Robotics & Deep Learning

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Robotics & Deep Learning for Intelligent Storage of PFBR Fuel Pins

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Articulated robotic arm

ABSTRACT

Nuclear fuel pins for Prototype Fast Breeder Reactor (PFBR) are transferred from the fuel fabrication facility to the reactor site in transport magazines. This article presents a framework for automated loading of nuclear fuel pins into transport magazines. This development aims to close the gap between the manual and fully automated loading systems. This article discusses the vision-guided robotic system for precise alignment of fuel pins with empty slots and accurate insertion by a robot. The article also presents an innovative deep learning technique for recognizing and recording fuel pin numbers engraved on end plugs. The system has pin alignment accuracy of ± 20 microns and repeatability of ±30 microns for automatic insertion.

KEYWORDS: *Robot, Vision guided alignment, Deep learning*

Introduction

The industrial environment needs robotic systems that intelligently makes autonomous decisions based on the physical environment. Vision-based systems can now robustly detect position and orientation of the mechanical components with a monocular camera even with imperfect illuminations [1,2]. Vision-guided alignment for tight tolerance assemblies can be achieved by precise robotic systems [3,4]. Further, a deep learning approach for number recognition can enable tracebility[5] of industrial components. Rapid developments in active environmental sensing techniques have enabled the development of high-performance robotic systems for challenging requirements[6,7].

This article describes the various system components and innovative methodologies used to develop a robotic system for autonomous loading of fuel pins into transport magazines.

System Description

The robotic system(Fig.1) has a precise position control system, an articulated robotic arm, a number identification system, and a magazine orientation measurement system. Presently, the system can place eight fuel pins on the pin-loading platform. The pin position control system performs precise alignment of the fuel pins with the transport magazine before loading a pin. After that, a robotic arm fitted with a specially designed gripper pushes the fuel pin into the assigned slot. As a part of the automation, a deep learning-based methodology extracts fuel pin numbers from the end-plug curved surface. Also, the image-based system computes cage orientation. All the developed sub-systems are working on the production floor.

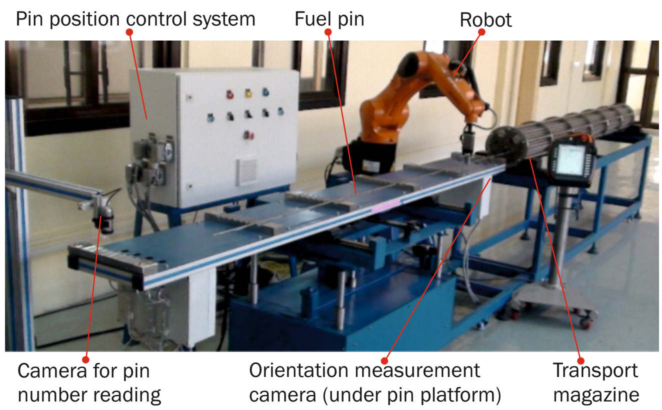

Fig.1: Robotic system for insertion of PFBR pins into transport magazine.

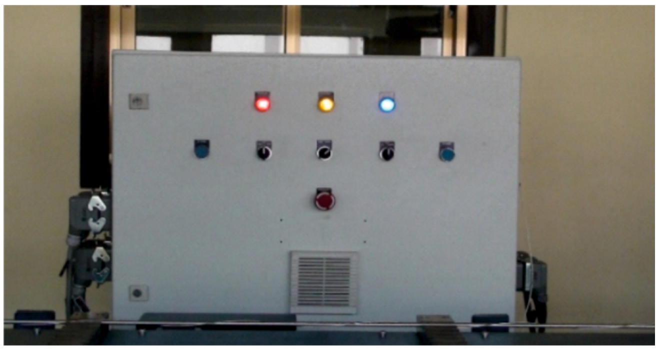

Fig.2: Controller for positioning of pin tray.

Pin position control system

We have designed and developed a two axes linear position control system (Fig.2) with ±20 microns accuracy. Tight tolerance between pin and slot necessitates the development of a system for accurate alignment. The control system issues commands for controlling the pin tray position using two servo motors (Fig.3).

