European Commission

Research Programme of the Research Fund for Coal and Steel

Technical Group: TGS 9

Consistent ladle tracking for optimisation of steel plant logistics and product quality

TrackOpt

Public

Birgit Palm, Bernd Kleimt
VDEh-Betriebsforschungsinstitut GmbH (BFI)
Düsseldorf, Germany

Alberto Viotto, Loris Bianco, Matteo Chini, Daniele Gaspardo
Ferriere Nord S.p.A. (FENO)
Osoppo, Italy

Grant Agreement Number: 753592

01.01.2018 – 31.12.2021

Deliverable 2.1 – Ladle tracking system in reliable operation at steel plant

Due 06 / 2020
Lead beneficiary: FENO

Table of contents

		Page
Project summary		2
1.	Installation of tracking system in industrial environment	3
1.1	Installation of ladle tracking system (Cameras and plates)	3
1.2	Installation of ladle tracking software and connection to process control system	13
2.	Operational trials with the developed tracking system	15
2.1	Testing the acquisition and storage of ladle tracking data	16
2.2	Testing the automated check in and check out of ladles	16
3.	Summary	19
4.	Next steps	19

Project summary

The project will implement automated ladle tracking systems to ensure consistent factory-wide tracking of the product from steelmaking via casting to delivery. The wireless tracking system in harsh steelworks environment will provide mandatory input data for projects on digitalisation (“Industry 4.0”). Automated, reliable information on actual position of ladles result in increased factory output (avoided hold-ups or downgrading of products due to mix-up of ladles) and in improved safety in steelworks. Furthermore the ladle tracking system will be used to optimise ladle logistics during both smooth production conditions and in case of sudden disturbances in production plan.

1. Installation of tracking system in industrial environment

1.1 Installation of ladle tracking system (Cameras and plates)

The first step for the supplier was the definition of 12 different configurations of the plates that are square size with a length of 400 mm. For each of them, there are three markers placed on the corner of the plate. They are useful for the work of the detection; in other words, they suggest to the algorithm the position and even the orientation of the plate inside the recorded scene by the OC.
Once the position of plate within the picture has been defined, the deterministic position of the 13 holes is the encoding of the identifier of each ladle. As an example, four configurations for the ladles are shown in **Figure 1**.

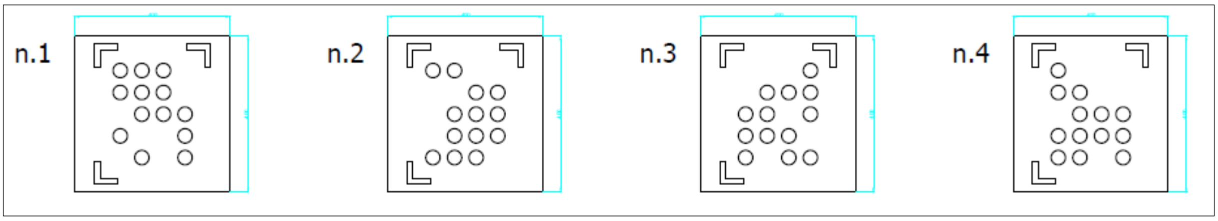

Figure 1: four examples about a unique encoding for the corresponding ladle identifier

Before the effective installation of the pattern recognition system at the plant, the supplier carried out some laboratory tests. The aim of these trials was the highlighting of potential weaknesses of the algorithm developed in Python.
The supplier has recreated the appearing of the plate in the recorded scene using a dummy one, similar to the real case. It performed the trials using different distances between the camera and the dummy-plate. Those varied according to the distances in the plant between 3 and 13 m.
It is clear that the controlled environment of a laboratory is quite different than a steel plant, but the first outcome was the changing of the markers in terms of thickness. In the first draft, that markers were smaller thus the rate of successful detection was not enough.
Operating in this way, several scenarios have been tested. For example, the plate has been rotated along the optical axes of the camera and the algorithm works fine up to 15°. For that case, using the markers, the system can detect the angle and automatically corrects it.
For each camera, a specific region-of-interest (ROI) about the acquired frame has been defined. This is the area when the plate will be stable for detection and recognition. Using a morphing matrix, the system becomes robust enough to manage the rotation of the plates along the horizontal and even vertical axes.

The other possible issues regarded by the optical monitoring in a steel plant are related to the lighting changing. For each camera the lens aperture, the shutter speed, and the gain are static. The system can detect the minimum and the maximum brightness values within the ROI. Using these two values dynamic thresholding is also possible.

The supplier provided to FENO the camera already calibrated for the thermographic applications. A graphite cylinder has been used for that calibration. This tool has a cover with a smaller hole than the diameter so that it simulates a black body. The height of the internal chamber is 35 mm, the external diameter is 40 mm and the diameter of the hole is 10 mm. The cylinder has been placed into the well of an electric heater by filling the empty spaces with quartz sand suitable for homogenizing the thermal bath.
The procedure involves setting the temperature on the well in a range from 100°C to 450°C in 50°C steps. At the same time, with the software developed in Python, the images are acquired and the maximum spot and dark area are measured (**Figure 2**).

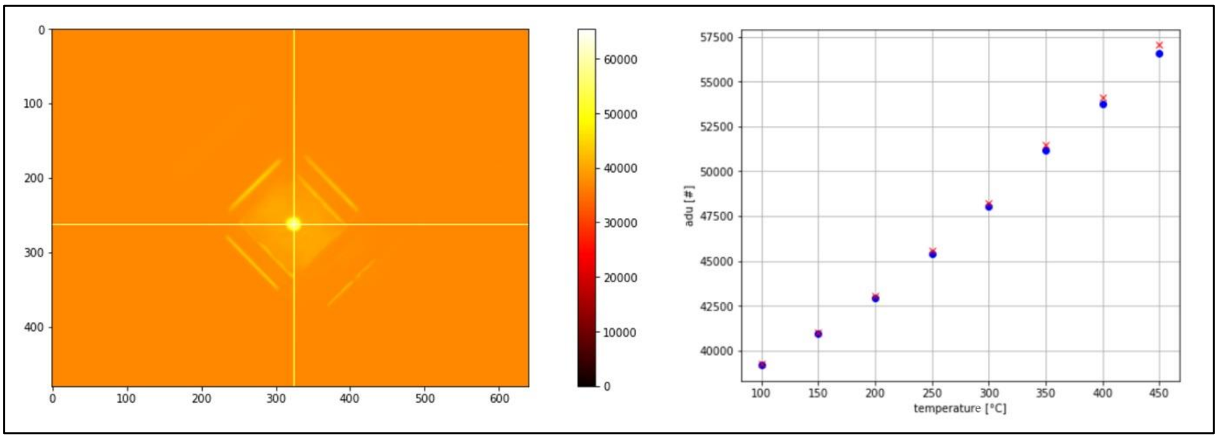

Figure 2: step of calibration for IR images (left); checked the matching between temperature and value acquired (right)

The purchased cameras are the following: six optical and one for infrared. For the first group, the chosen model was DALSA C1920. This is a colour camera that has a Sony IMX249 CMOS sensor for a maximum resolution of 1920 x 1200 pixels. The acquiring frame rate is up to 39 fps (frame-per-second) and it supports the GigE Vision Interface with a connectivity of 1 GBps. Instead, the IR camera is a Xenics LWIR 640 with a maximum resolution of 640 x 480 pixels. In this case, a less resolution, provide us a greater frame rate quantified up to 50 fps. For that camera, the GigE Vision Interface with a connectivity of 1 GBps is also available.

