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Automated Workplace of a Sheet Rolling Shop Operator: A Web Application for Monitoring Sheets Based on Computer Vision

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***Abstract*—The article discusses the development of an automated workstation (AWP) for a sheet rolling shop operator based on a web application using computer vision technologies. The proposed solution is aimed at increasing the accuracy of monitoring the movement of metal sheets, reducing the influence of the human factor and minimizing equipment downtime. The system features the following: integration of computer vision algorithms for detection and tracking of sheets in real time; visualization of the production process through an interactive mnemonic diagram with color marking of melts; two-way data exchange with industrial equipment via a JSON interface; a mechanism for handling abnormal situations (overlapping sheets, loss of marking); a web interface with differentiated access for operators and administrators. The technology stack includes Django (backend), PostgreSQL (storage of movement history), JSON data structure, Redis. The developed solution complies with the Industry 4.0 concept and can be scaled to other areas of metallurgical production.**

Keywords—automated workplace, web application, sheet metal rolling mill, industrial visualization

I. Introduction

In modern sheet rolling mills, the key problem remains the insufficient efficiency of control systems due to outdated technologies [1,2].

Laser sensors fail at high temperatures, requiring frequent repairs and manual intervention by operators [1]. As studies have shown, under operating conditions under the 2800 mill, the average service life of laser scanners is reduced by 40% due to thermal loads [3].

The lack of a single digital interface complicates sheet flow management, reducing the speed of decision-making [4]. According to the World Steel Association, this leads to losses of up to 15% of productivity during transitions between technological operations [2].

The human factor leads to data entry errors, which affects production accuracy and product quality. Statistics show that up to 12% of defects in sheet rolling are associated with incorrect parameter input by operators [2,3].

These problems can be solved by using an automated operator workstation (AWP) integrated with a computer vision system [5]. As proven in the research of the Research Institute "Metallurgavtomatika", such a solution allows:

- to reduce the number of manual operations by 60% [3];
- to increase the accuracy of parameter control to 99.7% [5];
- to switch from manual control to digital control in real time [4,5].

The latest developments in the field of industrial computer vision (using Siemens SIMATIC HMI solutions as an example) demonstrate the possibility of integrating such systems with existing equipment without stopping production [3,4].

Significant problems are caused by outdated SCADA interfaces, which are associated with functional limitations: lack of adaptive control (static mnemonic diagrams without support for dynamic visualization [6]); manual entry of 60% of parameters (errors occur in 12% of cases) [7]].

Incompatibility with modern standards: limited support for OPC UA (only Classic OPC) [8]; lack of API for integration with MES systems [9].

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There are ergonomic shortcomings: outdated UI/UX (interfaces from the 1990s with >20 elements on the screen [10]; average search time for the required parameter is 45-90 sec [11]); lack of mobility (binding to workstations with Windows XP [12]; impossibility of remote monitoring [13]).

There are operational problems: high demands on personnel (80% of operators over 50 years of age have difficulty learning [14]; the need for paper logs to duplicate data [15]).

The relevance of the development is due to the following.

The transition from outdated laser systems to digital solutions based on machine vision corresponds to the global digitalization of industry and is in line with Industry 4.0 trends [16]. According to McKinsey research, 78% of metallurgical enterprises have included computer vision in their digital transformation roadmaps [17].

Automation reduces dependence on the human factor, reduces downtime by 20-25% and increases control accuracy to 99.2% [18, 19]. These indicators affect the increase in production efficiency.

The economic benefit from the implementation of a web application for operators reduces sensor repair costs by 40% and optimizes sheet logistics in the flow [16]. PwC analysis shows the ROI of such solutions within 12-18 months [20].

Flexibility and scalability lie in the fact that software solutions based on computer vision are easier to adapt to new production conditions (30-50% faster) compared to hardware systems [21].

Thus, the development of a web application for an automated operator workplace based on computer vision algorithms is a pressing task that contributes to the modernization of metallurgical enterprises [16, 21].

