Smart Maintenance: A Wearable Augmented Reality Application Integrated with CMMS to Minimize Unscheduled Downtime

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Abstract. The ultimate goal of maintenance managers in any industrial firms is to maximize the uptime of the production assets and to keep the downtime to a minimum. These factors affect the capability of an industry to meet the production deadline while still ensuring the good quality product at minimum production cost. To realize this objective, effective maintenance method and innovative tool are required. Previous study has shown that the growing complexity of current manufacturing technologies will necessitate the increasing competent and trained personnel to resolve quickly the interruptions that occur in the shop floor. However, an efficient repair operation is sometimes difficult to achieve especially when the dysfunctional machine involves various possible problems and the assignment of skilled technician and resources to attend to the failed equipment requires more than just the information reported by the operator concerning what was not functioning on site. Augmented Reality (AR) as one of the emerging technologies in the framework of Industry 4.0 provides a way to accelerate the maintenance process and to minimize the recommissioning of maintenance work due to limited maintenance information provided by the operator. This paper presents the application of AR integrated with CMMS on the emerging computing platform Hololens to demonstrate the potential of this integration to optimize the pipeline of maintenance procedure in order to boost the profitability and competitive advantage of an industrial firm.

Keywords: Augmented Reality, CMMS, Hololens, Maintenance, Downtime
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1 INTRODUCTION

The ultimate goal of maintenance strategy in any industrial firms is to maximize the uptime of the production assets and to keep the downtime to a minimum. As the manufacturing technology keeps evolving to meet the diverse needs of the market such as the demand of higher quality product, lower cost, and shorter delivery time, the manufacturing firms are often required to leave the utilization of old manufacturing processes and adopt the new technologies. The deployment of these new technologies often come with growing technical complexity which requires increased technical expertise on how to maintain and repair it in the case of system failure [10]. Although the use of Computerized Maintenance Management Software (CMMS) has continually benefited industries to manage their maintenance program [8], the underlying procedure in rectifying the unexpected breakdown still has some drawbacks. This is mainly due to the fact that current practice of corrective maintenance is highly dependent on the expertise of the technicians who devise and carry out the maintenance plan based on the limited information provided by the operator on the site.

The innovative human-machine interface (HMI) utilizing AR for industrial application is becoming more active research area since AR has been considered as one of the pillars of Industry 4.0 that is believed to shape the future of industrial production system [3]. AR enables digital information to be superimposed onto the real environment paving the way of presenting contextual information to assist the recognition of critical information, performing correct procedure, as well as decision-making. With these features, AR finds its way in many applications as a productivity-enhancing technology especially in the complex task's domain that requires human intervention such as maintenance. For example, in the different maintenance applications, previous studies showed that the adoption of AR improved the technician performance over the traditional approach in task completion time and procedural mistake [5],[7]. Both studies found that the provision of relevant information with the support of AR enables user to locate the task quickly, select the proper tool, and perform the task accordingly. This is particularly important in the environment where maintenance tasks are often performed under-time pressure while the task errors are not tolerable such as in aviation maintenance. In this case, AR can help to reduce the stress and the associated human errors by guiding the technician through the maintenance sequences with a warning message to remind the operator the correct procedure [4].

The role of AR is also critical in the application where the corrective maintenance operation of the asset requires a wide range of engineering disciplines while the qualified personnel are not always present on-site such as in railway vehicle sector. Previous study demonstrated that this maintenance problem could be potentially addressed by the deployment of AR in the remote maintenance application [1]. The developed application allows remote expert from technical office to communicate visually and/or verbally to the on-site worker wearing AR glasses. Through the support of AR, the graphical instruction and video-maintenance related information can be added in the on-site worker visualization remotely through the remote expert's computer. In this way, AR can help untrained on-site operator to perform maintenance operation efficiently, minimizing the cost and time taken to complete maintenance operation. In other words, the digitalization of the maintenance information for AR system which is stored in the system permits the knowledge transfer of maintenance procedure easier and faster to the novice staff without expensive and time-consuming training [9]. This also suggests that the application of AR in maintenance is promising to foster the industrial growth. By applying AR-assisted maintenance, an industry can optimize the number of workforces for maintenance work since different maintenance procedures can be implemented in AR system allowing a wide range of tasks to be carried out by one operator [14].

Although AR has been shown in many aspects as a productivity-enhancing technology, AR system has not been fully developed, especially to minimize the unscheduled downtime due to unexpected breakdown, which can greatly affect the business performance and competitive advantage of an industrial firm. For instance, today's manufacturing enterprises are trying to upgrade their processing plant to advanced manufacturing processes as to provide quick response to the customer demand. In this case, the increased throughput may lead to high-pressure production schedule, and long downtime due to malfunction can influence the capability of an industry to meet the production deadline. Some commercial wearable AR systems [2],[6] have been designed to provide remote assistance of the expert knowledge to the shop floor directly in the technician viewpoint, which can reduce travel time and maintenance cost for the involvement of a skilled technician. Nevertheless, this type of assistance is highly dependent on the availability of the expert technician rather than a complementary support. Besides, for the machine whose maintenance operation is done rarely, the reliance on human capacity to troubleshoot the unexpected failure is often not efficient. In a more general perspective, the system maintenance experience stored in the CMMS and made available through the AR could also assist an untrained operator to diagnose and even fix unexpected simple failures without waiting for the remote help of an expert, as it is usually required in many commercially available applications. The record of information related to machine's life cycle and the digitalization of maintenance information in order to present relevant, systematic information in informing the right action for failure treatment can therefore generate productive value. The objectives of this work were twofold: (1) to show the integration of asset information system such as CMMS with AR wearable system and (2) to demonstrate how integrating asset information from CMMS with AR technology could reduce system downtime. The next section of this paper presents the challenges of maintenance task due to the increasing complexity of machine production and the potential of AR-CMMS integration in ensuring maintenance productivity. Following this, the system architecture and detail implementation of AR-CMMS system are presented. Finally, the potential benefits from implementing this system are summarized in conclusion.