The specific lens for each camera depends on the distance to the target that is the plate on the ladle. The overall scheme in which the cameras are placed into the FENO's layout is shown in **Figure 3**. For the seven cameras (6 OC and 1 IR) below are shown the distance involved and thus the most suitable lens for each position:

1. **Ladle waiting (heating) or after tapping**. Distance to the target: 9 m; Lens: 50 mm
2. **LF load/unload**. Distance to the target: 13 m; Lens: 75 mm
3. **CCM waiting**. Distance to the target: 7.5 m; Lens: 50 mm
4. **CCM unload**. Distance to the target: 7.5 m; Lens: 50 mm
5. **Horizontal ladle heating east**. Distance to the target: 3.5 m; Lens: 25 mm
6. **Horizontal ladle heating west**. Distance to the target: 12 m; Lens: 75 mm
7. **IR at the LF**. Distance to the target: 3.5 m; Lens: 18 mm

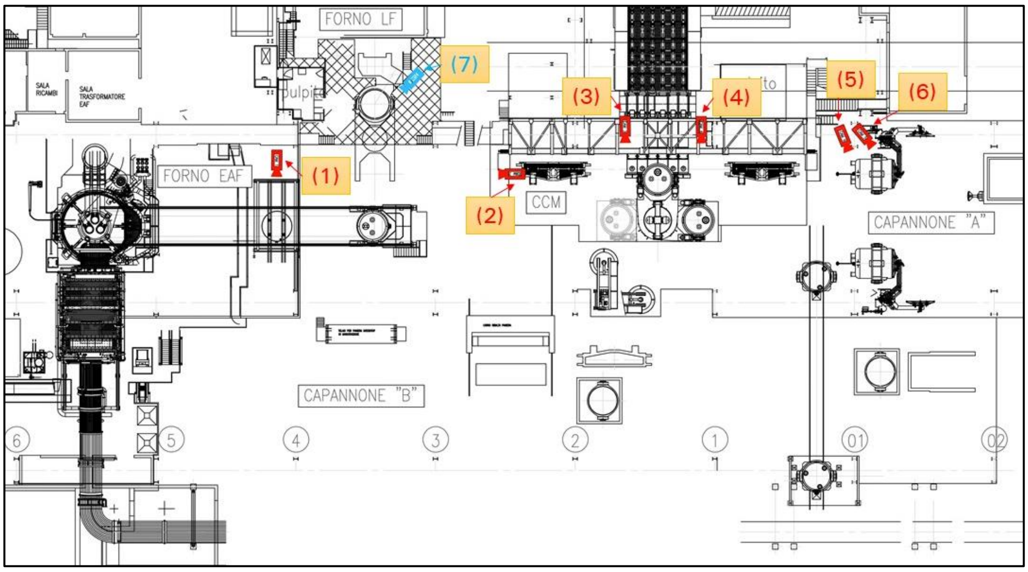

Figure 3: the 6 OCs are highlighted in red, the IR in blue

Introduction of a protection box has been quite mandatory to overcome the challenge with mechanical stress, heat radiation and dust that will affect the camera. In **Figure 4** is shown the case for one OC and a compressed air inlet is available against dust and partially for cooling.

Figure 4: a protection box has been introduced to challenge against dust and partially against heat

The process of installation of the plates on the ladles has reached the full coverage at mid-July. At the FENO's plant, there are 10 ladles 5 of which are usually active in the process. Every ladle remains in the cycle for 15-20 days and after that, it is under maintenance. Only during this latter phase, the task of the welding of the plates can take place. The pair of plates has been welded on both sides of the ladle at each handle.
For obtaining a greater contrast between the plate and the ladle where it is placed, those plates have been painted with white colour. In order to increase that contrast between the holes and the plate, a further improvement was the painting of the ladle surface where the plate is installed with black colour. The final configuration is made by a black colour background on which there is a plate painted in white.

The task of installation of the cameras at the plant has been completed. FENO has successfully installed all the OCs by early July. Thus, all electrical and network connections have been completed. The prearrangement of the wall brackets, as a support for the cameras, has been performed. The initial choice was to connect all the OCs to the compressed air mainly to remove the dust on the lens and to help the cooling of those cameras. These cameras are those near the CCM (waiting/unloading) corresponding to position #3 and #4. For the OC case, the contribution of the air to the cooling is not so relevant as expected. Meanwhile, it has been observed that the combination of a very dusty and hot environment as a steel plant and compressed air, can lead to the opposite effect with regard to lens cleaning.

Regarding the IR camera (pos. #7), because of its position near the LF, the scheduled installation had to be performed only during the periodic plant maintenance stop (almost every 15 days). FENO has completed the required preparational tasks for the installation of that camera (see **Figure 5**) thus the connections regarding the data and electricity. For managing the issues related to the critically high temperature in which the device is operating, cooling using air and some special shields have been introduced (see Figure 5).The cooling system has been also upgraded using a Vortex tube to improve the cooling by compressed air. Since the demanding tasks have been done, the final connection of the IR camera was realised in mid-July.

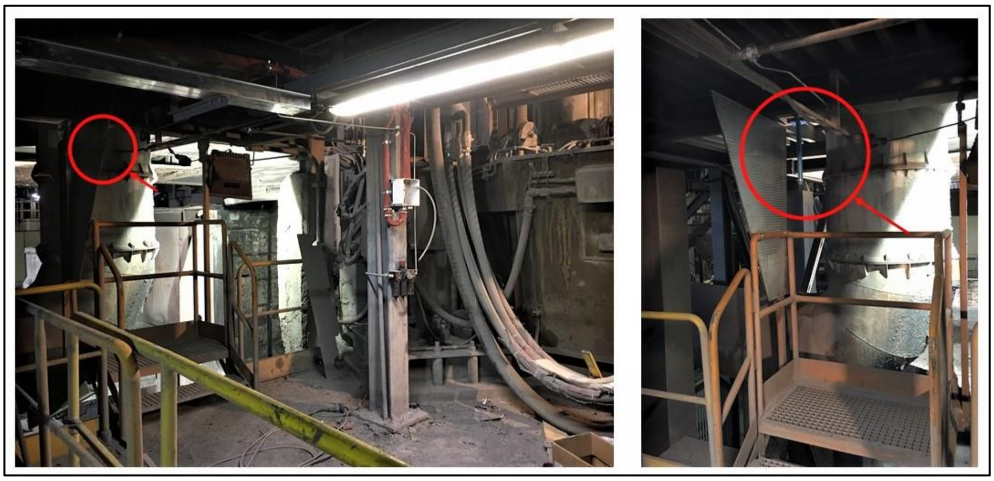

Figure 5: position for IR camera with cables isolated for granting a data and power connection (left), highlighted position of the camera is protected using a special protection shield (right) and cooled using Vortex tube (position #7)