Digital transformation of production - the transition to web applications is in line with the trends of Industry 4.0 and digital twins in metallurgy [22]. According to Accenture, 89% of metallurgical companies consider such solutions as key to digital transformation.

Optimization of operator work - an intuitive web interface reduces training time by 60% and minimizes errors by 35-40% [18]. MIT studies show an increase in management efficiency by 25-30%. Reduced operating costs – eliminating laser sensors reduces repair costs by 45-50% and reduces downtime by 30% [16]. BCG analysis confirms savings of $250-400k per year on one mill. Versatility and scalability – the web application can integrate with SCADA and MES systems (92% compatibility according to Siemens [23]), and adapt to new tasks 40% faster than hardware solutions [21].

The purpose of the web application is to create an automated operator workstation system for tracking sheet movements in the 2800 mill flow, which uses innovative computer vision techniques to provide accurate and reliable monitoring of sheet positions without visible markings.

II. Description of the Application

The sheet rolling shop section is a part of the production complex where metal sheets are processed and recorded. The section covers the process from the sheet leaving the marking machine to its entry into the tilter. The main purpose of creating a sheet tracking system in this section is to record the movement of materials and optimize production processes.

The main objects of observation are metal sheets that pass through the section of the shop. Each sheet has certain characteristics recorded by the system at the marking stage. In this section, the marking is invisible, and identification is carried out based on their previous position. The key process in the section is sheet transportation, which involves moving sheets from one processing stage to another, with important aspects being the precise determination of the sheet position. Quality control is carried out at some stages to verify that the sheets comply with established standards.

The main equipment in the section is surveillance cameras installed permanently above the section for continuous monitoring of the position and movement of sheets. The cameras transmit data to the tracking system, providing visual control. To obtain detailed information about any melt, an electronic melt passport is used, containing detailed information about each batch of metal. Data from the cameras is transmitted to the server via API, where it is processed. The collected data is stored in a PostgreSQL database.

The site operators are responsible for monitoring the current state of the sheets and promptly responding to changes in the transportation process, the management has access to the accumulated data for analysis and making strategic decisions to improve production processes and increase the efficiency of the site.

The main automation goals in the web application include accounting for the movement of materials to minimize losses and errors, increasing the overall efficiency of the site through accurate monitoring and timely response to changes. Additional tasks include ensuring the integration of the new tracking system with existing production systems for comprehensive process management.

The system uses video cameras to track the movement of sheets. The system determines the position of sheets in conditions of constant interference. Each sheet is determined regardless of its position in the flow. In conditions of overlapping sheets, they can be determined as one sheet. For each sheet, both the exact coordinate (in pixels on the screen) and the conditional coordinate (the section or the entire workshop is conditionally divided into sectors, each sector has a unique number) are determined. After determining the coordinates, JSON is formed in the format [(exact coordinate 1 X, exact coordinate 1 Y, conditional coordinate 1 X, conditional coordinate 1 Y), ..., (exact coordinate n X, exact coordinate n Y, conditional coordinate n X, conditional coordinate n Y)].

The system uses an algorithm to determine the relationship between the received coordinates of the sheets and their identifier [24]. The algorithm, having received a set of coordinates, will accurately determine which sheet each coordinate corresponds to. Each sheet is tracked independently of the others. The algorithm takes into account the number of sheets in the section to eliminate their loss in the system. In conditions of overlapping sheet movement, their definition as one sheet is unacceptable. When moving overlapping on a roller conveyor (roller table) in the system, the sheets will be on different conditional coordinates. When moving overlapping on a slapper in the system, the sheets will be on different sides of the slapper. Having determined the positions of each sheet, the system generates JSON for the visualization system in the format [{"id_slab": "text", "order": "text", "melting": "text", "batch": "text", "steel_grade": "text", "size": ["number", "number", "number"], "position": "number"}, ... , {"id_slab": "text", "order": "text", "melting": "text", "batch": "text", "steel_grade": "text", "size": ["number", "number", "number"], "position": "number"}].

The system maintains a history of sheet movements in the database. The database is filled with an algorithm for determining the links between the obtained coordinates and sheet identifiers. The database complies with the third normal form. It is integrated into the existing database (electronic melting passport). The history stores the arrival and departure times for each position in the workshop section. The information for generating JSON for the visualization system is also obtained by the above algorithm.

