Robotic Workstation for Safe Ladle Sliding Gate Maintenance

Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.

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Steel works are being integrated with new and smart production technologies that promote easy collaboration among all the components of the production chain, i.e., machines, tools and human operators, and smart services, which are essentially composed of the infrastructure allowing system integration along the manufacturing chain and smart energy management, allowing for increased energy efficiency.

This change is expected to have a positive impact on workers' health and safety, which is a main target for the iron and steel industry. The objectives of occupational safety and health management are:

- Protection of workers' health and safety in both the short term (i.e., prevention of accidents) and in the long term (e.g., elimination of physical stress that can cause musculoskeletal disorders, and the reduction of mental stress or repetitive tasks that can induce alienation and psychological distress, etc.).
- Improvement of working environment and safety conditions.
- Promotion of a work culture that supports health and safety.
- Cycle time reduction and efficiency increase.

Development

Robotics is already applied in the steel industry to replace human operators in cumbersome or repetitive operations.

The latest evolution of robotics aims to establish a more active human-robot cooperation in order to combine the abilities of both operators and robots by overcoming their limitations. The main strength of the so-called "symbiotic human-robot-cooperation" lies in the combination of robots' ability to achieve high productivity in structured environments and humans' ability to quickly self-adapt and react to unstructured environments. Within this paradigm, human operators are mostly devoted to tasks requiring sensitivity, advanced sensing, and reasoning capabilities to react to unplanned, unforeseeable or ever-changing situations, while robots exploit their ability, e.g., to handle high loads with high precision without depletion or to face harsher and potentially harmful tasks. Such a paradigm requires that robots and operators safely share the same workplaces, tools and fixtures, and leads to benefits from both the operational and the economical side. In effect, the collaboration of robots and humans in the same loop reduces the need for investments in expensive equipment and complex software, supporting the robot in coping with an unstructured environment. On the other hand, the robots can carry out heavy and repetitive works, which represent a "waste" of the human abilities and expose the operators to potential risks to their health and safety.

In many areas of today's steel works, the implementation of human-robot cooperation is more difficult with respect to the other industrial sectors due to adverse environmental conditions. High temperatures, dust, emissions of hot offgases and steam, very variable light conditions, presence of toxic and/or aggressive substances, and huge dimensions of machinery and workpieces represent obstacles for the application of traditional robotic cells. The maintenance of the ladle sliding gate and cleaning or replacement of its refractory components is emblematic in this respect. Within such project, a robotic workstation has been specifically designed and applied to support the maintenance operations of the sliding gate of the ladle in a real industrial context.

The Robotic Application

The maintenance of the sliding gate is a complex operation of paramount importance to ensure safe and smooth operation in the steelmaking area. This device is placed on the bottom of the ladle and allows the liquid steel to flow from the ladle to the tundish of the continuous casting machine. The robot picks and places the different tools from the warehouse in order to inspect, extract and replace the different refractory components.

The tools, which are handled by the robot, have been specifically designed and engineered, also based on suitably modified commercial components. They are used to handle the oxygen lance tool, to remove and place the two plates, to extract and place the internal nozzle, and to spray the graphite on the refractory nozzle head. On the other hand, the application on the refractory components of the mortar, which ensure adhesion to the metallic components of the sliding gate, is not performed by the robot but is performed by the operator. This operation does not require proximity to the ladle bottom: the operator can apply the mortar when the refractory component is located on the support by remaining inside the pulpit and opening a window while the robot is disabled for safety reasons.

The need to pick and release different tools by connecting and disconnecting each of them implied the development of different systems to allow communication and interaction with all the devices present on the tools themselves. A wireless solution has been selected to this purpose, as it is more suitable to cope with the harsh environmental conditions. The reason lies in the fact that, in the long term, the presence of particles compromises the functionalities of the connectors, which should be used for a wired technology by preventing the tools' proper operation.