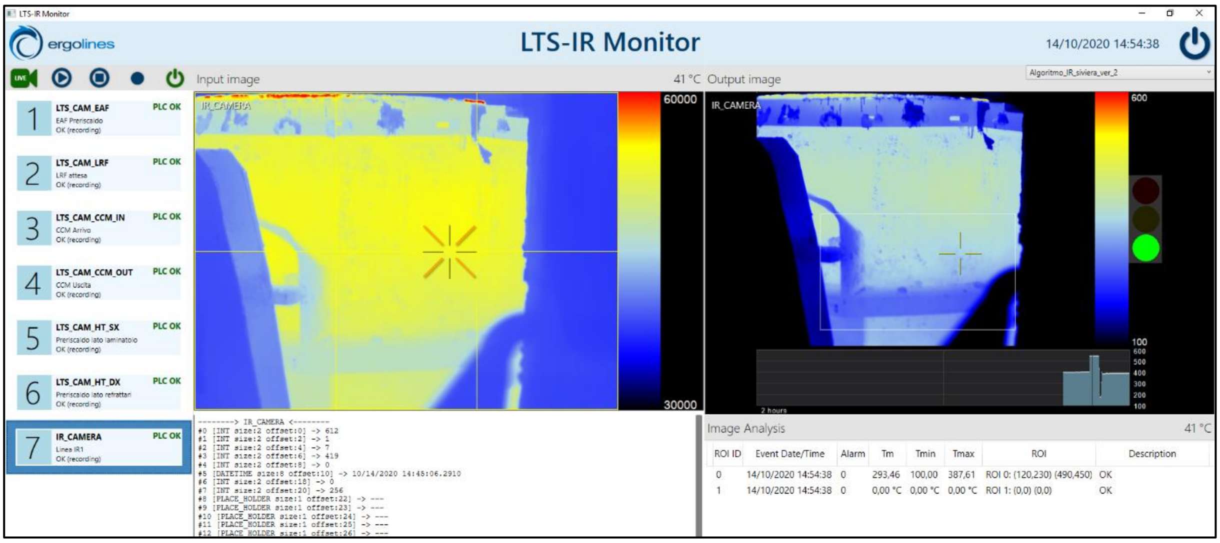

Figure 6: a screenshot of "IR at the LF" (position #7)

During the deployment of the software provided by the supplier, some bugs have been found. In particular, the issues were not related to the algorithm for the detection and decoding of the plates but mainly to the correct way to manage the dataflow of the cameras. This has implied the step-by-step connection to the PC-Server of one camera at a time. For that reason, the installation started only with the OC related to position #2 (LF load/unload) (**Figure 9** and **Figure 10**).To avoid any networking problems, after a week of testing all the other OCs have been put online. The last camera installed was the IR because of the high demanding task due to the nearby to the LF (**Figure 19**, **Figure 20** and **Figure 6**).

According to the layout shown in **Figure 3**, for a better understanding of the scenes monitored by the OCs and IR camera, below are reported the field-of-view of the cameras involved. There are also provided the pictures regarding the appearance of the different cameras.

Figure 7: view from “Ladle waiting (heating) or after tapping” (position #1)

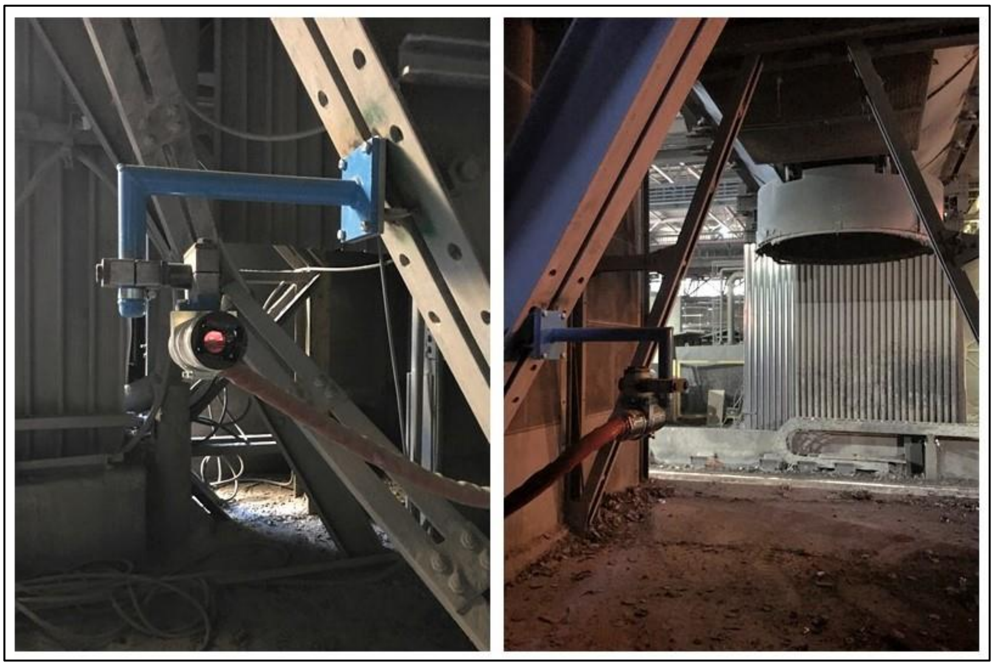

Figure 8: OC for monitoring “Ladle waiting (heating) or after tapping” (position #1)

Figure 9: view from “LF load/unload” (position #2)

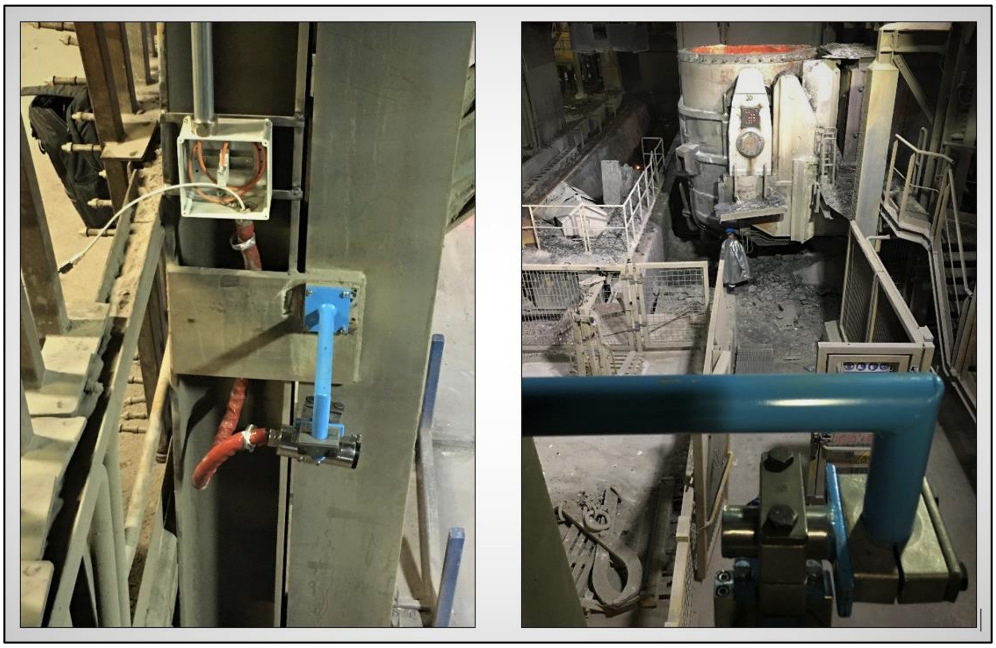

Figure 10: a picture taken during the installation of the OC (left). The field-of-view of and with the OC at the position #2, LF load/unload (right).