2 THE IMPACT OF MACHINE COMPLEXITY AND AR-CMMS SYSTEM ON MAINTENANCE PRODUCTIVITY

Today's manufacturers are faced with the challenges to adapt to the rapid shifts in market demand. As product's life cycle shortens, businesses must strategically adapt their manufacturing operation to maximize flexibility, reduce production cost and the delivery time. The legacy manufacturing processes are no longer capable to cope with the current trend of customers expectations such as product customization and shorter time to market. The evolution in additive manufacturing, automated machines, and industrial robots are changing the manufacturing processes in industries as they increase overall efficiency. Nevertheless, despite providing greater functionalities, these production assets rely on the sophisticated technologies which are not easy to troubleshoot when the malfunction occurs.

In the general industrial practice, the critical machines production is usually equipped with the sensors and warning system to alert the operator when the normal operating condition is not satisfied. Figure 1. shows the general practice of corrective maintenance using CMMS.

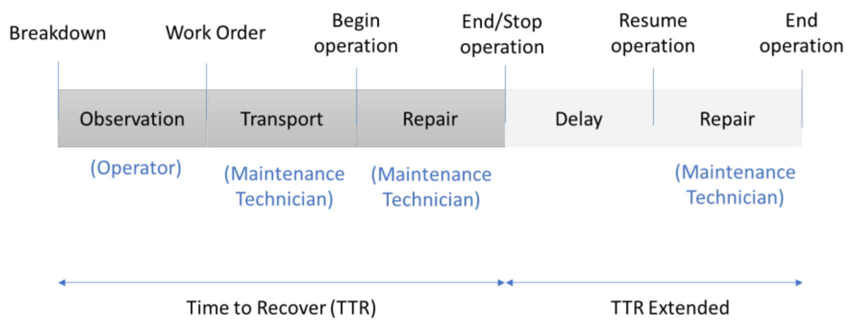

Figure 1: General procedure to rectify unexpected breakdown using CMMS.

When the unexpected breakdown is detected, the operator needs to check and to report the high-level problem of what he observes (e.g. the effect of failure) through Work Order (WO) in CMMS. In this phase, the maintenance jobs that need to be attended by maintenance technicians will be appeared in the CMMS. The technicians will review the work request provided by the operator and examine the information to have some ideas of what could be the problem before arriving to the plant area where the machine breakdown occurred. When the technician arrives, he carries out the maintenance procedure and once the repair on the breakdown machine is completed, the work order is finalized and closed, which also indicates that maintenance work has been successful in putting back the machine to the normal operating condition. In the other case, if the maintenance cannot be concluded because of the missing resources (e.g. spare part) or lack of expertise, the maintenance operation will be postponed until it is feasible to be resumed. The time to recover (TTR) is the time that is required in maintenance operation to bring the equipment back into the normal operating condition. However, this maintenance procedure could lead to a prolonged unscheduled downtime which could prevent and reduce the productivity gain of an organization's processes. This situation occurs, especially when there are no qualified personnel standing by to troubleshoot the specific problem, and sometimes it may take a while for the expert to reach the area where maintenance need to be performed. Moreover, in the setting of a complex production process, the dysfunctional equipment could involve multiple possibilities of the problem that may not be easily predicted for devising effective maintenance plan. Thus, the current procedure not only has a setback, but also potentially entails a recommissioning of the expert technicians and resources since the maintenance plan was created based on the information related to what is not functioning reported by the operator and not the identification of the cause of failure.

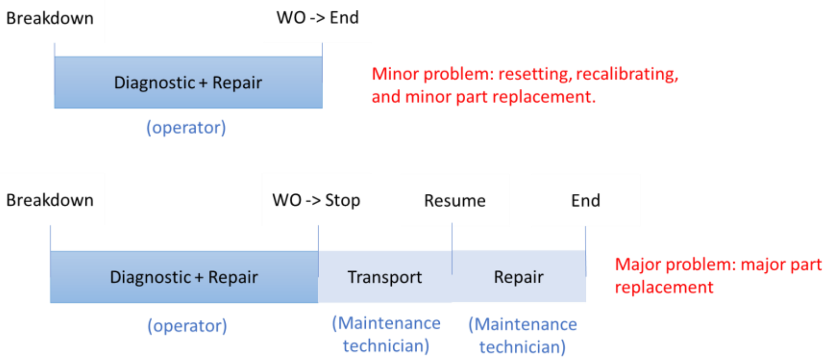

Figure 2: The procedure to rectify unexpected breakdown using AR-CMMS system.