The Vision System

Among the tools, the so-called "vision tool" (Fig. 1) is of particular importance, being a fundamental component of the vision system, which equips the robotic workstation. The vision tool incorporates a 2D vision camera and a 3D laser scanner with red blade AT Compact Sensor, which is a 3D sensor with integrated laser line generator.

The vision tool is handled by the robot to perform all the preliminary and intermediate inspection operations (Fig. 2), which are needed for the completion of the whole maintenance sequence.

Command Pulpit

The command pulpit is in an air-conditioned container and houses a touch screen for the human-machine interface (HMI), a panel hosting the commands for the device which sustains and rotates the ladles, and two screens depicting the outcome of the different inspection operations (Fig. 3). The pulpit is equipped with a window that allows the operators to view the operations.

Moreover, a secondary vision system is positioned externally to the cell and is composed of four cameras and a video recorder that sends the images to the monitor inside the pulpit by jointly recording them. This can allow checking former videos whenever needed. The four surveillance cameras are located in the robotic cell in order to allow operators and technicians to monitor all the sections of the robotic cells without blind spots. A top model for the cameras has

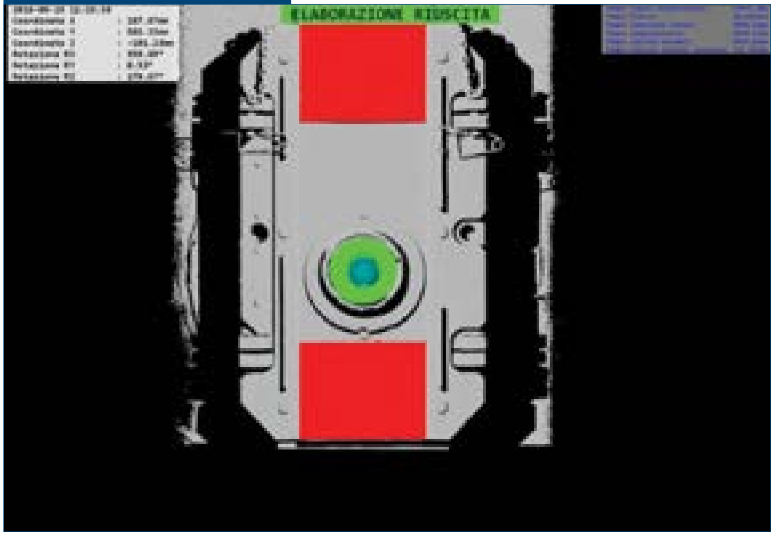
Figure 1

Vision tool.

Figure 2

Oxy-lance cleaning cycle.

Figure 3



3D machine vision scan.

Figure 4

Human-machine interface.

been selected that comes equipped with a 4 MP sensor that allows for a very high resolution and the capture of all the detail of the performed operating cycles.

The benefit of this additional monitoring system lies in the consideration that the diagnosis and solution of a problem in some cases could be very difficult without having a direct "vision" of the actual performance of the robotic cell.

The Human-Machine Interface

The HMI allows the operator to control, execute and view all the operations developed by the robot. Such interface is accessible through a 21.5-inch touch screen placed in the pulpit, while the images recorded by the primary vision system as well as the outcomes of the image processing are displayed by panels located above the window of the pulpit.

Conclusion

A fully engineered robotic cell has been presented that supports the operators of the steel shop in the critical operation of maintenance of the ladle sliding gate. The development of such workstation required ad-hoc design of mechanical components and specific software developments, including artificial vision and a smart HMI. The robotic cell is successful in relieving the operators from several cumbersome operations, therefore contributing to the improvement of workers' health and safety protection in the steel shop. Relevant benefits are also expected in the improved repeatability and traceability of the whole maintenance operation as well as in the improvement of ladle maintenance cycle time.

Future work will be targeted to improving the automation level by means of an ad-hoc design of the sliding gate to fully exploit the robotic support to the maintenance operations.

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Reference

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