Figure 11: view from "CCM waiting" (position #3)

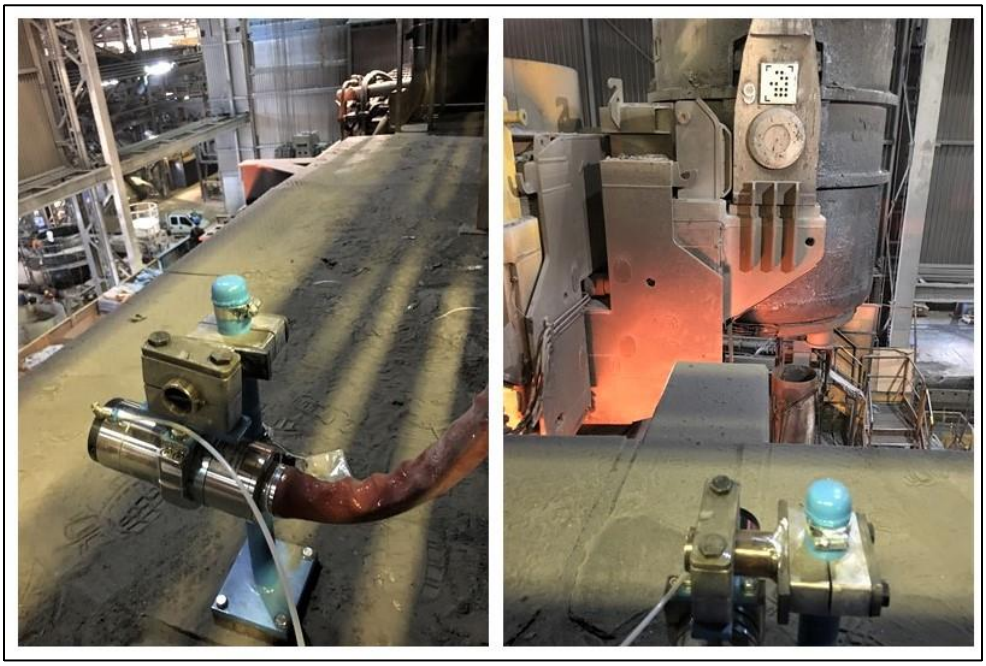

Figure 12: OC for monitoring "CCM waiting" (position #3)

Figure 13: view from “CCM unload” (position #4)

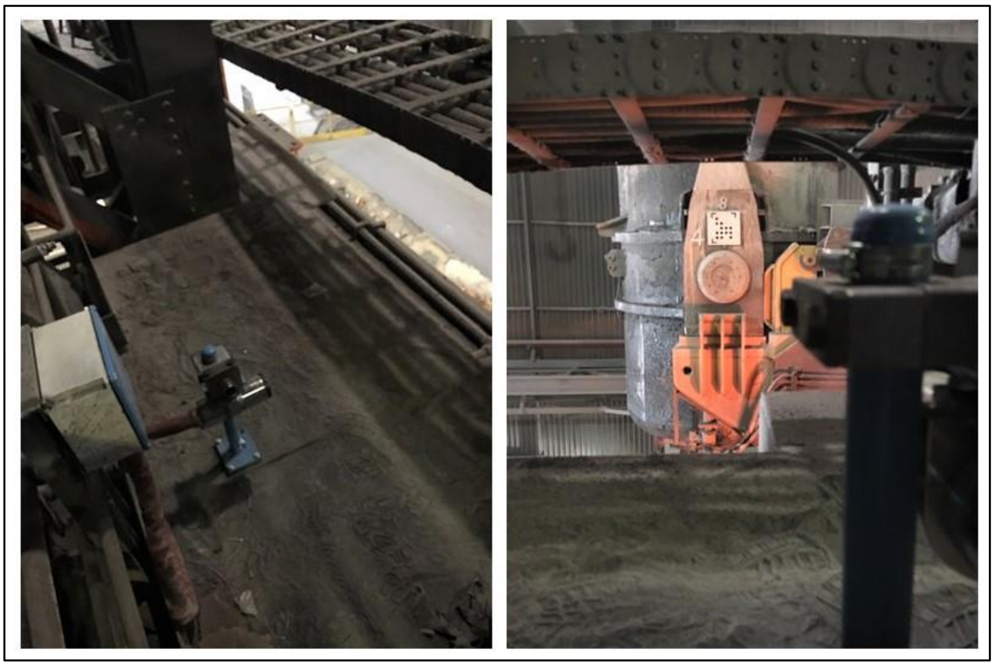

Figure 14: OC for monitoring “CCM unload” (position #4)

Figure 15: view from “Horizontal ladle heating east” (position #5)

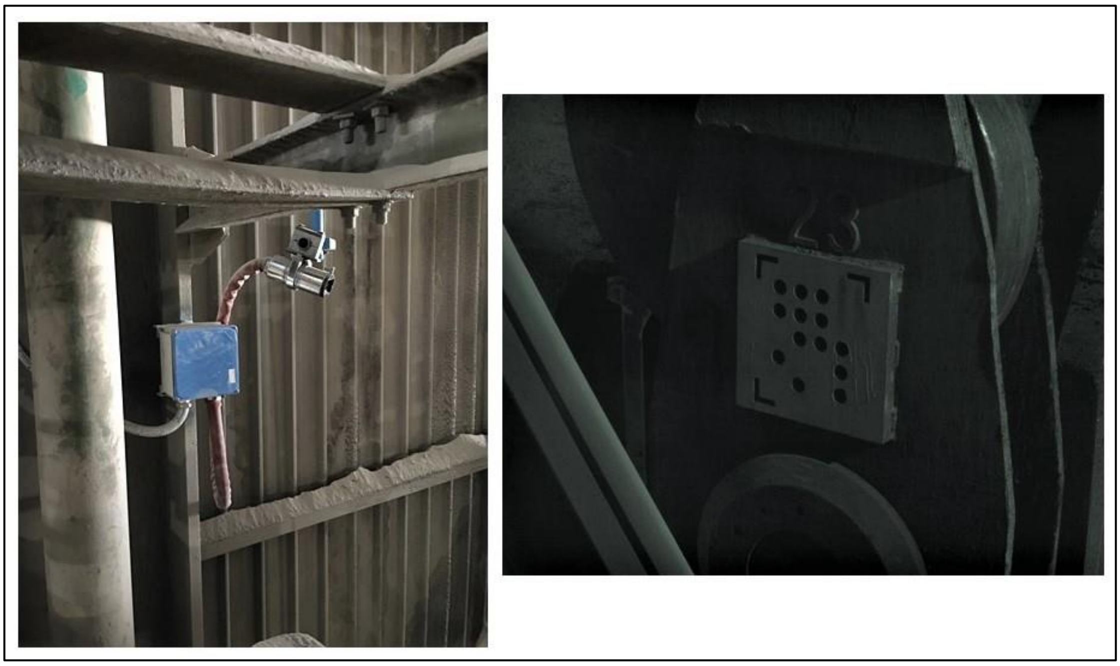

Figure 16: OC for monitoring “Horizontal ladle heating east” (position #5)

