A Study on Automating Rolling-stock Maintenance in the Rail Industry using Robotics

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Abstract: Maintenance cost of United Kingdom's rail rolling stock is a substantial portion of its whole life costs. Therefore, it is vital to conduct these maintenance tasks in an efficient and cost-effective manner to minimize operational costs while maximizing safety, quality, and consistency of service. The introduction of robotics and other intelligent mechanisms to maintenance processes would be an ideal solution to these challenges. Hence, this research suggests introducing autonomous maintenance systems equipped with industrial robots to tasks within the railway system, specifically for rolling-stock maintenance. The paper summarizes on-going and future work of a case-study conduct in conjunction with a UK railway operator.

1 INTRODUCTION

1.1 Maintenance in General

Maintenance can be defined as a task or series of tasks which protect or reinstate the anticipated condition of a system and these tasks include all technical, administrative and managerial actions taken (Márquez, 2007). Further, maintenance is categorized into three major groups: preventive maintenance, scheduled maintenance and unforeseen maintenance (Parker and Draper, 1998). Proper maintenance of infrastructure, machines, systems and other resources are essential for any industry to provide a safer, reliable and resilient output (Márquez, 2007). In general, maintenance tasks are costly and on the other hand, maintenance could be hazardous; being accountable for 25-30% of fatalities in the United Kingdoms manufacturing industry (Fraser, 2014)(HSE, 1999).

1.2 Involvement of Robots in Maintenance

Robots that are designed for maintenance tasks can be found in many different applications; especially in the nuclear industry there are robots deployed for inspection, scheduled maintenance, disaster management and rescue operations (Pegman et al., 2006)(Nagatani et al., 2013)(Lee et al., 2013). Some of the other applications are semi-automated highway maintenance tasks such as crack sealing, automatic warning corn dispensing, data collection and lamp post maintenance (Lasky and Ravani, 2000)(Chan et al., 2015)(Armada et al., 2005). Further, robots designated for maintenance can be seen in the electric power distribution sector for maintenance of live wires (Kochan, 2001)(Maruyama, 2000), in facility management field to clean glass-wall of high-rise buildings (Tokhi et al., 2007)(Onori and Kochan, 2005), and in the railway industry to lay railway tracks, rail grinding and ongoing research in robotic train front-end cleaning (Villedieu and Francois, 1995)(Farnsworth and Tomiyama, 2014)(Moura and Erden, 2017)(Tomiyama et al., 2017). Due to the high levels of dexterity required, and a limited ability to cope with non-rigidly organized environments, the majority of robots currently deployed in the maintenance sector are teleoperated, remotely controlled or require close human supervision (Farnsworth and Tomiyama, 2014). Further, due to the complex nature of the maintenance tasks these robots need to be heavily customized and specially designed for a particular task and therefore, lack the flexibility and reconfigurability common to industrial robots. Also, these fixed robotic and hard automation systems have large initial investments compared to systems based on standard industrial robots (Gupta and Arora, 2009).

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1.3 Application of Industrial Robots Nationally and Internationally

Automated work-cells fitted with industrial robots are ubiquitous in the manufacturing sector, due largely to the nature of task repetition. The total percentage of robots installed in direct production-related tasks amounts 78% of the total robots installed in the UK see figure 1 (BARA, 2012). Though industrial robots are commonly found in the manufacturing sector, opportunities available for introducing such systems into maintenance are more challenging and this is mainly caused due to lack of available technologies to cope with complexities linked to maintenance tasks.

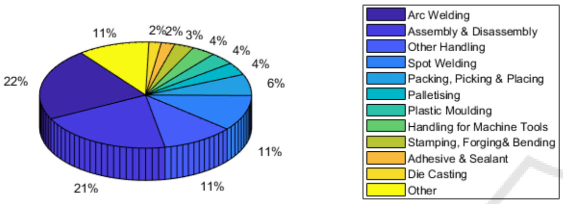

Figure 1: UK robot application by process.

According to the World Robotics 2014 data, annual shipments of industrial robots have increased over time despite the drastic drop in 2009 which was due to world's economic recession see figure 2 (IFR, 2015). Further, as shown in figure 2 it can be seen that the same trend exists within UK (BARA, 2012). Therefore, it is evident that industrial robots are becoming increasingly popular nationally and internationally. Over the period of 15 years from 1990, the mean quality-adjusted unit price of industrial robots in the UK, US and four other EU countries has dropped down by nearly 80% - refer figure 3. Therefore, robots are becoming more popular among industrial practitioners perhaps due to their reduced prices and improved quality, hence allowing shorter payback periods.

