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A PLC BASED ROBUST MONITORING MODEL FOR THE LABELLING MACHINE AUTOMATION PROCESS

MODEL ODPORNY SYSTEMU MONITOROWANIA W AUTOMATYZACJI PROCESU ETYKIETOWANIA Z WYKORZYSTANIEM STEROWNIKÓW PLC

This paper presents a method for improving the labelling process and a robust monitoring model for the labelling machine with the purpose of reducing waste of labels and bottles.The proposed monitoring method is based on a combination of Matlab®-designed and hardware-in-the-loop (HIL) simulationas well as Arena Simulation. The method solves problems with the application of labels during the labelling stage and provides a robust monitoring algorithm that recognizes defective labels before they are stuck onto bottles.The Grafcet optimal algorithm for recognizing defective labels is executed. The Matlab®Stateflow model for monitoring and recognizing defective labels is applied. The proposed algorithms are complete, and optimized solutions are ready for implementation in the existing PLC supervisory control system. Based on HIL simulations, the proposed method ensures an increase of the total production quantity. Statistical data was collected directly from the field, classified using Statfit software, and used in Arena Simulation software to present the difference and benefits before and after using the PLC-based robust monitoring model for the labelling machine automation process.

Keywords*: label defects detection, robust monitoring Stateflow® model, labelling, PLC, HIL simulation.*

W pracy przedstawiono metodę poprawy procesu etykietowania oraz model odporny monitorowania uszkodzeń etykiet w celu zmniejszenia ilości odpadów etykiet i butelek. Opracowanie proponowanej metody monitorowania i wykrywania wad etykiet opiera się na wykorzystaniu kombinacji funkcji środowiska Matlab® oraz symulacji sprzętowej (ang. hardware-in-the-loop, HIL). Nowa metoda rozwiązuje problemy związane z wykrywaniem uszkodzeń przyklejanych etykiet do butelek w przemysłowej linii produkcyjnej oraz zawiera model odporny detekcji wad etykiet. Algorytm systemu monitorowania w procesie etykietowania został przedstawiony za pomocą sieci Grafcet, a następnie zrealizowany w środowisku Matlab Stateflow®. Proponowane algorytmy monitorowania/detekcji zostały zoptymalizowane pod kątem ich realizacji w istniejącym systemie sterowania opartym o programowalne sterowniki logiczne (ang. programmable logic controllers, PLCs). Przeprowadzone symulacje sprzętowe HIL pomyślnie weryfikują opracowane rozwiązania podnoszące efektywność produkcji. Zaproponowany odporny model detekcji uszkodzeń etykiet został zaimplementowany w układzie sterowania linii produkcyjnej i zweryfikowany eksperymentalnie. Zebrane dane statystyczne bezpośrednio z obiektu sterowania zostały opracowane w programie Statfit. Oprogramowanie Arena Simulation zostało wykorzystane do porównania wyników pracy linii produkcyjnej przed i po wprowadzeniu modelu wykrywania uszkodzeń etykiet.

Słowa kluczowe*: wykrywanie wad etykiety, model odporny monitorowania Stateflow®, etykietowanie, sterownik PLC, symulacja sprzętowa HIL.*

1. Introduction

Nowadays, many industrial applications require a low-cost solution for improving their productivity and the quantity of products. Monitoring systems are especially important at the production stage, where waste of material and products should be limited to a minimum. Monitoring systems based on programmable logic controllers (PLC), I/O-devices and distributed sensors/actuators are economic solutions [12]. These systems can also be coupled and cooperate with an existing network of digital control devices. Moreover, hardware-in-the-loop simulation using PLC-open functions, and, for example, Matlab® software models, can be used to design and test a suitable monitoring system in a cheap and fast way [10].