On the contrary, the integration of CMMS with AR technology has the potential to reduce the downtime due to unexpected breakdown. Figure 2 shows that AR-CMMS system in some cases can help the untrained operator to perform diagnostic and corrective maintenance when the problem is minor, and thereby eliminating the unnecessary waiting time for the skilled worker to attend to the problematic equipment. In the case of the major problem, the system can guide the operator to perform diagnostic on the possible problem as to narrow down the cause of failure, which eventually lead to a more accurate planning of maintenance action (e.g., maintenance priority, assignment of maintenance crew, required tools, and spare part ordering), and thus avoiding the non-productive maintenance operation and recommissioning. The utilization of AR in maintenance undoubtedly brings remarkable benefits to the companies in terms of increased productivity and reduced production cost. This is especially true when AR is appropriately implemented in the setting where the machine to be maintained is complex, the variability of error and duration among different technicians is high, the maintenance task to be performed is rare, and the operation need to be done in a remote location [11].

3 AUGMENTED REALITY SYSTEM INTEGRATED WITH CMMS

CMMS ties together equipment information, maintenance data and schedules, failure history, as well as parts inventory. The main use of a CMMS is to effectively plan preventive and predictive maintenance as to minimize the number of surprise breakdowns and work outages. However, the new form of integration between CMMS and AR allows the enhancement of contextual awareness against unexpected breakdown, and hence, provides right actions to deal with it through explicit visualization of asset information, manual from manufacturer, best-practice maintenance and diagnostic procedure, as well as the availability of the spare parts. On the other hand, the continuous advancement of AR technologies introduced in the market is making AR implementation more feasible to address the real industrial problem especially for maintenance. The maintenance tasks performed on the machine production often consist of complicated instruction and a large volume of information such as recognition of the right component and precise procedures for mounting and dismounting. In order to ensure a seamless and effective maintenance execution, the provision of AR information in the user's field of view while leaving user's hands free to follow the guided task are crucial. The release of the Hololens by Microsoft as a wearable device for AR display will allow user to see an AR-enriched environment while still permitting them to perform maintenance task with both hands. In this way, the effective procedure of maintenance processes can be planned and displayed to the unskilled operator, guiding him to diagnose the problem and even to carry out the correct maintenance task more intuitively and safely. The architecture of the system is presented in Figure 3.

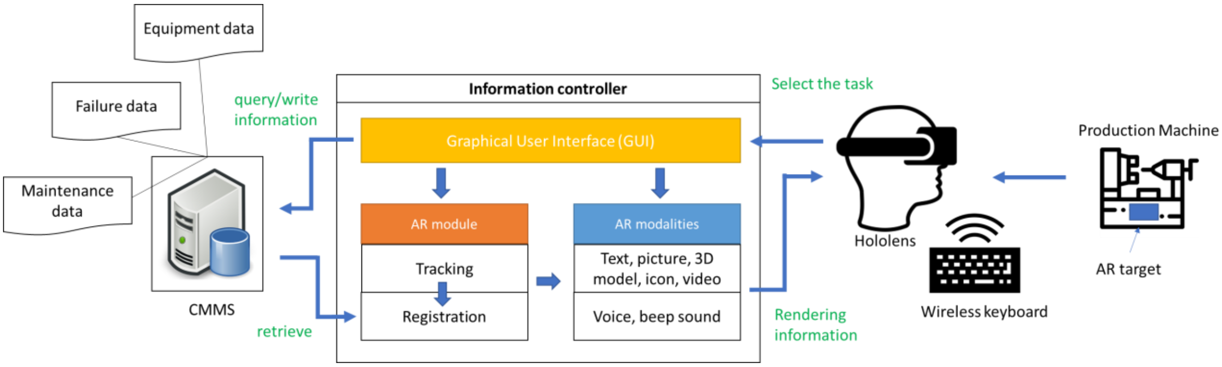

Figure 3: The architecture of AR-CMMS system.

The developed system consists of Computer Maintenance Management Software (CMMS), a wearable AR system using the Hololens, and information controller. The detail description of the system is described in the following sub-sections.

3.1 CMMS Database

CMMS stores all the asset information in a database including the maintenance schedule, the detail record of maintenance work that have been performed and the inventory of spare part and supplies. This information can be accessed and updated by a customized application through the Software Development Kit (SDK) or web service that interacts with a webserver of CMMS database. Each CMMS software has its own database system and the way to access it. The format of database in this work was presented as a relational database and the figure below shows how asset information such as equipment data, failure history, maintenance information, and spare part were organized and associated.