Figure 17: view from “Horizontal ladle heating west” (position #6)

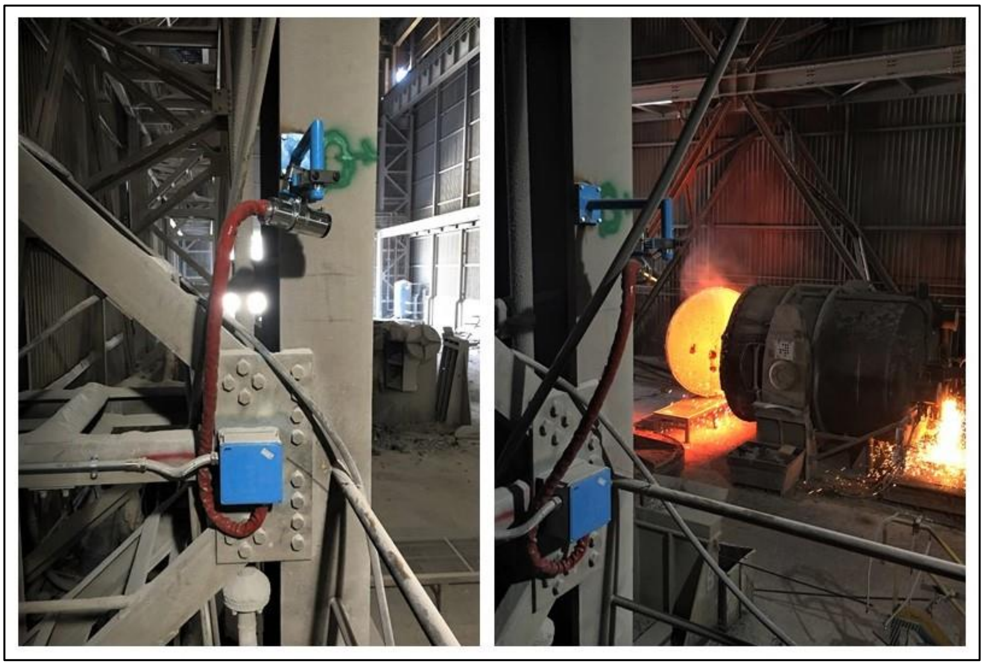

Figure 18: OC for monitoring “Horizontal ladle heating west” (position #6)

Figure 19: view from “IR at the LF” (position #7)

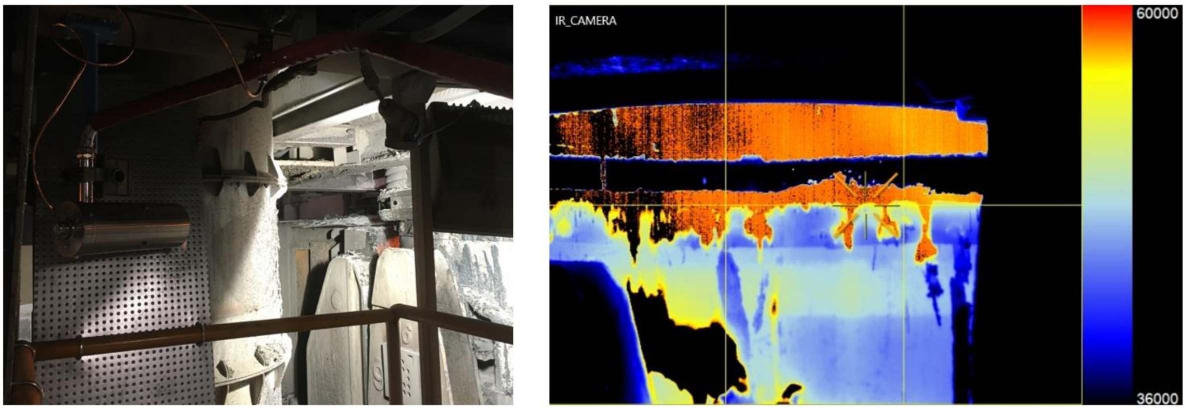

Figure 20: IR camera (position #7); first layout tested (left); first IR data flow acquired (right)

1.2 Installation of ladle tracking software and connection to process control system

A new PC-Server has been introduced to collect the dataflow from the six OC and IR. For this purpose, it has been chosen with connectivity of 10 Gigabit (**Figure 21**). For a full integration to the FENO's systems, it has been designed to communicate with the PLC of the plant. In this way, the ID and the timestamp of every recognized plate are stored in a database and the integration of the information provided by the Level 2 is also possible. The fusion of these two data sources provides the history of every ladle and is suitable for effective optimization of the ladle logistics.

Figure 21: a picture of the PC-Server

The supplier provided a software platform with two main parts: collecting the raw images from the OCs and decoding the plate configuration into the ladle identifier. The software is also able to collect the thermographic information about the ladle at LF coming from the IR-camera.

As mentioned in chapter 1.1 some issues regarding the connection of the OCs to the data network of the plant have been found. Since the introduction of the system, an appropriate acquisition frequency was an important parameter to be defined. The choice of such factor is a trade-off between the amount of dataflow sent to PC-Server and the minimum level of information to effectively detect and recognize the plates.

FENO started the video capture using a rate of 10 fps (for first test and validation), then reduced to 2 fps. During the trials, FENO demonstrated that a dataflow rate of 0.5 fps is sufficient for the recognition. Similarly, 1 frame about the thermographic status of the ladle every 2 seconds is enough to monitor its thermal trends. In these evaluation steps, particular attention was focused on Machine Vision aspects such as quality of the frames captured by the camera and fine-tuning the acquiring parameter of the device such as gain, contrast, white balance, etc.

Every raw image collected and stored into the PC-Server is processed by the software provided by the supplier. At this moment on the FENO machine, there is installed a beta-version of that software. Regularly FENO provides the new recorded image to the supplier on which it is performing the fine-tuning of the algorithms.

The application LTS-IR Monitor has been developed in Python and it works as shown in **Figure 22**.
In this case the OC is monitoring the LF load/unload (pos. #2). The left box is represented the live stream of the camera in which the yellow cross is referred to as the fixed ROI (Region-Of-Interest) calibrated and customized for every camera. This is the area when the detection task is performed. Using several Computer Vision tools the software tries to find the three markers that identify a plate. Once these markers have been found, the decoding phase can start. The outcome of that algorithm is shown in the box of the right where there is an artificial representation of the plate. In the middle of these boxes, surrounded by a green circle there is the decoded identifier. As a next step, this information is also sent to the PLC, then collected into a database including the timestamp and the OC that is referred to.

