Internet of Things (IoT) for Dynamic Change Management in Mass Customization

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ABSTRACT

Mass customization manufacturers always find it challenging to produce high quality products at the lowest possible cost with minimal lead-time. The challenge is even more severe for these manufacturers when it comes to their survival in today's dynamically changing market where customers drive the process by searching for the information they need in order to create their own products and services [1]. As customer-centric mass customization manufacturers, organizations should increase their change-adaptability to maintain their competitive edge in the ever-growing and ever-changing market. A successful mass customization strategy should involve developing production lines that are highly agile to reconfiguration, leading towards reduced setup time in order to cope with the expected or unexpected changes to the production process. Besides this, the importance of 'zero mistakes' in all activities along the value-creation process should also be prioritized. Therefore, the research aims to investigate the feasibility of IoT application towards effective change implementation for mass customization in a dynamic manufacturing environment. This paper presents an architecture for dynamic change management that could provide a new competitive strategy for mass customization manufacturers. A set of IoT devices is used as illustrative examples for the dynamic change management implementation in mass customization manufacturing. The architecture of such dynamic change management is to turn operation data in dynamic form and link all together, permitting them to integrate rapidly in the most optimized combination or sequence required to perform change instantly. This architecture allows for well-informed real-time decision-making and more importantly, provides the manufacturers with the ability to predict problems before they occur.

KEYWORDS

Mass Customization, Internet of Things, Change Management

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1 INTRODUCTION

Mass customization refers to the process to deliver wide-market goods and services, which are tailored to satisfy the specific needs of the customers. The implementation of this concept, initially introduced by Davis [2], has been supported fundamentally through theoretical and empirical studies [3–9] . Although many companies have operated based on this business model, only few managed to achieve success [4]. This is because mass customization manufacturers face difficulties to effectively execute change process to optimize their market and to meet the diverse product demands by their customers. The change process for mass customization should be very sophisticated to be implemented mainly due to the complexity of equipment and labor used along with production lines [10], limiting the potential for mass customization. There is much literature published related to mass customization. However, the literature related to change management for mass customization is scarce. On top of this, Construction Industry Institute (CII) research team also found out that there are no formal processes to assure that change in a mass customization setup can be properly implemented [11]. Thus, the potential of mass customization implementation cannot be fulfilled.

In this modern dynamic changing market, customer orders can often vary in any moment of time even after the components/parts have already been delivered to the production line. Therefore, mass customization manufacturers must always be able to bring essential change ability of manufacturing processes to a higher level to assure effective mass customization environment. They should be able to provide quick response and to swiftly adapt to product/process change to create a competitive edge over their competitors. Not capable of doing so would result in them drowning in the ever-growing changes of their market.

Change requirements from customers are forcing mass customization manufacturers to redesign and to modify product frequently. Typically, such change data is expected to be sufficient in supporting certain personnel in handling various mass customized products/process. However, traditional change process procedures commonly used in production lines interfere with the factory's dynamic environment, as the information associated with the mass customization process is enormous and complex. Therefore, an effective operating system in factory floor is required to ease the implementation of the efficient change process in a mass customization environment. An adequate management system should be prepared for the relationships and the interactions among tasks, functions, departments, and organizations, which promotes the flow of information, ideas and integration of dynamic change process.

1.1 Conventional Change Process in a Mass Customization Environment

The overview of the conventional change process in mass customization organization is showed in Figure 1. This shows that conventional change process practice is associated with certain difficulties and constraints. The formal use of conventional change process is a centralized structure with extra layers in the hierarchy. When a change is triggered by customer, the actual change process in production floor will only be started when the approval documents have been released. The impact of change will be severe if it occurs when the production has already started. In order to get the documents released from the engineering team, local operating team could have missed the golden hours to prepare for the required change, possibly causing late delivery of the product. Another issue that arises in the change process is the lack of operational data that is connected to enterprise applications. Neither the R&D team nor the operation team has the actual manufacturing data when the change is taking place.