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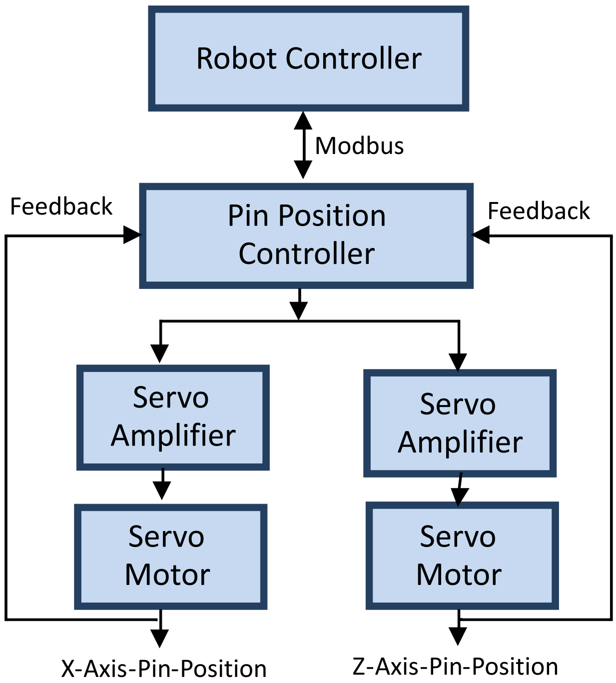

Fig.3: Pin Control System.

Fig.4: Articulated robotic arm.

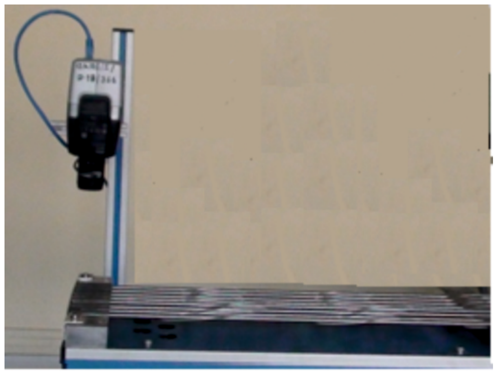

Fig.5: Camera for reading pin number.

Articulated Robotic Arm

A robotic arm with a maximum reach of 900 mm, performs insertion operation (Fig.4). The robot controller pre-computes all insertion positions. Loading of one pin requires six successive robotic pushing operations, and the robot controller completes all the processes within 24s with repeatability of ±30 microns. The robot also performs deep pin insertion into the slot, thus ensuring that fuel pins are not overhanging.

Pin Number Reading Camera

All the fuel pins have unique numbers engraved on the end plugs. This number ensures the traceability of the pin. A Bosch Dinion IP camera of 1280 (H) x 720 (V) resolution (Fig.5) captures the image of the end plug for extracting the pin number. The Control system performs scanning of all the pin numbers before initiating the loading operation. After insertion of each pin into the magazine, the software saves the pin number and corresponding magazine slot number.

User interface

Loading fuel pins into a transport magazine requires pin number scanning, pin positioning, insertion with the help of robot, and database preparation. Graphical User Interface software controls all the operations for pin insertion (Fig.6). The operator can validate extracted pin numbers before storing them in the database. The user interface depicts filled, empty, or block status for all the slots during the entire loading operation. Also, mapping information of pin number vs. slot number is displayed.