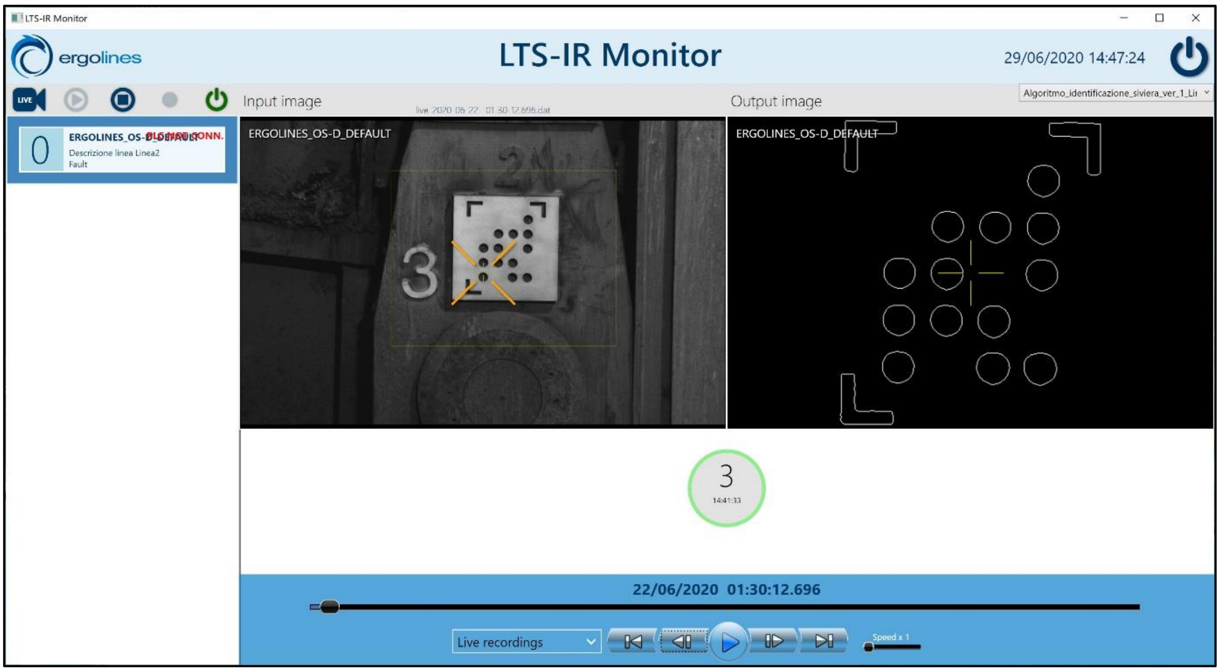

Figure 22: an example of the software, the identifier of the ladle #3 is retrieved from the corresponding plate

The connection of the software to the data plant network is only in the first step. As mention before, for debugging the raw images collected are stored in the PC-Server and every 36 hours are overwritten. At the same time, every event recognized by the software is appended in a log file. The aim of that file was concerned with the checking of the timing of every decoding. From the beginning, this task seemed complex and difficult to apply. For its concrete application, the next step must be the complete integration of the developed system into the process control system.
In this regard, a second step was performing to the full and effective integration of the software in the FENO's network. The software communicates in a proper way with the PLC. In this stage, the automation of Level 2 of the plant reads that information and stores them in an apposite data structure. The final step is the integration of the information coming from the LTS with those from Level 2 that are useful and informative for the tracking of the ladles. FENO has defined which are those variables and communicated them to the Level 2 supplier for an alteration of the automation of the plant. The supplier will provide soon a database for the storage of the information to an effective tracking.

Besides the definition of the dataflow for OCs, similarly those regarded the IR-camera has been defined. The data concerning the temperature trend are sent to PLC and then stored in the database.

2. Operational trials with the developed tracking system

First trials were performed as a "warming-up" of the system. Using the one installed camera, FENO checked the connection of the acquired raw images, and thus the effective dataflow to the PC-Server. In this case, the correct decoding of the plate into the corresponding ladle identifier was validated for two ladles that had the plate installed of 5 ladles that are in the plant cycle.
Additionally, FENO collected pictures and after three days of recording, all the images were sent to the supplier of hardware and software. Using this data, the supplier fine-tuned the system for the plates seen in the acquired images. In every upgrade, the supplier has provided to FENO a stronger and more reliable version of the software for effective identification of the ladles.

After the first period of trials, a couple of times it happened that for different reasons (i.e. temporary dust or slag on the plate) the required contrast in the capture frames was missing. It could be due to a coverage of one or more holes of the plates or due to a layer on the plate concerning a slag leakage (or dirt).

To overcome those cases the algorithm has to be sufficiently strong. A prior solution was a designing of the 12 configurations to be different enough from the others. As an upgrade of the software, the supplier delivered to FENO a version with a more robust algorithm that is able to decode the plate configuration although at most three holes are covered or the required contrast is less than usual. In **Figure 23** there is the case of a plate successfully decoded into an ID although a slag leakage on it.

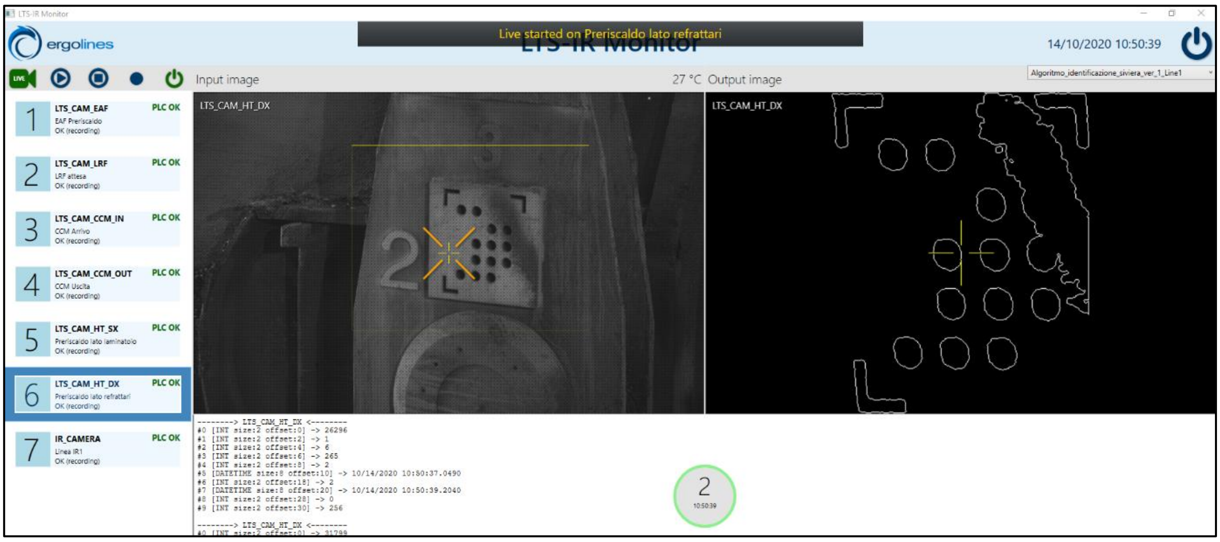

Figure 23: case of a critical plate successfully decoded (position #6)

2.1 *Testing the acquisition and storage of ladle tracking data*

After the warming-up of the system with the dataflow coming from one single camera, all the remaining OCs have been networked. Following a proper configuration, the dataflows are managed by the PC-Server. The LTS-IR Monitor is, therefore, able to process these live streams. This is the part in which the decoding task is operating. As mentioned above, if recognition of a plate is successful the information (timestamp, ladle ID, and OC identifier) are sent to the PLC. In any case, the images of each camera are also stored in the PC-Server. For the very first initial phase of debugging, FENO defined a configuration with a sampling rate of 10 fps for each OC while the data are stored for almost 12 hours, then overwritten.