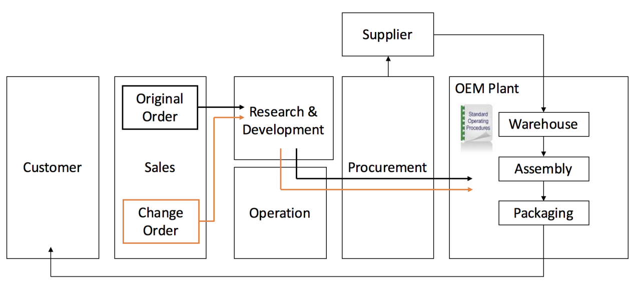

Figure 1: Centralized change process structure for customized product

Besides this, human operators, who are disconnected from relevant and essential production related electronic data (product data management), will be confused by the delivery of new components before any paper-based operating manuals are provided to them. The human operators are constraint from interacting with available documents that is pre-formatted. Besides, the process to get the documents released is often associated with long lead times, which is caused by extensive document management. This is time consuming to check-out the old documents and to prepare new documents to send for approval. Centralized structure for change process can be efficient if the manufacturing environment is very stable and the parts changes very little. The bureaucracies of this kind of change process are static and unresponsive to changes in the environment that have limited the flexibility and speed of local decision-making.

On top of that, human operators, in a mass customization system, tend not to question the basic design of the product that they are assigned to assemble. They would assume that it is what the customers want. This will lead to a high tendency of errors in assembly of the changed components, which might result in costly reworks and delays. As a consequences, OEM manufacturers could face difficulties in order to identify possible disturbances or changes in the need for the changed component and to readjust production plans and facility allocations to avoid significant impact on the productivity time line.

1.2 Enabler for Efficient Change Process in Mass Customization

Changes will not only affect production planning but will also influence cost and scheduling, directly or indirectly. When the impact of change can be predicted, then only time, cost and resource can be allocated to affect the change. Well-managed change is important to avoid unwanted problems. Therefore, mass customization manufacturers must have the ability to respond to change effectively to minimize any form of negative impact on the production. Implementing effective change process is a challenge in mass customization manufacturing mainly due to the complexity of equipment and labor used along the production line [10].

With the unveiling of the fourth industrial revolution or Industry 4.0 in recent years, Internet of Things (IoT), as one of the key elements for industry 4.0, has become a hot topic among industrialist. IoT refers to physical devices that are inter-networked with electronics, software, sensors, actuators and network connectivity. The internetwork created enables these physical devices to receive and exchange essential information in real-time. Internet technologies could be the key enabler for efficient dynamic change management in mass customization manufacturing. Internet technologies could prove to be essential in setting up a dynamic network that is more than capable of handling high-intensity information for efficient manufacturing planning and control system in real-time for mass customization manufacturers. This will provide visibility and control of the factory floor by connecting human operators, sensors and operations data across multiple machines and lines, allowing for the ability to monitor performance and to identify inefficiencies along the production line. The potential of IoT application in Industry 4.0 has lightened up once again the feasibility of mass customization. Therefore, this research aims to investigate the feasibility of IoT application towards effective change implementation for mass customization in a dynamic manufacturing environment.

This paper introduces the primary/fundamental concepts and technologies of IoT that could benefit dynamic change management in mass customization manufacturing. This paper also proposes an architecture of dynamic change management, showing all operating modules that are connected for well-informed real-time decision-making to provide the ability to predict problems before they occur in factory floor. The development of IoT for industrial application can be extended to a higher skill base for information technology and computer-integrated manufacturing in order to implement dynamic change process in mass customization factory floor. This will help to achieve sustainable competitive advantage for mass customization manufacturers in the ever-growing changes market.

2 PARADIGMS FOR DYNAMIC CHANGE MANAGEMENT

A dynamic change management approach is adopted alongside with the integration of internet technologies in order to implement an effective mass customization environment. A dynamic change management architecture composes of three components, namely:

i Dynamic linkage in operating field
ii Real-time environment
iii Monitoring and early error detection

2.1 Dynamic linkage in operating field

One of the issues limiting the success of mass customization in change processes is the lack of an integrated network to avoid manufacturing data loss along the production line. There is some useful computer-aided engineering software for engineering change management. However, the electronic data is often disconnected from the human operators, who are working on the front line of production. On the other hand, automated systems cannot effectively and efficiently distribute planning and control tasks to human operators on the factory floor, who have the first-hand experience of the production process and could influence the process by their actions [6]. Hence, a participation of human operator in dynamic change management cannot be neglected. To complete the change activities, the human operator needs information or collection of data and requirements. However, communication methods between equipment and human operators are still cumbersome. This is because human operators' hands will most probably be occupied with product assembling task.