Manufacturing firms could have a wide variety of production machines with different characteristics of failure history and maintenance instructions. Linking all this information together and visualize the relevant information in appropriate modality to the human operator can generate productive value in dealing with unexpected breakdown. Figure 4. shows how each individual table such as Machine, Failures, Causes, Instruction, and Sparepart are linked by the Maintenance table. Machines table can contain information about the machineID, name of the machine, vendor name, date of purchase, etc. This machine can have the failure history which is stored in the Failures table that contain the information about FailureID, failure name as well as the frequency. Furthermore, each failure can have multiple causes which are stored in the Causes table that record the information of Causes ID and name of cause. For every CauseID there is a specific maintenance record associated with it which is identified by MaintenanceID and provides the information about the maintenance instructions identified by InstructionID, the tools and spare part required to perform the task, as well as the downtime during the maintenance activity. The provision of the past data could help providing insights to untrained operator to deal with a sudden malfunction of the equipment and support a skilled technician in planning the effective maintenance plan with a minimum delay. For example, the access to the inventory record permits the operator to see if the required spare part for repair is available or the new ones need to be ordered.

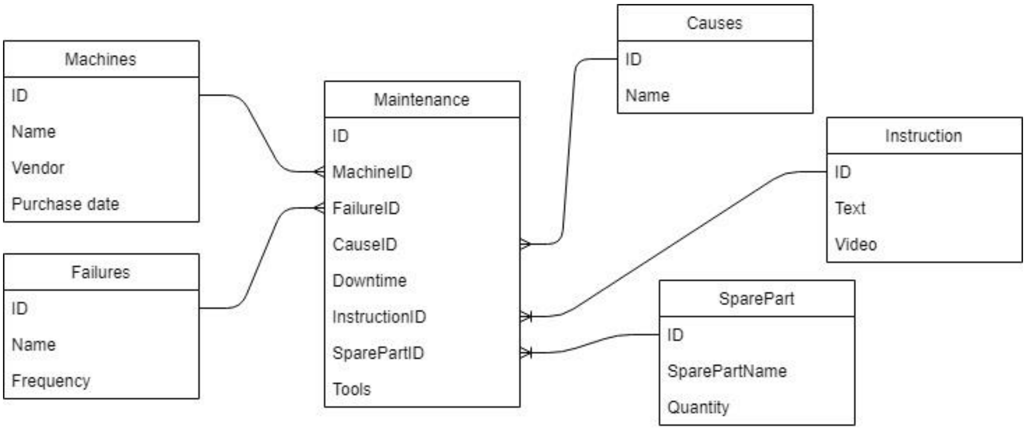

Figure 4: UML diagram that describes the relation of the records between machines, failures, causes, spare part, and maintenance actions performed.

3.2 AR Device and Data Input

The device used in this work to receive, visualize, and send the information to CMMS database was developed on the Hololens. This device consists of a wide array of sensors that continuously collect the user's head and hand movement as well as his surrounding environment. Head tracking is done by means of gyroscope, accelerometer, and magnetometer that make up an Inertial Measurement Unit (IMU). The Hololens also includes one depth camera and four environmental sensing cameras to detect hand gestures and the physical objects in the surrounding area. The headset also contains a 2-megapixels photo/HD video camera that can be used to track the target reference in space for the placement of AR objects. This information acquired from the sensors are used to synchronize the AR objects to coexist in the physical 3D space where the user expects them to be. The visualization of the AR object is rendered through optic systems composed of holographic lenses in front of the user's eyes and an optical projection system that beams the holograms to the holographic lenses. Besides, the device also has a microphone to record the voice for command control and speaker to deliver auditory information. The interaction between the user and the GUI was made through hand gestures and voice recognition. Meanwhile, the interface that requires long data input was provided through a wireless keyboard which is paired with the Hololens via Bluetooth.

3.3 Information Controller

Information controller is a core engine that control AR engine and information delivery as well as manage and handle the processing of data input and output between The Hololens and CMMS database. To ease the setup and the integration of different components in AR-CMMS system, Unity3d [12] was used as the core engine to build the information controller. Unity3d is a cross-platform, easy to use game engine for building Virtual Reality (VR) application. It has a game editor to facilitate the developer in the design of GUI for user interaction. Unity3d also supports the integration of multiple AR engines, one of which used in this system was Vuforia 8.0.10 which is compatible with The Hololens. AR engine consists of two main modules: (1) tracking of position and orientation of AR target, and (2) registering digital content to the location where AR target is detected. Vuforia supports different kinds of AR targets on which digital content can be superimposed such as Image Target, Model Target, and Object Target [13]. In the first implementation, Image target was used as a reference location in the physical world where the AR objects are placed relative to the user's view. Once the AR target is detected, the delivery of digital content can be visualized in different AR modalities such as visual (text, picture, 3D model, icons, video) and/or audio (voice message, beep sound).

3.4 CMMS Database and Information Controller Communication

This sub-section shows how the communication between a CMMS database and AR application was established by means of a web service. Hololens contains 802.11ac-capable, 2x2 Wi-Fi radio to connect to the internal Wi-Fi network where the server of the CMMS database exists.