1.4 Railway Industry in the United Kingdom

According to the Office of Rail and Road, in 2014 UK shows growth of passenger rail journeys by 143% and rail has carried 10% more freight compared to 2004. Furthermore, in 2014, over 1.6bn passenger journeys were made see figure 4 (ORR, 2014). Also, the UK railway industry can be identified as one of the leading factors in the transport sector and the economy being responsible for 12bn spends a year (UKTI, 2014). Therefore, UK rail is among the top most rapidly growing industries. Due to rapid expansion and increased competition, companies associated with the

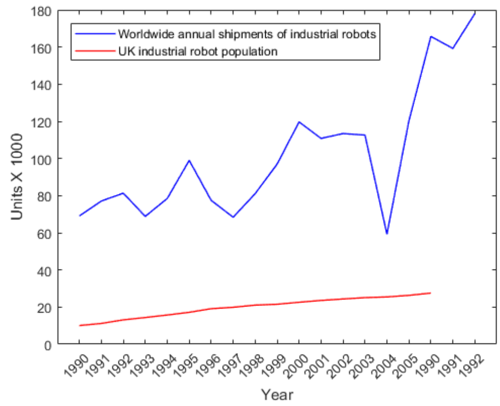

Figure 2: Industrial robots over time (World Robotics and BARA Robot Facts).

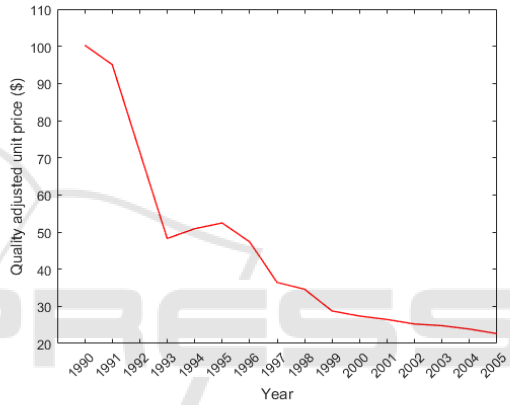

Figure 3: Price of industrial robots over time (IFR 2006).

railway industry progressively drive towards continuous improvement of existing facilities, resources and processes. That said, optimizing the usage, inspection, and maintenance of train fleets in a cost-effective manner remains a key challenge for the sector. Reducing inspection and maintenance costs, whilst maintaining/improving safety is a priority for not just train operating companies, but the rail industry both nationally and internationally. According to the Value for Money Study published in 2011 May, which was a joint assignment by the Department for Transport and the Office of Rail Regulation Network, rolling stock maintenance and financing has been estimated to be 1.78bn a year which accounts for 15% of total UK railway costs (McNulty, 2011).

Rolling stock maintenance could be clustered, distributed over local contractors and encourage them to be specialists in the field, and apply techniques to achieve increased productivity through automation (McNulty, 2011). Also, it has been identified that increased automation is a key objective in the Rail Technical Strategy 2012 and is expected to obtain operational cost benefits by intelligent maintenance tech-

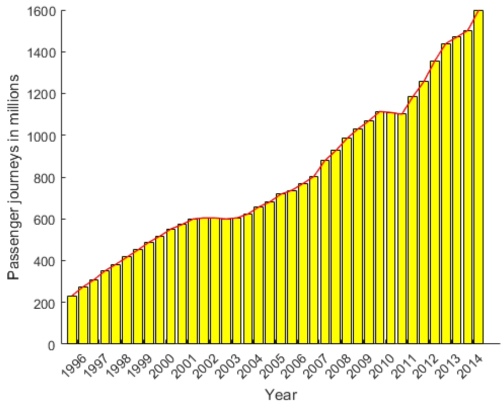

Figure 4: UK'S overall passenger railway journeys (ORR - 2014).

niques (TSGL, 2012). Further, "Robotics and Autonomous Systems (RAS)-2020" has identified that UK could save 1tn over the following 20 years by applying RAS to the transport sector (RAS, 2014). Therefore, the introduction of autonomous systems in order to eliminate or minimize human intervention in maintenance processes would be an ideal technique and it can be viewed that UK railway industry is in the right stage to invest in automation (RRUKA, 2015).