Internet of Things (IoT) presents an interesting approach to effectively integrate numerous connected devices that rely on sensory, communication, networking, and information processing technologies with interface processors to form a global dynamic network infrastructure [20]. Myo armband has been used here to study human-computer interaction in the factory floor. Myo armband is a wearable technology that reads electrical activity of user's muscles to control a robot with gestures and motion under hands-free environment. The interaction of controlling Parrot Bebop 2 by the gestures from Myo armband is presented in Figure 2. Gestural interaction devices like Myo armband could be beneficial for the factory floor as it can be used without an external static sensor. Thus, the human operator will have the freedom to still move around while performing their routine work properly. This kind of gestural interaction device provides an advantage where the human operator is not required to carry any mechanical devices to remote control equipment from a certain distance. Gestures are instinctive, human beings are skilled, and little thought is needed [21], and will allow for the human operator to focus on the production task itself.

Such gestural interaction device will enable human operators to remotely control computers and machines in the factory plant for information support during occurrences of an unexpected change task. Application of gestural interactions via Myo armband will significantly improve the efficiency of dynamic change management implementation. With the assistance of such advanced wearable technologies, human operators can now fulfill their potential by taking on the role as strategic decision-makers and flexible problem-solvers on the factory floor [22].

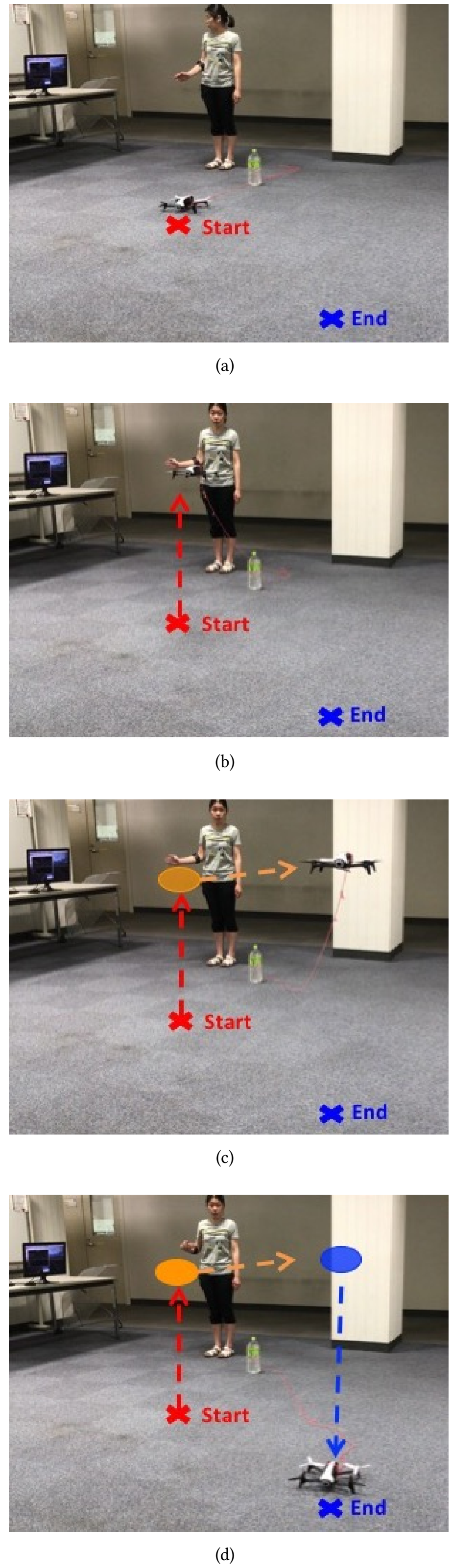

Figure 2: Remote control of drone using gestural commands based on Myo armband

Another challenge as discussed above with relation to dynamic change management for mass customization manufacturers involves handling of higher-intensity information of the production processes. The higher-intensity information refers to the raw data input, originating from a multitude of data sources that need to be monitored and controlled in the manufacturing system. With growing number of smart devices used in the factory floor, it is essential to establish high efficiency ways to tie into already existing manufacturing information technologies through the use of standardized, platform-independent interfaces such as OPC-UA [22]. In addition, most of the smart devices, such as drones, Myo and Leap Motion, do not have sufficient computational power to process the sensor signal carrying the raw input data. Thus, an interface processing device, such as laptop, tablet or raspberry PI, will have to be employed in the production floor to process the raw input from the aforementioned smart devices. The processed raw input data will then only be possible to be integrated into the manufacturing system.

2.2 Real-time environment

In a modern dynamic changing market, customer orders can often vary in any moment of time even after the components parts have already been delivered to the production line. Therefore, mass customization manufacturers have to be highly agile in responding to the requested changes in order to avoid any potential slowdowns or bottlenecks across the production line. Implementation of a dynamic network linking equipments and human operators provides the means to take appropriate actions during a dynamic change process. Forewarned is forearmed, and the critical factor that determines the effectiveness of project change control is how fast the right people is aware of the change and takes necessary actions accordingly.