The system displays the movement of sheets in the flow in real time. Visualization is implemented as a web application, where a section of the workshop is displayed. Each sheet is clearly visible, the color of the sheet will depend on its batch (each batch has a unique, contrasting color that is not yet on the screen). The color of the batch is assigned in the tracking system and will be the same for all users of the application.

When designing the user interface (UI) for a sheet metal tracking system in a sheet metal rolling mill, it is important to consider the needs of the users. The interface should provide easy access to the necessary information, intuitive navigation, and meet the specific tasks of each group.

The operators of the section are interested in operational information about the current state of the production process, as well as the ability to quickly respond to changes. For them, it makes sense to develop an interface with a main window that displays a mnemonic diagram of the section. This diagram should present all the sheets arranged according to their actual position in the shop.

The main elements of the interface are as follows:

- Mnemonic diagram: the sheets are arranged on the screen in the same way as they are in the real shop. This helps operators easily navigate and visually track the movement of sheets.

- Color coding: since one heat can include several sheets, each sheet is highlighted with a frame of a certain color. The color of the frame is unique for each heat, so that operators can immediately understand which sheets belong to one production cycle, and all users of the system will have the same colors of the heats.

- Detailed information about each sheet can be presented in two ways: directly on the mnemonic diagram next to each sheet. However, this approach can make the diagram too busy and difficult to perceive. A separate panel or a pop-up window when clicking on a specific sheet helps to avoid visual noise and makes the interface cleaner.

- Information common to all sheets of one heat (for example, the heat number) can be placed in a separate panel ("legend"). This will help to reduce the amount of repeating data on the mnemonic diagram and simplify perception. Since it may be inconvenient for the operator to hover the mouse cursor over the sheet and get all the information about it, the same information for sheets is displayed in the legend, the rest is applied to the sheet.

Operators can view the mnemonic diagram of the section and work statistics. In addition to the ability to monitor current processes, the administrator can manage access rights, granting or revoking permission to view mnemonic diagrams to other employees. For the sheet tracking system in the sheet rolling shop, the use case diagram is shown in Figure 1.

The system has the following states: user identification, viewing the position of sheets on the mnemonic diagram, viewing statistics, managing user rights. Figure 2 shows the state diagram.

Each user action initiates a sequence of actions. During user authorization, it is necessary to validate the data, find the user in the database, check the correctness of the entered password, and only then redirect the user to the main page of the application. These sequences can be traced in the activity diagram, which is shown in Figure 3.

After successful authentication, it is necessary to define the user's access rights. Once the rights are defined, the visualization system requests data on the position of the sheets, which initiates the collection and transmission of information about them on the server. Similar actions occur to display statistics and change user rights. A more accurate flow of information is shown in the sequence diagram in Figure 4.

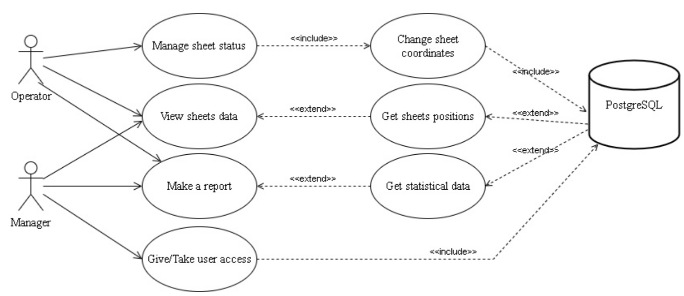

Fig. 1. Use Case Diagram.