1.5 Motivation and Scope of the Study

Based on above evidence it would be highly beneficial to introduce off the shelf industrial robots for rolling stock maintenance. Therefore, this research seeks a set of advanced skills and techniques to introduce industrial robots into autonomous maintenance applications in the railway industry through identification of viable maintenance tasks for automation. Further, this research will focus on adapting automation techniques in existing manufacturing to maintenance processes and address the key challenges in-cooperated with such automation exercises. The scope of this project is to examine the feasibility of introducing off the shelf industrial robots to automate "Siemens Class 380 Desiro" power bogie gear fluid changing task and develop advance sensing modules/algorithms required for robot manipulation in maintenance environments. Shown in figure 5 is the main gearbox of Siemens Class 380 illustrating wire lock, fill/drain plugs and inspection window, and the curved tooth coupling cover of Class 380 power bogies. Technicians have to drain the oil out from both main gearbox and curved coupler and refill them with new oil after inspecting for the presence of water in oil or any metal debris in the magnetic filler caps. All the guidelines for this process are provided in detailed maintenance procedures provided by the manufacturer.

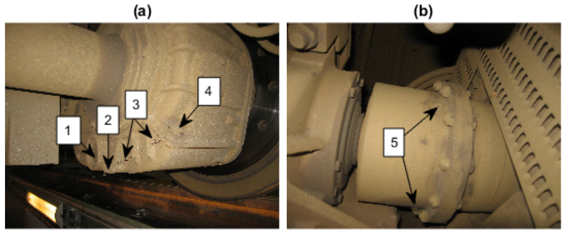

Figure 5: (a) Class 380 main gearbox where (1) Inspection window, (2) Drain plug, (3) Wirelocks and (4) Filler plug, and (b) Curved coupling cover Class 380 where (5) Drain/filler plugs.

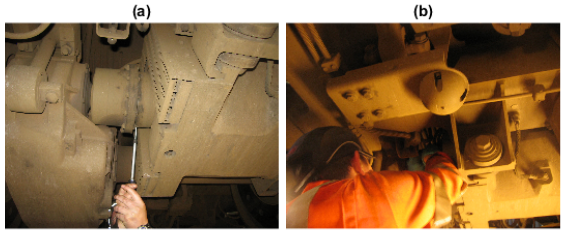

Figure 6: (a) and (b) Technician performing Class 380 curved coupler oil change.

Both these maintenance processes involve complicated practices such as removal and application of wire-locks in the main gearbox and locating the position of drain/filler plugs of curved coupler since it rotates as the train drives. These processes should be relatively straightforward to an experienced technical person but are quite challenging for an automated system due to lack of positional repeatability. Further, these items are located in difficult to reach positions (refer figure 6) where technicians need to execute the bulk of the work related to these maintenance tasks in unergonomic environments which may pose potential health and safety hazards, for example, oil spill slip/trip risks. Therefore, the team has identified this as one of the tasks to be explored further to introduce automation.

2 WORKFLOW STRATEGY AND EXPERIMENTAL SETUP

This study consists of several stages. At the initial phase, as a part of the preliminary feasibility study, data collection and computer-based simulations will be conducted. The approach includes the development of physically modelled off line tasks in a laboratory setting to replicate the automation context. A fully functional 6 axis articulated industrial robot - Fanuc LR Mate 200iD will be used for the mock tests to gain detailed knowledge of the task prior to implementation and how difficulties can be overcome