Changes in manufacturing conditions could be executed quickly by relying on latest production related information. Thus, the adoption of real-time capability will provide manufacturers with real-time information to make key manufacturing decisions. To execute a successful change strategy, production line needs to be proactive in reconfiguring and reducing setup time needed to cope with changes in production. Greater planning capability is one of the important criterion for mass customization manufacturers to foster dynamic changes. Real-time information platforms provide greater planning capability by allowing manufacturers to view up-to-the-minute production progress in factory-floor.

Planners and managers can use the production progress data to create better production plans whenever unpredicted changes are triggered. They can also identify disturbances or changes in the need for parts and readjust production plans or facility allocations before these changes significantly impact productivity. Real-time operation data executed in the factory can then be immediately recorded in electronic documents for reporting, eliminating/reducing errors associated with human factors. This will save the time to digitize the data collected in paper forms [12].

Another challenge with relation to dynamic change management for mass customization manufacturers involves handling of high-intensity information of the production processes. The high-intensity information refers to the raw data input, originating from a multitude of data sources that need to be monitored and controlled in the manufacturing system. Connecting human operators, machines and smart devices in the factory will generate big data. The big data needs smart infrastructure to capture, to manage and to process them within an acceptable time frame [20]. The emerging and developing technology of cloud computing is considered as a promising computing paradigm for this big data.

Mass customization can utilize numerous cloud platforms for big data management such as ThingWorx, Google Cloud, and Bosch IoT suite. Capitalizing on IoT for dynamic change management requires network infrastructure as IoT will generate an unprecedented volume and variety of data in the factory floor. Internet-based computing is required to provides shared computer processing resources and data to multiple computers and other devices on demand. Cloud computing is not enough for real-time data processing due to its inherent problems, such as unreliable latency, lack of mobility support and location-awareness [?]. Fog computing is a new kind of network infrastructure that provides resources for services at the edge of the network. The fog computing extends the cloud computing to be closer to IoT devices through provisioning, trimming and pre-processing the data before sending to the cloud. With the right tools, mass customization manufacturers will be capable of managing the manufacturing data for greater agility in the change process.

2.3 Monitoring and early error detection

Mass customization capability of a firm is determined by its ability to produce customized products with cost effectiveness, volume effectiveness, and responsiveness [8]. Errors in producing custom-made products will be extremely costly as compared to errors in producing mass products. This is because the custom-made product is unlikely to be sold to others aside from the customer who requested for it. Apart from cost, mistakes and errors during production could cause late delivery of product to customers. Not to mention, these could cause the customers to lose confidence towards the mass customization manufacturers. Thus, a closed monitoring and early error detection method is critical to ensure the customized product is correctly built and delivered on time. Deployment of a system that stresses the importance of ‘zero-mistakes’ in production is indispensable for a dynamic change in mass customization manufacturing [15]. Therefore, the last component for effective dynamic change management requires monitoring and early error detection along the production line of a mass customization manufacturer.