The final acquiring settings have been defined to a framerate of 0,5 fps and historical storing of 36 hours. That latter service would be removed when the database storage will be reliable and online.

The behaviour of the software will be continuously monitored also in the future and FENO is in regular contact with the supplier to overcome possible problems.

2.2 *Testing the automated check in and check out of ladles*

The first analysis of the input/output of the LTS-IR Monitor, the software for decoding the plates and providing the ladle ID, has highlighted the challenging conditions in which the OCs are operating. In the following are reported the screenshots related to each OC.

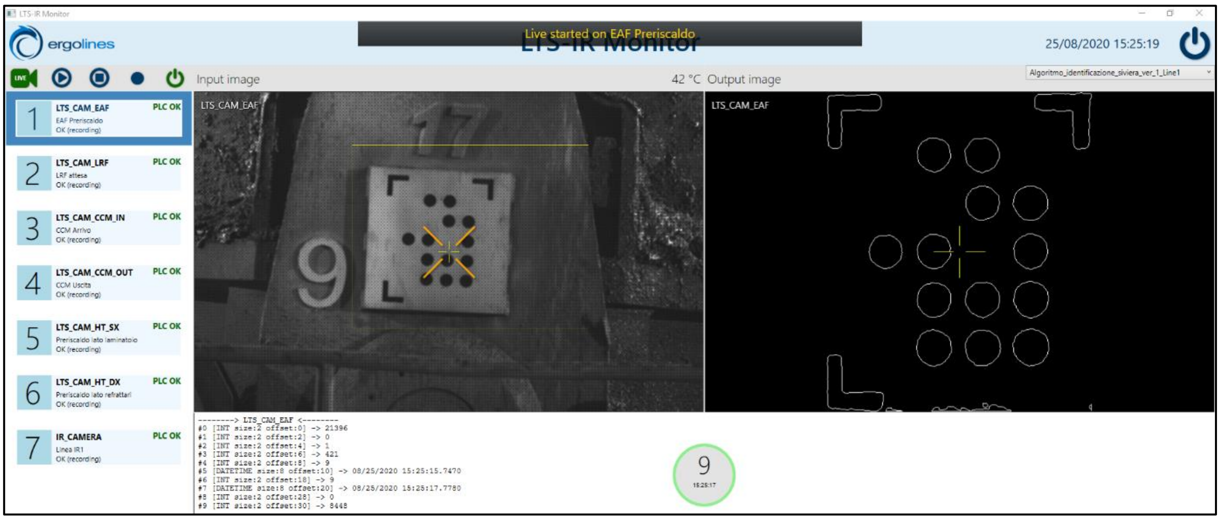

Figure 24: a screenshot of “Ladle waiting (heating) or after tapping” (position #1)

Figure 25: a screenshot of “LF load/unload” (position #2)

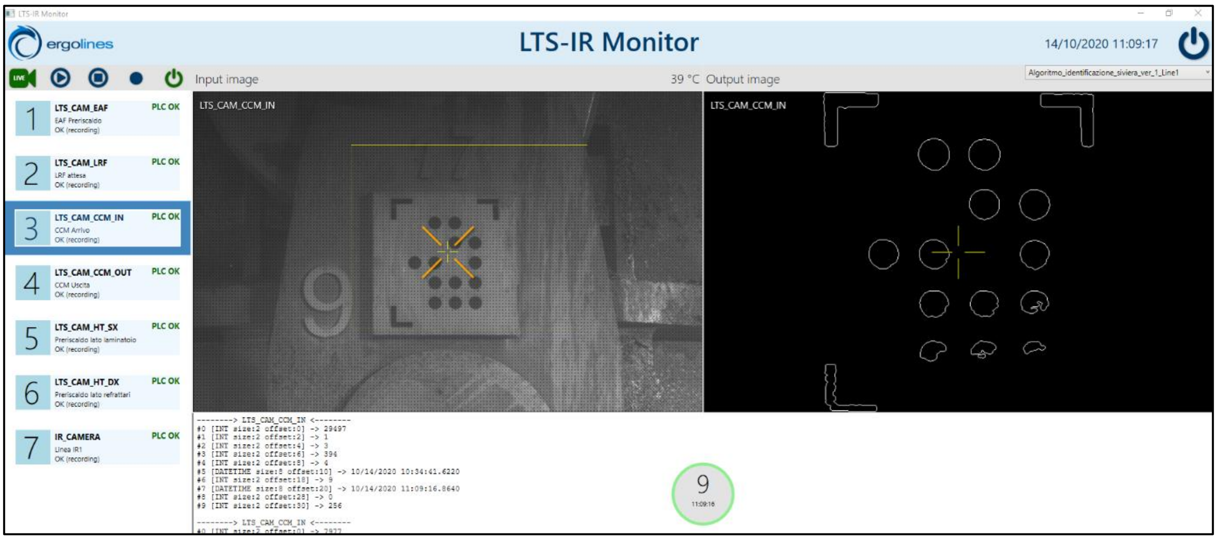

Figure 26: a screenshot of “CCM waiting” (position #3)

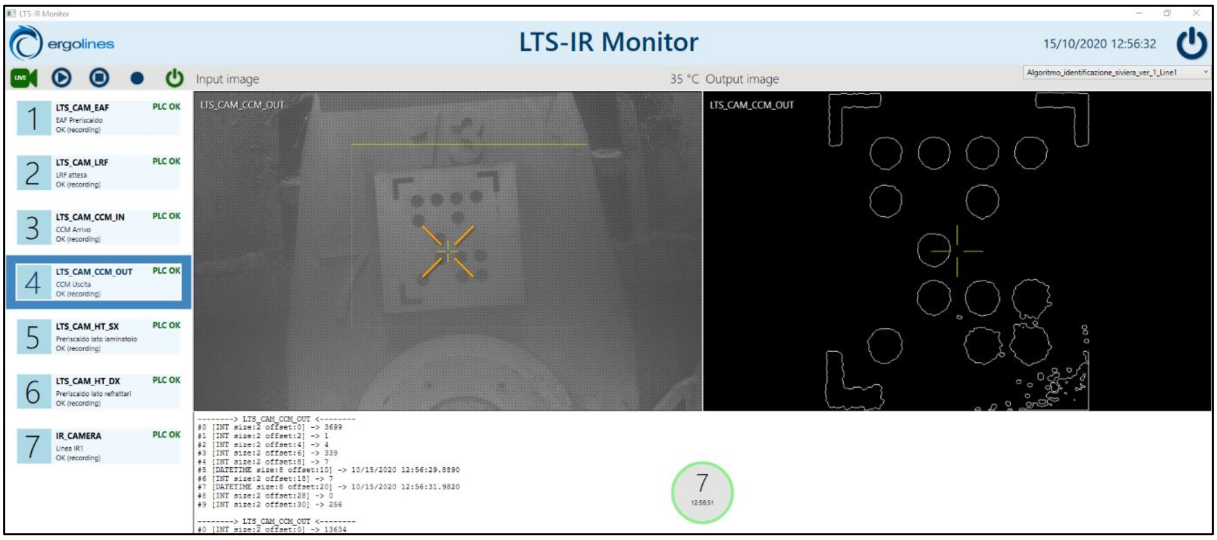

Figure 27: a screenshot of “CCM unload” (position #4)