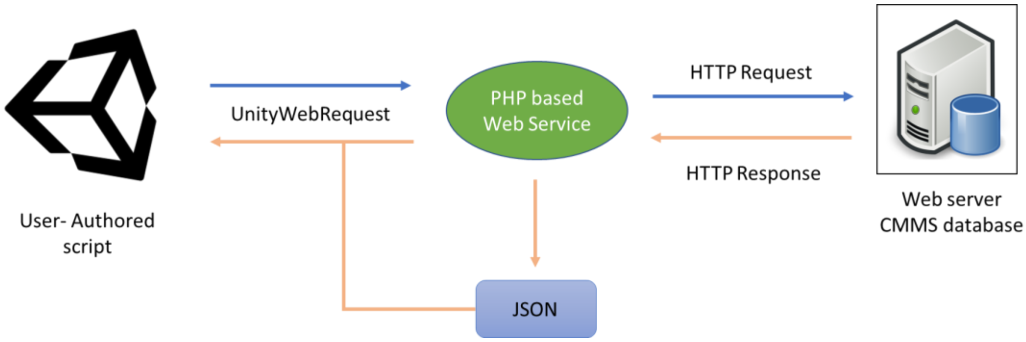

Figure 5: The interaction between Unity-based application with Web server CMMS database.

The AR engine in this work was developed based on Unity3d which has a built-in implementation class *UnityWebRequest* for composing HTTP requests and handling HTTP responses, allowing Unity based application to interact with the web server back-ends. A PHP based web service was created to facilitate the interaction between AR application and web server. To request maintenance information displayed on the Hololens, the data input (e.g., Machine ID, FailureName) was sent from AR application to CMMS database server via HTTP POST. In response to this request, web service queried the asset information and sent the maintenance instructions text in JSON format through a PHP function *json_decode*. The data received from the server database was read from *DownloadHandler* object and UnityJSONSerializer was used to convert JSON text into Unity object. Some other data format sent from the database such as image, audio clip, and video, were read through *DownloadHandlerTexture*, *DownloadHandlerAudioClip*, and *DownloadHandlerMovieTexture* respectively and Unity objects such as *Image, audioclip*, and *videoplayer* were used for storing the resources. After that, Unity scripts were written to integrate and manage the downloaded information, AR tracking information, AR modality, and other multimedia resources for information delivery. Figure 5. shows the communication workflow.

4 SYSTEM IMPLEMENTATION

The development of the AR-CMMS system for maintenance was demonstrated on a desktop 3D printer which is an emerging technology that will transform how the products are manufactured in the future. Due to the advancement in the underlying technology, a malfunction of 3D printer can be caused by multiple sources of problem. In this study, two types of failures were considered: (1) failure that involves fixable component (easy task) and (2) failure that requires certain expertise to solve the problem (difficult task). In fact, 3D printer can have many print issues. However, for the sake of demonstration, two print problems (i.e., nothing comes out of the nozzle and layer shift) were chosen to show the potential of the proposed approach.

Steps to proceed with the development of AR-CMMS system are as follow: first, the relation of different components of information was designed to efficiently store a large volume of data and effectively retrieve the required data. Figure 6. shows a sample of data organization in a database that links machine data with failure history and its associated causes along with maintenance actions that have been performed. One specific machine (MachineID) can have a failure (FailureID) that consists of multiple sources of problem (CauseID). For each source, a specific maintenance guide (InstructionID) can be properly planned and designed from the manual book which is complemented by the know-how knowledge of the skilled technician.

ID	MACHINE NAME	VENDOR NAME	PURCHASE DATE
1	3D printer	Sharebot	11-05-2017
2	3D printer	Shining3D	12-01-2018
3	Laser Cutting	SainSmart	15-03-2016
4	CNC Milling	SoraLuce	19-09-2015
....	....	....	

CAUSE ID	CAUSE NAME
1	Broken filament
2	Nozzle too close to print head
3	Nozzle clogged
4	Current voltage setting
5	Loosen belt or grub screw
6	Problem on stepper motor
....	....

ID	MACHINE ID	FAILURE ID	CAUSE ID	DOWNTIME	INSTRUCTION ID	TOOLS	SPARE PART
1	1	1	1	20	....	....	....
2	1	1	2	5	....	....	....
3	1	1	3	50	....	....	....
....	....	....	....	....	....	....	....

ID	FAILURE_NAME	FREQUENCY
1	No filament comes out from the nozzle	15
2	Print not sticking to the bed	10
3	Layer shift	2
....	....	....

Figure 6: The link of asset information in a relational database.

Next, the GUI for AR-CMMS system was designed to display relevant asset information. For example, maintenance instructions can be displayed in the text format or verbal messages, followed by labels to pinpoint the location of the target, animated 3D models or video to clearly show how the task should be done. Interaction of GUI was built on user's gaze to the target and the recognition of hand gestures and voice command were programmed on the Hololens to navigate the menu and control the digital contents. For instances, air tap alone for click action, air tap and hold to perform "click and drag" action, voice commands such as "Next" and "Back" to go to the next or previous instruction.

AR target (i.e. Image target) was attached to the 3D printer to provide the location in which the digital content (e.g., video) must be placed in the reference frame of the user's view. Multiple targets with different sizes could be utilized, allowing more virtual objects pop up in the desired location.