In recent years, researchers used RFID technology to identify, trace and monitor objects locally or globally [12, 24]. However, there is a drawback to RFID systems where they require human operators to tag and to read the tag manually. These will pose certain difficulties to implement this technology in large scale involving complex products, such as vehicle or heavy-duty equipment production [24]. On top of this, the cost of RFID tags is another challenge for manufacturers who produce large-scale products that make up thousands of parts. The work in progress visibility and traceability could be further improved through integration of more advanced IoT technologies to form an autonomous surveillance system for early warning.

Using modern smart surveillance systems that can be integrated into computer vision and artificial intelligence community, these will allow for real-time monitoring and detection, which is essential for dynamic change management in mass customization manufacturing. With computer vision technology, video captured through the factory's surveillance system can be transformed into digitized data for object detection and recognition [25]. The method will allow for object detection and will capture manufacturing data for seamless real-time synchronization with material and associated information flow on the factory floor. Using object recognition technology, it will improve work in progress visibility and traceability by enabling real-time adaptive decision mode to optimize operational logistics [12]. The data generated from this visual computing system can be integrated into existing manufacturing system based on the provided data interface platform.

For automated cameras to be effective in error detection during manufacturing processes, the viewing range of the camera has to be able to cover the whole factory floor. Implementing closed-circuit television (CCTV), which has limited camera viewing, could be costly. This is because during product assembly, the camera views could be impeded by different product orientations. Therefore, mass customization manufacturer could adopt unmanned aerial vehicle (UAV) equipped with a camera be used to provide substantial flexibility as compared to CCTV. The video stream from UAV is connected to the computer in real-time. UAV does not require a mounting platform and can fly to any location, thereby able to take photographs or real-time videos from a range of areas inside the factory. The UAV can also fly autonomously without colliding with obstacles and has faster speed as compared to ground robots [26]. This is helped by the technology advancements where latest UAV is also equipped with indoor navigation systems for autonomous navigation in an indoor environment. The UAV can also be programmed to perform scheduled flight for inspection of product assembly progress from time to time. Such autonomous surveillance system will be capable of providing real-time monitoring and error detection. This will reduce the risk of the wrong custom-made product being manufactured.

3 ARCHITECTURE FOR DYNAMIC CHANGE MANAGEMENT

From the three most important topics discussed above, it is summarized that a dynamic change management architecture composes of three essential components, namely:

i Dynamic network linking in operating system
ii Real-time environment
iii Monitoring and early error detection

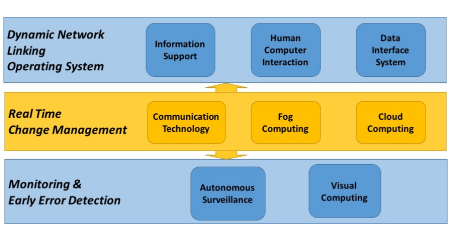

Figure 3: Dynamic change management architecture

Each component is associated with a set of unified requirements. For dynamic linkage in operating field, the dynamic operating data plays an important role as information support for the change process. The efficiency of information support to human operator is improved by the use of human-computer interaction devices that enable human operator to remote control electronic devices or robots under hand free environment. This has to be supported by data interface process devices to complete the data integration activities. Communication technology, fog computing and cloud computing are fundamental elements to provide real-time platform in dynamic change management. Efficient change implementation need monitoring, thus autonomous surveillance and visual computing are must have elements for this paradigm.

The approach for IoT deployment in dynamic change management for a mass customization manufacturer is illustrated in figure 4. The combined platform to gather and consolidate changes of data across lines and locations are summarized in the given diagram.

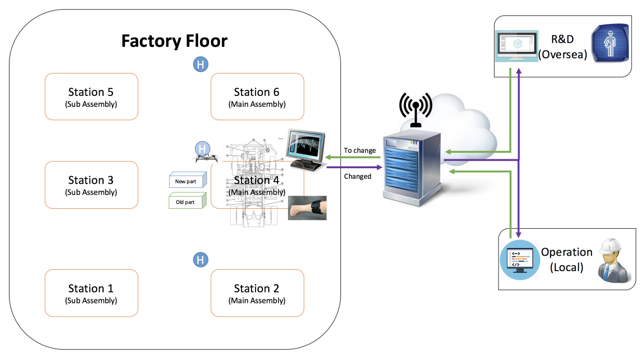

Figure 4: IoT deployment in dynamic change management for mass customization manufacturer

4 CHALLENGES OF IOT INTEGRATION

Integration of IoT technology in dynamic change management for mass customization manufacturers are promising for higher achievement. Despite the positive prospect, there are unsolved issues that could arise from both technological and usage point of view, such as 1) reliability and availability, 2) interoperability and 3) security of IoT devices/applications.