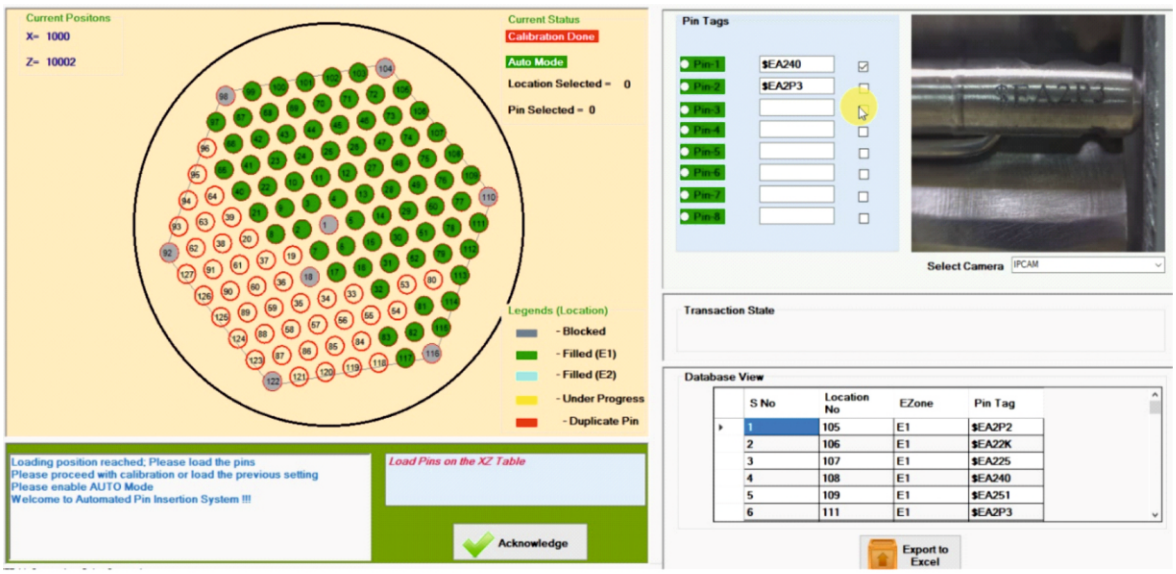

Fig.6: Graphical User Interface for Robotic Pin Insertion system (i) Status of 120 slots: Green(filled), No color (empty) (ii) End plug image and number detected by deep neural network (iii) Database for slot number and corresponding inserted pin number.

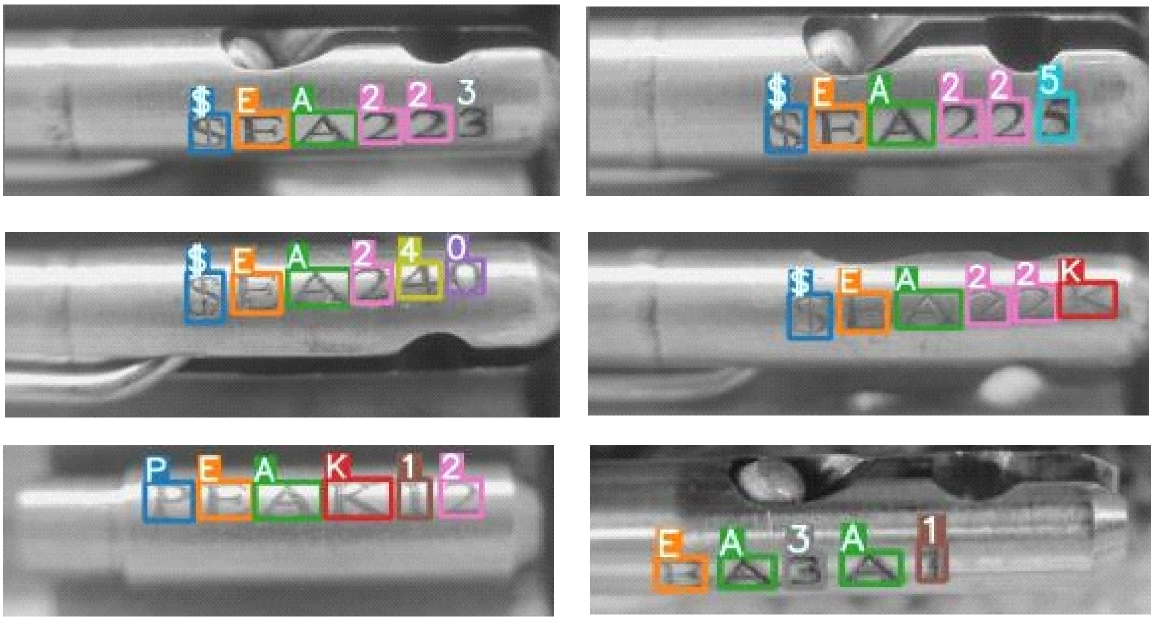

Fig.7: Recognition of fuel pin number with deep learning system.