After the setup of information database, GUI, and AR engine, PHP based web services were created to bridge the data exchange between AR system and a CMMS web server. Figure 7. shows one of the PHP scripts to retrieve the instruction from the CMMS database. Several steps carried out by the web service involves the establishment of AR application connection to a CMMS web server, the read of user input (e.g., Machine ID, FailureName), the retrieval of FailureID from the FailureName, the retrieval of maintenance information from MachineID and FailureID, the retrieval of maintenance instruction text from InstructionID, and data output in JSON format.

```php
<?php
    // Connect to DB
    $con = mysqli_connect('localhost', 'root','root','unityaccess');

    if($con->connect_error)
    {
        die("Connection failed. ". $con->connect_error);
    }
    echo "Connected succesfully <br>";

    // Variable submitted by user
    $machine_id = $_POST["MachineID"];
    $failure = $_POST["FailureName"];

    // Retrieve the FailureID
    $sql = "SELECT FailureID from failures where FailureName = '" . $failure ."'";
    $result = mysqli_query($con, $sql);

    if($result->num_rows > 0){

        if($row = $result->fetch_assoc()){
            $failure_ID = $row["FailureID"];
            //echo $failure_ID;
        }
    }
    else{
        echo "-1";
    }

    // Retrieve maintenance Information from MachineID and FailureID
    $sql1 = "SELECT * FROM causes NATURAL JOIN maintenance
    WHERE (MachineID = '" . $machine_id . "' AND FailureID = '" .$failure_ID."')";

    $result1 = mysqli_query($con, $sql1);
    $json_array = array();
    if($result1->num_rows > 0){

        while($row1 = $result1->fetch_assoc()){
            $json_array[] = $row1;
            $InstructionID[] = $row1["InstructionID"];

        }
    }
    else{
        echo "-2";
    }

    // Retrieve maintenance instruction text from InstructionID
    $ids = join(',', array_map('intval', $InstructionID));
    $sql2 = "SELECT instruction.InstructionID, instruction.Text
    FROM instruction WHERE InstructionID in ($ids)" ;

    $result2 = mysqli_query($con, $sql2);
    $json_array2 = array();
    if($result2->num_rows > 0){

        while($row2 = $result2->fetch_assoc()){
            $json_array2[] = $row2;

        }
    }
    else{
        echo "-3";
    }

    // Output the data in JSON Format
    echo json_encode($json_array);
    echo json_encode($json_array2);

?>
```

Figure 7: A PHP based web service to retrieve maintenance instruction.

Figure 8(b) shows that user can access the functionality of the AR application through GUI for the task that he wants to perform (e.g. diagnostic task) or create the work order (WO) using wireless keyboard to input the data as shown in Figure 8(a). By looking directly to the AR target attached on the machine, the camera on the Hololens can detect the ID of the machine and the system can retrieve the information of the asset from CMMS database. When the unexpected breakdown occurs, the operator can report through the voice command or type the failure name that he observes, and possible causes will be displayed to the operator. The operator can inspect the possible causes one by one and follow the diagnostic procedure through step by step maintenance instruction text and video presented in the display. The possible causes will be marked in green if the operator finds no issue with the suspected cause as shown in Figure 8(c). When the actual problem is detected and fixed by the operator through the guidance of AR-CMMS system (Figure 8(d)), the operator needs to create and close the WO to update the maintenance history of the machine. On the other hand, when the failure is not recognized by the system or the root cause of the failure cannot be found (i.e., new source of problem), the operator can make a skype call to the skilled technician. The diagnostic process continues with the aid of the skilled technician seeing the machine through the operator's view with the Hololens. If after the remote involvement of the skill technician the new root cause of failure is found but cannot be fixed immediately due to the missing tool or spare part, operator needs to create and open a WO in CMMS. The same action is also taken when the root cause cannot be identified. The system will send the open WO and this new WO will be accessible by maintenance technician who will replan maintenance task, execute, and close the WO. Figure 9. shows the flow chart of maintenance activity using AR-CMMS system.