4.1 Reliability and Availability

The availability of IoT must be accomplished at hardware and software levels in order to effectively implement the dynamic project change management as discussed in this paper. Availability of hardware refers to the existence of devices that are compatible with the functionalities and safety in the factory floor. Software availability refers to ability of the IoT applications that are compatible with existence manufacturing systems. Failure of IoT devices in field might put the human operator in danger and possibly affect the system operation. This could lead to further financial loss to the organization.

Aside from the issue of availability, the reliability of the IoT systems should also be seriously considered. In order to have an efficient dynamic change management in the factory floor, reliability check must be implemented in software and hardware throughout all the IoT layers. Unreliable data gathering, processing and transferring could lead to disasters in the operating network, internally and externally. Reliability of the system should take into consideration more critical requirements related to the emergency response applications [20]. As an example, let's take the reliability and availability of the Myo armband. In the application of Myo armband to remote control a drone, unreliable Myo armband detection of hand gestures has been experienced, which will affect the outcome of the drone control, and lead to the crash of the drone. Such unreliability of the system should be ironed out before full implementation of the dynamic change management.

4.2 Interoperability

Most of the IoT devices cannot directly connect with each other because it requires a data interface process to manage the devices and get data out of one 'language' and into another. For example, the drone itself cannot directly read the EMG raw data from Myo armband. Thus, a data interface processor, like raspberry PI, is employed to process the EMG raw data input from the Myo armband into programmable logic (PLC) data that can be sent to the drone to execute relevant movement commands. This would require a lot of custom code to account for all the different protocols and brands of IoT devices used. The tedious setup to get all IoT devices to effectively talk to each other and connect to the network of existing manufacturing system has been holding back many companies in getting IoT up and running in their factory. End-to-end interoperability of IoT devices/applications is still an open issue. Therefore, the need to handle a large number of heterogeneous raw data that belongs to different platforms remains a challenge in designing and building effective IoT services in mass customization manufacturing plants.

4.3 Security

Many IoT technologies are limited to public use and are not suitable for industrial applications, which have strict requirements in terms of safety and security. IoT is vulnerable to cyber attacks as most of the communications are wireless. Besides wireless communication, many IoT devices has low capabilities in computing resources especially passive components. Thus, they cannot support complex security schemes. For example, the security of UAV is questioned when a security researcher announced to public that he can hijack control other flying UAVs through a modified Parrot AR Drone 2 with his custom software called SkyJack. This shows that security is still a significant open issue for IoT adoption in mass customization manufacturing plants. Therefore, there is a need to have standard and architecture for the IoT security in order to have a widespread adoption of IoT technologies in industrial.

5 CONCLUSIONS

This paper investigates the feasibility of the feasibility of IoT application towards effective change implementation for mass customization in a dynamic manufacturing environment. A set of IoT devices is used to demonstrate IoT application for dynamic change management implementation in mass customization manufacturing. A framework is proposed to improve efficiencies of change management in mass customization manufacturing processes through implementation of internet technologies. The challenges in having successful dynamic change management in mass customization manufacturing processes involve the need to create a dynamic network linking manufacturing equipment with human operators and also to have sufficient computational power to process sophisticated manufacturing data during the production phase. The dynamic change management discussed in this paper requires effective real-time monitoring and early detection of manufacturing errors.

IoT technologies are essential in the effective implementation of mass customization. The new concept of dynamic change management described in this paper, together with fast growing trends of the smart factory concept, will have major positive implications to improve the competitive edge of mass customization manufacturers. The importance of smart and dynamic change management to fully reveal the competitive strategy for mass customization manufacturing aligns well with the demands of the marketplace of tomorrow has been presented in this paper.

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