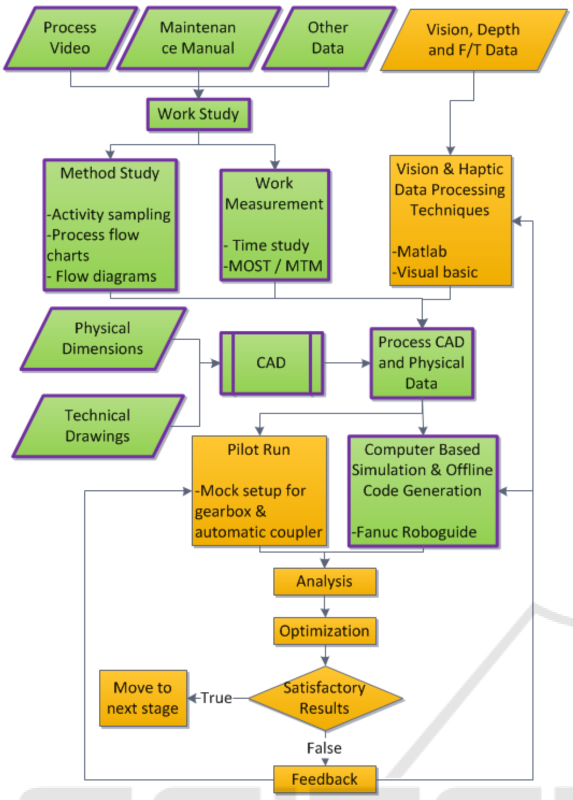

Figure 7: Fundamental workflow of the project.

with reduced financial and technical risk. The fundamental workflow of this project is shown below and visualized in green are the actions to be taken during the phase 1 which are currently ongoing (figure 7). As it can be seen project steps will take a cyclic pattern to optimize the output to the desired level. Work study data collection is currently underway and these data will be collected by observations and video analysis of the actual maintenance tasks, referring to maintenance instructions and communicating with expertise in the field such as technicians, engineers, and managers at Abelio Scotrail, Shields Depot, Glasgow. Data will be processed using standard work study methods: Method study and Work measurement and compared with that by Farnsworth 2014 (Farnsworth and Tomiyama, 2014). Also, key geometric details and critical dimensions of the parts to model the experimental setups will be recorded in parallel to work study data collection.

2.1 Prototype Design and Computer-based Robot Simulations

Computer aided designs of scaled-down Class 380 curved gear coupler and end of arm tool were modelled as shown in figure 8. It is been assured that the

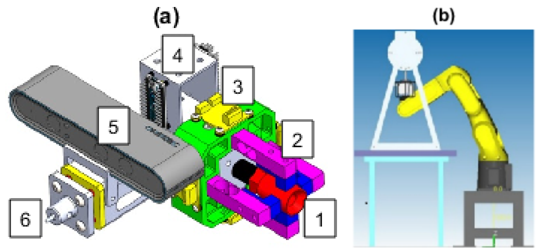

Figure 8: (a) Proposed CAD of end of arm tooling where (1) Floating tip to detect precise location of guide pin, (2) 4 X Micro load cells, (3) 4 X Wheatstone bridges, (4) 2 X Arduino Nano, (5) ToF and RGB sensors and (6) Tip to inspect electric connectors, and (b) Fanuc Roboguide virtual work cells designed for Class 380 curved coupler.

mock coupler contains key physical features required to conduct the pilot test. The final design is to be confirmed based on the input from Abelio-ScotRail expertise, the output of computer-based simulations and manufacturability. Rapid prototyping and CNC milling will be utilized for the fabrication. Vision and force sensing modules are incorporated to the robots end of arm tooling (EOAT) and equipped with a micro-controller to process machine learning algorithms expected to develop in future. Further, it is aimed to enhance tools reconfigurability with automatic tool changing techniques. The software package ROBOGUIDE provided by Fanuc has been used to conduct computer-based simulation of the process and experimental setup. Roboguide is an advanced simulation which allows users to model robotic workcells, process verification, offline code generation and robot motion confirmation such as collision detections, program verification, cycle time and payload validation. Further, this software permits users to program robots using a flexible programming language similar to Pascal (KAREL) other than traditional teach pendant programming.

Illustrated in figure 9 is a conceptual work-cell of the train gear fluid changing platform designed using Roboguide software for a preliminary feasibility study. The virtual work-cell would assist the team members to visualize robot positioning inside the existing service bay, design and allocation of multiple end of arm tooling (EOAT), set up of robotic vision systems, placement of force-torque sensing equipment, oil discharging and dispensing methods and other factors such as health and safety requirements.