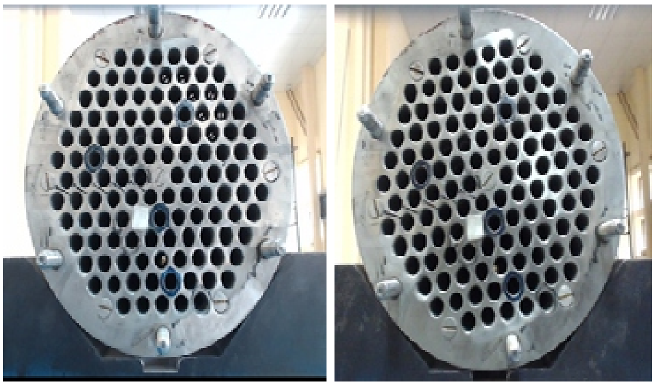

Fig.8: Orientation error because of variable transport magazine placement.

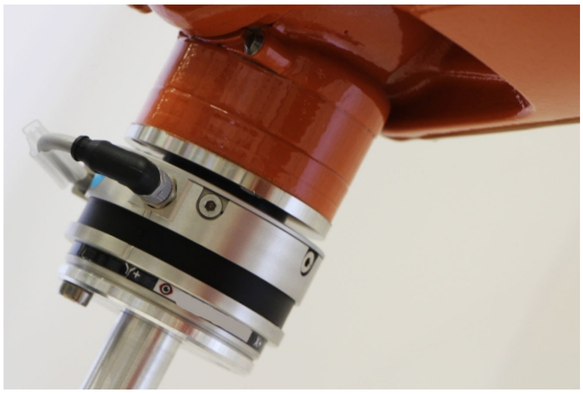

Fig.9: Force/Torque sensor for monitoring excess forces.

Innovative Techniques

Traditional industrial image processing solutions for number reading are unsuitable because of specular reflections, inconsistent number position, and the possibility of distorted and partial images. Hence, we have developed a novel deep learning technique using supervised learning. Further, estimating transport cage orientation was challenging, as installing sensors on the transport cage is not feasible. Therefore, we developed a unique vision-based technique for identifying features from the image for orientation measurement.

Deep Learning for Number Reading

A deep learning system for recognizing alphanumeric code from images (Fig.7) is one of the critical components of the automation system. The developed deep learning network identifies the engraved code sequence with an accuracy of 99.7%. We have performed supervised learning for identifying and classifying alphanumeric digits with more than 10000 images. The trained network recognizes and displays fuel pin numbers on the user interface in less than 500 msec. The operator validates this number before updating the database. The developed system helps to prevent unnecessary exposure as it is not required to go near to the pins for reading respective numbers.

Orientation Measurement System

Small orientation error (Fig.8) is possible after placement of transport magazine by a crane. The orientation error needs to be measured to modify pin position commands appropriately. A homography matrix extracts the features from images to compute rotation information. The system has a rotational measurement accuracy of $\pm 0.01^{\circ}$. We have verified the system's performance on the production floor with transport magazines in different orientations.

Online Force Monitoring for Safe Insertion

Safe insertion of fuel pin is critical as any undue forces on it may lead to bending of fuel pin. Inaccurate fuel pin alignment with the assigned magazine slot may cause forces to exceed the threshold safe limit. Therefore, during the robotic pushing of the fuel pin, force and torque values at the robot's end effector are continuously monitored. A force/torque sensor (Fig.9) between the robot and the gripper communicates with the robot. The robot halts operations when the force and torque values exceed the predefined threshold levels.

Conclusion

We have installed the robotic system (Fig.10) at PFBR fuel fabrication facility. The system provides active aid to human operators and protects them from radioactive hazards.

Fig.10: Robotic system installed at PFBR fabrication facility.

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