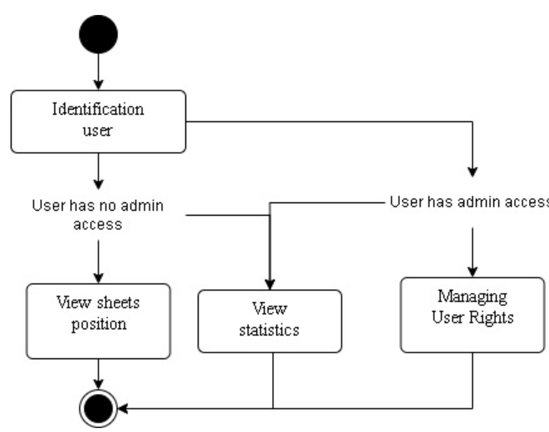

Fig. 2. State diagram.

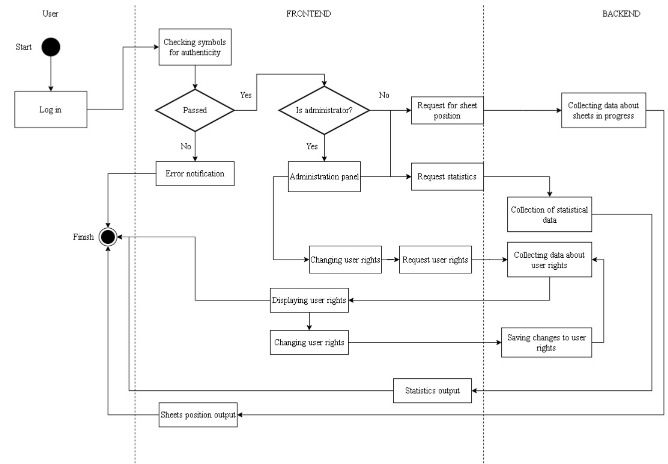

Fig. 3. Activity diagram.

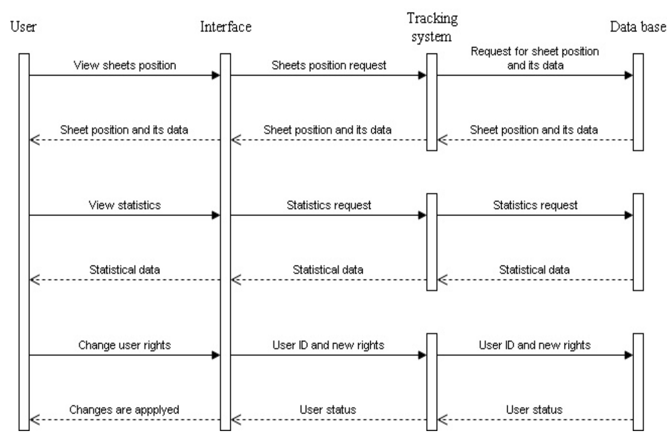

Fig. 4. Activity diagram.

III. Operation of the Automated Workplace of the Sheet Rolling Shop Operator

When logging into the system, the user is greeted by an authorization window where he is asked to enter his login and password to log into the system. The user will be registered in the system when appointed to the position of site operator. If authorization is successful, information about the user (Name, ID in the database, access level to the system) is saved in the cookie files. The appearance of the authorization page is shown in Figure 5.

After authorization, the user gets to the main page of the web application - the mnemonic diagram of the workshop section. The mnemonic diagram consists of 17 positions, repeating the outlines of the section in the workshop. On the mnemonic diagram, sheets are located in accordance with their position in the workshop, while the sheets can only be in one position. When changing the position of the sheets, the sheets are instantly moved to a new position on the mnemonic diagram. Each sheet displays its parameters, such as the slab number from which the sheet was rolled, order number, batch, thickness, width and length. To the right of the mnemonic diagram is a legend. It contains the heat number and steel grade. A unique color is assigned to each heat and it is guaranteed that the color will be the same for all users. All sheets rolled from one heat will have the same color. The main page is shown in Figure 6.

At the top of the page, the user sees the current time and name, which are displayed on all pages of the web application except the authorization page, a button to go to statistics, a button to log out of the system, by clicking on which the user will get to the authorization page, and the cookies will be cleared. If the user has administrator rights, then a button to go to the admin panel will appear next to the button to go to statistics.

The statistics page displays the number of sheets that passed through this section of the workshop, their average time spent in position, and a list of orders whose sheets passed through the section. In the date field, the user can specify the date for which statistics will be displayed. The current date is set by default. The data is updated automatically when the date changes, without requiring any additional actions. Figure 7 shows the statistics page.