2.2 Proposed Sensing Model

In order to cope with complexities and moderate levels of disorder commonly found in maintenance environments, the robot should be able to sense its environment. Therefore, this research suggests a combi-

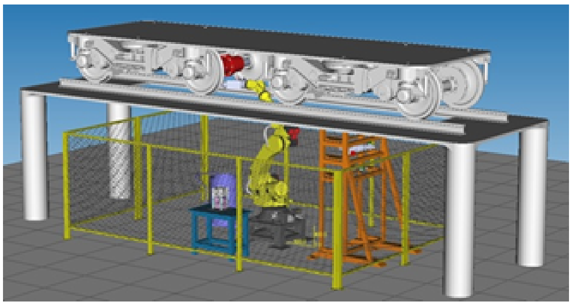

Figure 9: Preliminary work-cell designed by Roboguide Class 380 gear oil change platform.

nation of both vision and haptic data processing techniques to bring up a smart sensing methodology. A time of flight and a RGB sensor is proposed to capture depth and intensity data of the environment that will be used for the initial positioning of the robot. The precise manipulation of the robot is supposed to achieve through force sensing module equipped with four micro load-cells coupled to Wheatstone bridges - see figure 8(a). Moreover, both the main gearbox and curved coupler are located in dirty and difficult to access positions, and it is quite difficult to precisely control parking position of the train itself. Therefore, proposed system should be robust to noise and accommodate the high level of anticipated tolerances.

3 RESULTS

Object identification and localization methodologies are developed at this stage of the research by fusing ToF and RGB sensors. Conventional edge detection techniques didnt prove to be successful in detecting objects due to the high level of environmental noises presented, geometric ambiguities and surface characteristics of the targets. Therefore, a template matching algorithm which encapsulates geometric and intensity data is developed to detect electrical pin candidates of the automatic train coupler. The developed methodology is robust to rotation, ambient light and surface ambiguities, and able to detect all electrical connectors effectively within the anticipated work envelope - see figure 10. Further, detection and localization of the drain/filler plugs of the curved coupler and main gearbox is equally challenging and advanced machine learning algorithms are used to detect and localize the said targets refer figure 11. Moreover, the images used in validation phase are captured in normal working conditions without the aid of any artificial lights or filtered backgrounds.

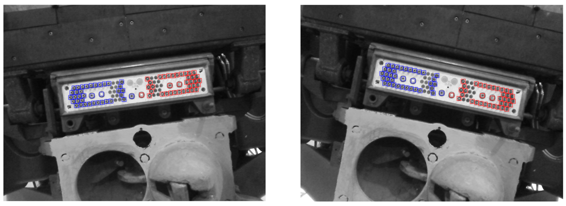

Figure 10: Successfully identified and localized electrical connector of the Siemens Class 380 Scharfenberg train coupler.

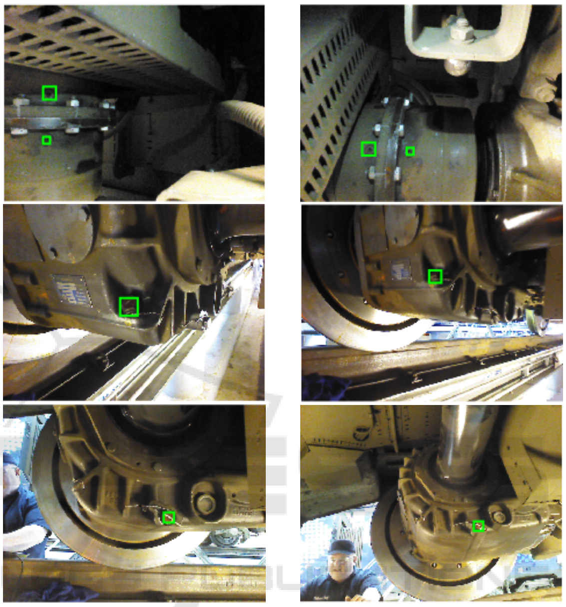

Figure 11: Identified drain/filler plugs of curved coupler (1st row), identified filler plug of the main gearbox (2nd row) and identified drain plug of the main gearbox (3rd row).

4 CONCLUSION

Not to overlook the rapid progress made by recent industrial robots and sensory equipment, the majority of present day robots in the manufacturing industry manipulate in rigidly organized worlds. In most instances these highly organized environments are created by the precise position of the parts, implementation of jigs and fixtures to guide tools, creating clear, clean and bright environments. The introduction of such techniques entirely to the maintenance sector is not straightforward and this could be viewed as one of the primary hindrances to implement fully autonomous systems equipped with industrial robots in maintenance tasks. Therefore, in a wider scope, this research pursues a set of advanced sensor (RGB, depth, and force) fusion techniques to create a hybrid sensing model that could be coupled with industrial robots enabling them to cope with low-moderate levels of disorders commonly found in maintenance sectors. More importantly these techniques are limited to maintenance environments but certainly can be adapted to manufacturing industry as well.

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