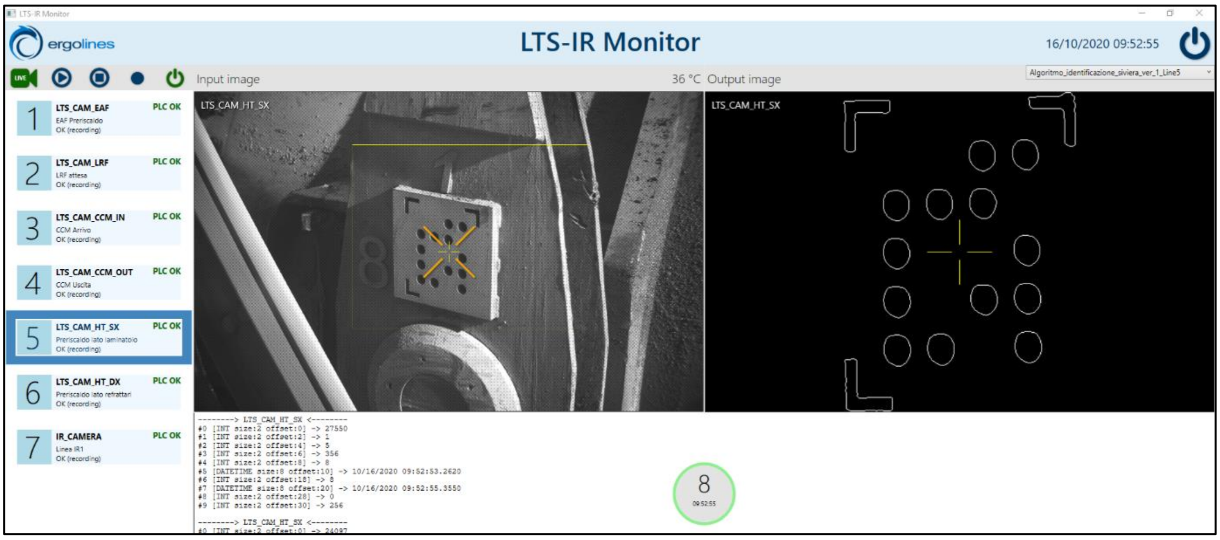

Figure 28: a screenshot of “Horizontal ladle heating east” (position #5)

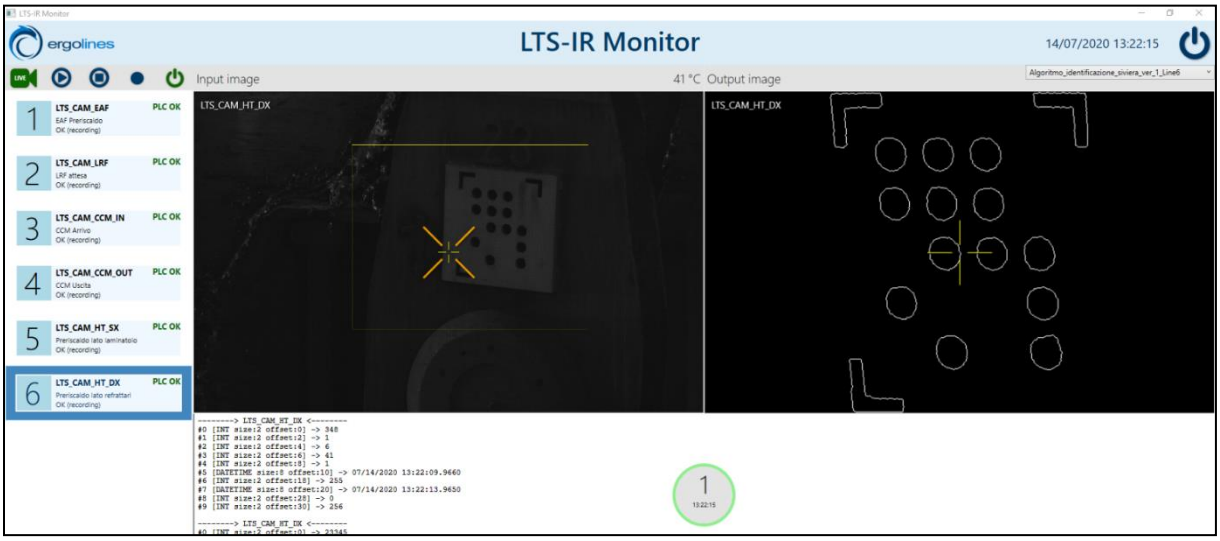

Figure 29: a screenshot of “Horizontal ladle heating west” (position #6)

Analysing the behaviour of the software, the case related to position nr. 2 (LF load/unload) is the easiest to manage (Figure 25). FENO observed a very high rate of successful identification of the ladles at that position.

For the other optical cameras, the first outcomes have suggested the introduction of two different strategies to improve the quality of the grabbed frames.
First of all, the brightness of the acquired pictures is a relevant factor to be considered. To obtain a correct balancing of the lights, FENO has manually increased the aperture of the lens of the involved OC considered the different environmental conditions during the day and night. The second way was at the software level. It has been demonstrated that LTS-IR Monitor works well when the plate appears not rotated within the ROI (in the pictures, the rotation regarded the horizontal and vertical axes; this is not the optical axes of the camera). To overcome this, a proper morphing coefficient has been introduced to obtain an automatic adjustment regarded the rotation of the frame (see also chapter 1).
FENO has provided several weeks of recorded data to the supplier. For each camera, the implementation of the corrected coefficients corresponds to a continuously upgraded version of the software parameters. A tailored ROI for each OC is also mandatory for obtaining of the correct decoding.

After this first step of the software check (correct decoding of the plates), FENO has started to perform long-term trials. When the supplier will install to FENO the altered version of the Level 2 automation, the whole system will be stable and the checking of the timing of the detection will be performed. This will be a demanding task that provides a measure of the reliability of the system by checking the information collected by the new tracking system and those coming from Level 2 automation.

3. Summary

At FENO steel plant all the plates with the individual identifying code and all seven cameras were installed. The installation of the software for identification of the ladle was also completed. The installation was finalised regarding:

- Plates: mid-July
- OCs: early July
- IR: mid-July
- Connection with PLC and data storage on DB: mid-October
- Data integration with Level 2: mid-November

The software collects the raw images from the cameras and decodes the plate configuration into the ladle ID.
As described in the previous chapters the final installation of hardware has been completed and the testing of software was done. Some tasks regarding the software testing are in progress, as it will be improved throughout the project. After a few months of operating, all the plates are quite fine. The identification of the plate is active and working well in industrial conditions.

4. Next steps

The next step will be to carry out further long-term trials over some months to record tracking data of ladle heats for optimisation of the tracking system and logistic in following WP3 as well as for evaluation in WP4.