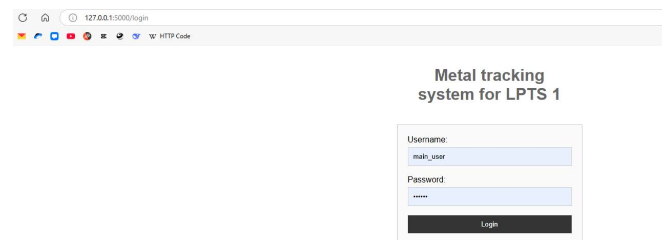

Fig. 5. User authorization window.

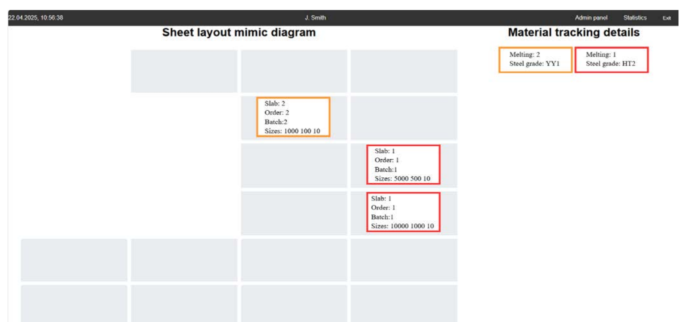

Fig. 6. Web application home page.

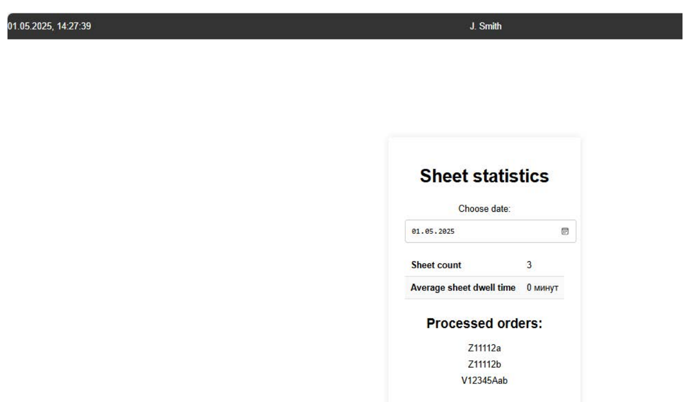

Fig. 7. Statistics Page.

By going to the admin panel, the user will see all users registered in the system, the administrator has access to functions with the ability to change the name, login, password, administrator rights. Loading is carried out by 10 users with each click on the button, until all users are loaded, after which the button will not be visible to the user. Figure 8 shows the admin panel page. At the top of the page, the user can return to the main page or go to the user registration page.

Once you go to the new user registration page, you can see a form where you need to enter the user name, login, password and access rights. The registration page is shown in the Figure 9.

To store information about sheets and users, a database has been developed in the PostgreSQL DBMS, which contains 5 tables. The ERD diagram of the database is shown in the Figure 10.

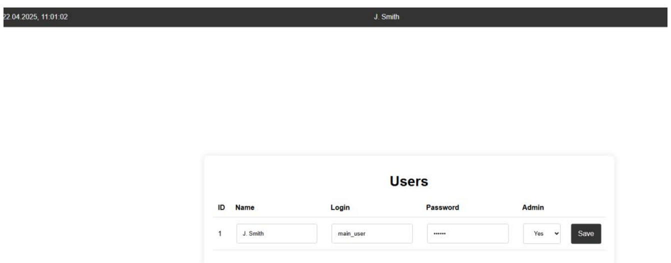

Fig. 8. Admin Panel.

