and adaptable manufacturing environment with lower cost and higher efficiency. In the future research, it is important to evaluate the integration mechanism on different equipment and explore a detailed business model for the Cloud manufacturing services at high level.

Especially in the background of resources decrease, pollutions increase and mounting environmental pressures, it is remarkably important to properly recycle the electronic devices and better utilise the resources located inside them. In traditional approaches, it is very difficult to track the locations and changes of EEE after they are sold to the consumers. Thus, customised or case-based component recovery is nearly impossible. Recovery efforts are, and can only be, focused on treating WEEE as general discarded waste and recycling the reusable materials. In this research, the manufacturing Cloud is extended to remanufacturing processes in form of services, and a collaborative data environment is developed to maintain the trustworthy information of product details dynamically. As a neutral WEEE management platform, WRCloud breaks the boundaries between different EEE stakeholders and provides a shared service and information pool to support the component recovery from individual level to international level. In addition, the closed-loop WRCloud service chain is also proposed, along with the uniformed WEEE data models compliant with current ISO standards. The proposed system and mechanisms are validated via case studies across multiple levels. With the help of Cloud environment, normal WEEE can be integrated in the information system in terms of IoMT.

In the future, the WEEE remanufacturing Cloud can be further developed based on close collaborations with the recycling industry and benefited from more supporting mechanisms, e.g. location module, service orchestration module, logistic planning module and so forth. It is also important to encourage the involvement of original equipment manufacturers. As part of extended producer responsibility, manufacturers need to share the environmental information of products near end-of-life at certain levels without exposing any sensitive data. In practice, the Cloud-based system also fosters the willingness of the original manufacturers' participation since it offers a feasible environment to achieve the environmental goals.

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