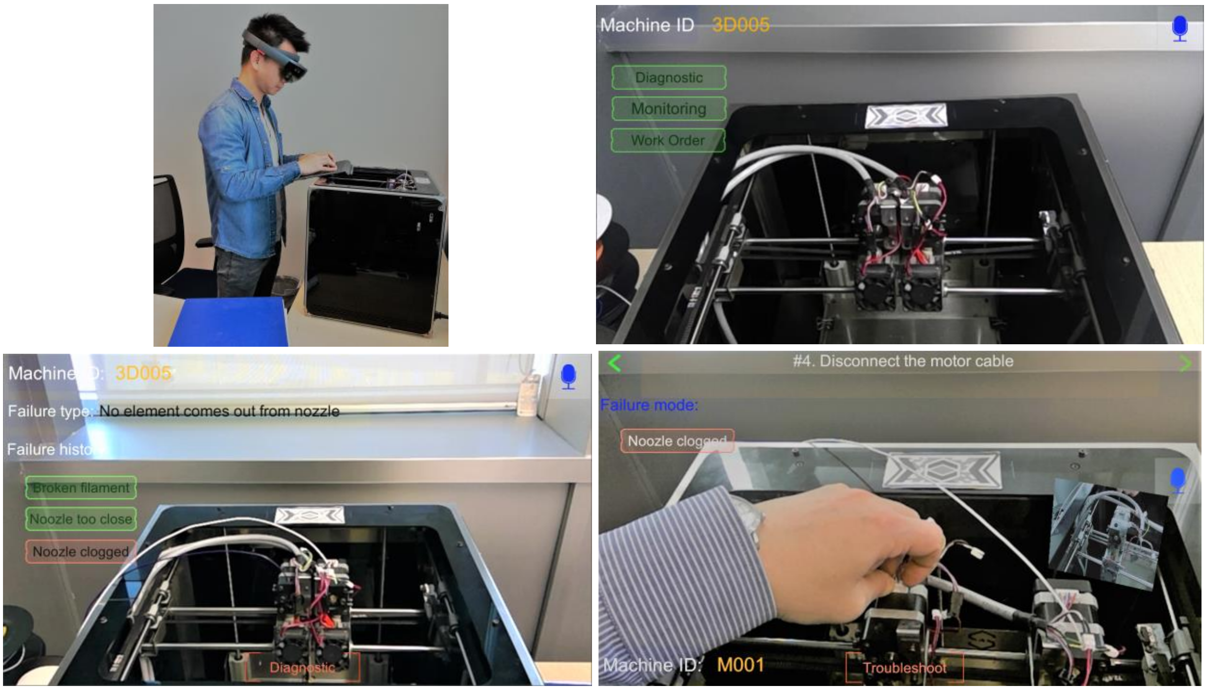

Figure 8: AR system integrated with CMMS to deal with unexpected breakdown. The figures from left to right and top to bottom are: (a) a user wearing Hololens and using wireless keyboard, (b) functionality of the system, (c) diagnostic operation based on failure history, (d) AR system guided the operator through text instruction and video on how to troubleshoot the problem.

This working paradigm allows the unexpected breakdown to be handled immediately by the unskilled operator in the shop floor with the aid of AR-CMMS system. The system can guide the untrained operator with AR instruction to perform a systematic diagnostic to examine the source of the failure or even to perform corrective maintenance on the minor problem. In comparison with the traditional approach, the corrective maintenance is subject to delay as it relies heavily on the expertise of the technician which causes the failed equipment to be inactive for a longer time and consequently leads to production loss. Furthermore, in a rare case that requires higher expertise to fix the problem such as the malfunction of the stepper motor that causes layer shift, the proposed system can assist operator to rule out the unlikely sources of failure through diagnostic task, and thereby providing a more specific information about the actual failure (i.e. identified problem is on the stepper motor). This can help the technician to plan a more accurate and productive maintenance planning (e.g. order a spare part) to restore the machine to its normal operating condition. Moreover, the system can record every maintenance activity performed by either operator or technician. This enables the assessment of maintenance procedures with the associated equipment for quality control, performance evaluation, and cost analysis in attempt to derive the best practices for maintenance actions. The AR assisted maintenance system can be upgraded based on the company's best practices and distributed to other branches of the manufacturing industries that run the production with the same type of machine.