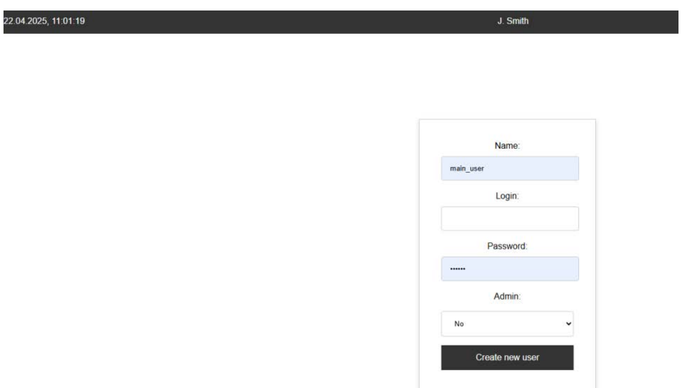

Fig. 9. User Registration Panel.

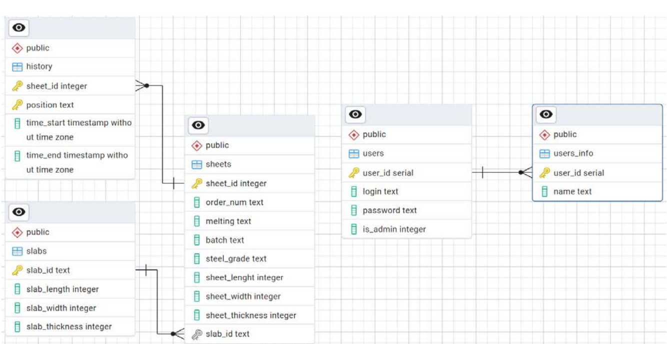

Fig. 10. ERD diagram of the database.

The users table stores the login, password and access rights code (where 0 means that the user does not have administrator rights, 1 - the user is an administrator) of each user. The users_info table is linked to this table by the serial key (integer data type with auto incrementation) by a one-to-one relationship type, where additional information about the user is stored. This structure was chosen so that, in case of possible expansion of the user information, it would be possible to add new fields to this table without completely clearing it.

The sheets, slabs and history tables are used for the metal tracking system. The slabs table stores information about slabs, their number, length, width and thickness. This table is linked to the sheets table by the slab_id key by a one-to-many relationship type, since several sheets can be rolled from one slab. For each sheet, the database stores its unique number, steel grade, batch, length, width, thickness, melt number, order, slab from which the sheet was rolled. To be able to view the history of movement and obtain statistical data, a sheets table has been created, which is linked to the history table by a one-to-many relationship. This table records the time of sheet arrival at a position on the site. As soon as the sheet is moved to a new position, the time of exit from the current one is recorded and a record is created for the new one. The keys of the table are two fields: sheet_id and position. This ensures the uniqueness of the keys, since there are about 8 or 10 records per sheet, each of which must have a unique key. Using only one key does not allow for such uniqueness.

The API uses the http protocol version 1.1. Requests are made via the IP of the machine on which the server is running (for example, the IP of the machine is 192.168.1.101, then the server will accept requests via the URL http://192.168.1.101:5000/). The application pages are located at the following lbhtrnjhbzv:

- Authorization page: /login
- Mnemonic diagram page: /sheets
- Statistics page: /statistic
- Admin panel: /admin_panel
- User registration page: /new_user

CONCLUSIONS

Automation of tracking processes allows not only to minimize risks associated with the human factor, but also to reduce equipment downtime, and improve the quality of the final product [27]. Thus, this work is aimed at solving the important problem of modernizing production processes in the metallurgical industry, which meets modern requirements for automation and digitalization of industry.

The implementation of an automated sheet movement tracking system based on computer vision will eliminate the key drawbacks of the existing solution, such as dependence on laser sensors and their vulnerability to high temperatures. This will provide more reliable and accurate monitoring of the position of sheets without the need for visible marking, which will reduce production downtime and minimize the impact of the human factor.

The implementation of this system will not only increase the efficiency of the 2800 mill, but also reduce operating costs, improving the quality of the products. Thus, the proposed solution meets modern trends in automation and digitalization of the metallurgical industry, contributing to an increase in the competitiveness of the enterprise. Further research could be aimed at optimizing computer vision algorithms to operate in high temperature conditions and other challenging production conditions.

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