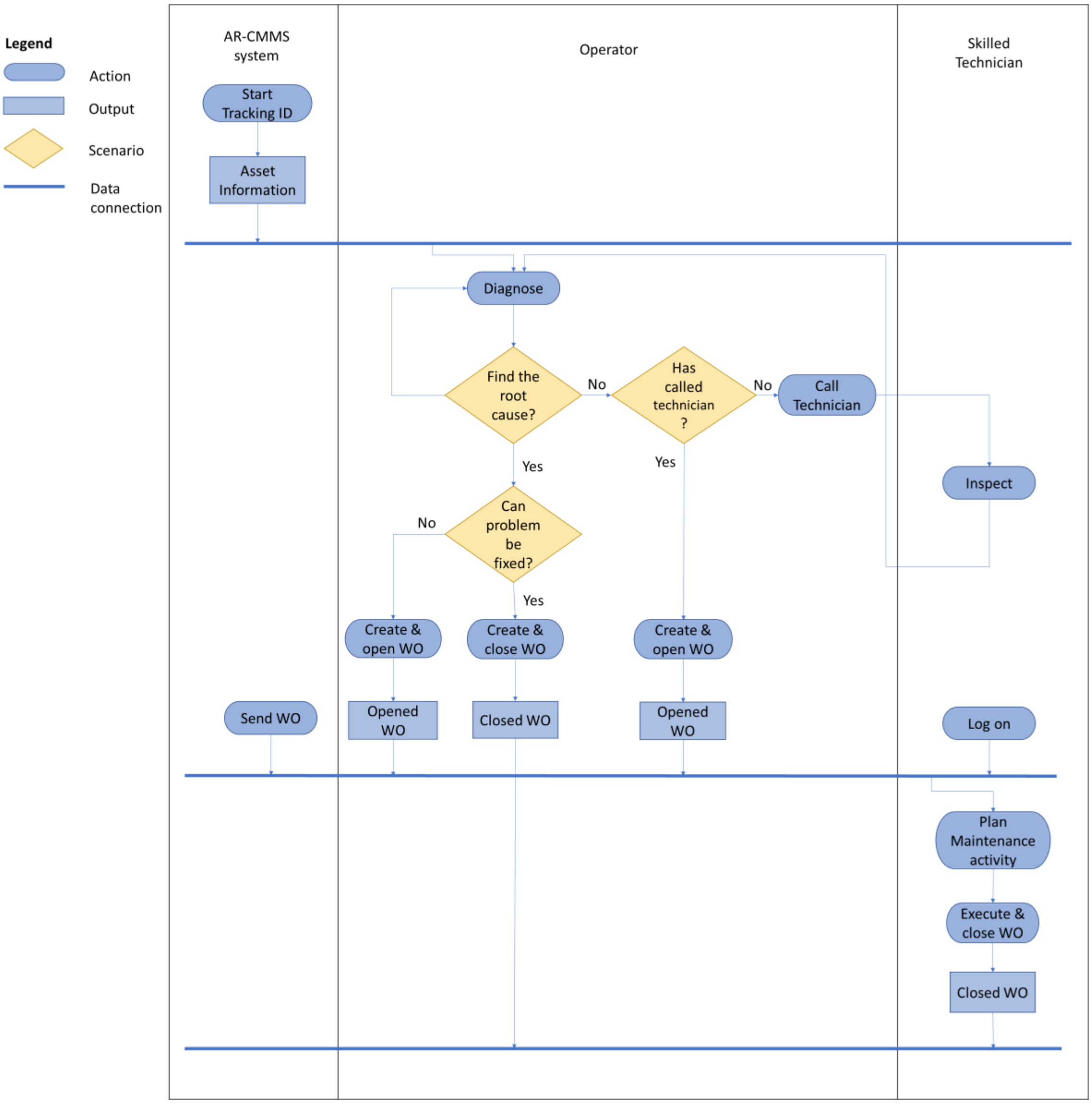

Figure 9: The flowchart of machine breakdown rectification through AR-CMMS system.

5 CONCLUSION

The main purpose of the AR system and CMMS integration is to establish a more effective approach to deal with unexpected breakdown in the current contexts of industrial setting that are characterized by complexity, connectivity, and diversity of the production system. Through the provision of a complete information such as asset information and best practice maintenance action in the AR environment, this approach can assist an untrained operator to immediately diagnose or even fix the failed equipment as to minimize the length of the unscheduled downtime. Furthermore, the early inspection of the dysfunctional asset can help to devise a more accurate planning of maintenance operation, and thereby avoiding the non-productive maintenance operation and recommissioning. The reduction of time to recovery will improve the availability of the equipment and hence, increase the profitability and competitive advantage of an industrial firm. Further study will focus on the experimental study for evaluating the usability of the system.

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REFERENCES

[1] Azpiazu, J.; Siltanen, S.; Multanen, P.; Mäkiranta, A, Barrena, N.; Díez, A, Smith, T.: Remote support for maintenance tasks by the use of Augmented Reality, the ManuVAR project. 9th Congress on Virtual Reality Applications (CARVI), Vitoria-Gasteiz, Spain, 2011, 10–11.

[2] Daqri, http://daqri.com/ [last accessed 12/05/2019]

[3] Davies, R.: Digitalisation for productivity and growth, European Parliamentary Research Service, 10, 2015.

[4] De Crescenzio, F.; Fantini, M.; Persiani, F.; Di Stefano, L.; Azzari, P.; Salti, S.: Augmented reality for aircraft maintenance training and operations support, IEEE Computer Graphics and Applications, 31(1), 2011, 96–101. http://doi.org/10.1109/MCG.2011.4

[5] Fiorentino, M.; Uva, A. E.; Gattullo, M.; Debernardis, S.; Monno, G.: Augmented reality on large screen for interactive maintenance instructions, Computers in Industry, 65(2), 2014, 270–278. http://doi.org/10.1016/j.compind.2013.11.004

[6] Fountx, http://fountx.com/ [last acacessed 12/05/2019]

[7] Henderson, S.; Feiner, S.: Exploring the benefits of augmented reality documentation for maintenance and repair, IEEE Transactions on Visualization and Computer Graphics, 17(10), 2011, 1355-1368. http://doi.org/10.1109/TVCG.2010.245

[8] Labib, A. W.: A decision analysis model for maintenance policy selection using a CMMS, Journal of Quality in Maintenance Engineering, 10.3, 2004, 191-202. http://doi.org/10.1108/13552510410553244

[9] Sanna, A.; Manuri, F.; Lamberti, F.; Member, S.; Paravati, G.; Pezzolla, P.: Using handheld devices to support Augmented Reality-based maintenance and assembly tasks, IEEE International Conference on Consumer Electronics (ICCE), 2015, 178–179. http://doi.org/10.1109/ICCE.2015.7066370

[10] Swanson, L.: An empirical study of the relationship between production technology and maintenance management, International Journal of Production Economics, 53, 1997, 191–207. http://doi.org/10.1016/S0925-5273(97)00113-8

[11] Palmarini, R., Erkoyuncu, J.A. and Roy, R., 2017: An innovative process to select Augmented Reality (AR) technology for maintenance, Procedia CIRP, 59, 23-28. http://doi.org/10.1016/j.procir.2016.10.001

[12] Unity, http://unity.com/ [last accessed 29/03/2019]

[13] Vuforia, http://www.vuforia.com/ [last accessed 29/03/2019]

[14] Wójcicki, T.: Supporting the diagnostics and the maintenance of technical devices with augmented reality, Diagnostyka, 15(1), 2014, 43-47.