Many corporations have on-going research projects aimed towards reducing waste in manufacturing systems. In the literature, a number of papers are focused on using PLC technology in various industrial processes. Diagnostic techniques for PLC-controlled flexible manufacturing systems (FMS's) are proposed by Hu et al. (1999) [5]. Maria G. Ioannides (2004) describes the implementation of a monitoring and control system for an induction motor based on a programmable logic controller and provides the implementation of the hardware and software for speed control and protection with the results obtained from induction motor performance tests [6]. Georges, B. and Aubin, J. (2001) examined GE Syprotec Inc. of Canada's design of a PLC-based transformer monitoring and control system (TMCS). The TMCS aims to manage the operational flow and to enhance the performance of a transformer [2]. A. Ramirez-Serrano, S. C. Zhu, S. K. H. Chan, S. S. W. Chan, M. Ficocelli and B. Benhabib (2002) presented a new PC/PLC-based software/hardware architecture for the control of flexible manufacturing work cells [7]. Hairui, W. and Yong, Z. (2009) focus on a process control system for management of carbon dioxide content in food by using a distributed control system based on configuration software and PLC [4]. Theiss, S., et al. (2006) present an additional software entity (“monitoring agent”) which provides process data acquisition and improves sampling resolution and flexibility of real-time PLC (programmable logic controller) devices [8]. Arrofiq, M. and Saad, N. (2007) designed and implemented a PLC-based fuzzy logic controller for induction motor speed control with a constant V/Hz ratio [1]. M.F. Zaeha, C. Poernbachera, J. Milberg (2005) discuss the difficulty of developing PLC software for modern machine tools due to their increasing complexity and functionality and present a model-based development and simulation-aided verification of control software [9].

The most modern and high-tech lubricants plant of the multinational oil, gas and energy company, British Petroleum, is located in Gemlik, Turkey. The plant produces motor oils and lubricants for the domestic and foreign market. The plant produced 70,000 tonnes of lubricants in 2011. The plant is mainly divided into three departments: logistics, production and filling. The logistics department is divided into two sections. The first one is responsible for delivering raw materials to the production facility. Section two receives produced lubricants from conveyors and organizes freight traffic within the plant complex. The production department receives raw materials and additives from both the logistics department and the dock via transfer pipes. Finally, the filling process is carried outin a separate building in the production complex, where aluminium cans and plastic bottles are filled with final products – the lubricants.

This paper focuses on a problem that occurred at the filling facility. Especially during the summer months, the glue of the labels melts, and the labelling machine cannot apply the labels properly. The labelling machine cannot detect defective labels, it can only detect them after sticking them onto a bottle via its sensors. However, the application of a defective label also causes the bottle to be disposed of, because the surface of the bottle becomes gluey and wet, which is inconvenient for sticking on another label.The workflow at the filling facility is presented in Fig. 1.

The work-flow begins with the loading of bottles onto the conveyor line by field workers, and bottles follow the path of conveyors presented in Fig. 1. Before the start of the work-flow, a field worker loads label rolls into the machine, and when a bottle reaches the labelling station, the machine sticks the label onto the bottle. After application, the machine’s quality control system, which uses a programmable logic controller (PLC), performs quality control via its sensors and decides whether or not the applied label is compliant with quality standards. If it is, the bottle is delivered to the next station, the bottling station. If not, the machine disposes of the bottle, meaning that both the label and the bottle are lost. This complication was causing deviations from production plans and waste of materials used in production. Therefore, more bottles and labels had to be put into the system in order to obtain the desired total production quantity, since a lot of bottles, along with their labels, are disposed of because of the problem.

Finally, this paper presents a PLC-based robust monitoring model for the labelling machine, which reduces waste of labels and bottles and optimizesthe algorithm for recognizing defective labels.

2. Process

The detailed work-flow at the filling facility is presented in Fig. 2. In this figure, the PLC-based monitoring system is only introduced for the labelling machine. It is important to note that bottling, capping and packaging systems also have similar quality control systems, however they are not presented, since this paper is only focused on the problem occurring in the labelling sub-process.

A conveyor carries out the entire process at the filling facility, meaning that human intervention is only necessary for inspecting the process and loading supplementary production products (such as grease – labels, etc.). A brief description of the whole flow is presented below:

- after filling orders from the planning department are received, bottles are loaded into the conveyor system,
- at the labelling station, labels are stuck onto bottles. The labels show the features of the products. They consist of the corporate logo, product name and product-specific information. Rolls of labels are put into the machine by the responsible operator, and the machine automatically applies them. If the PLC detects a bottle with a defective label, the labelling machine disposes of both the label and the bottle. The bottle is also disposed of, be-

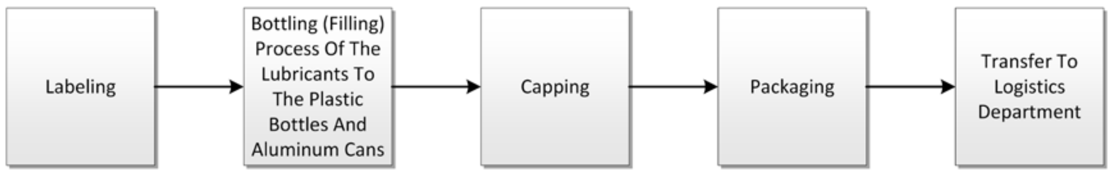

Fig. 1. Workflow of the filling process

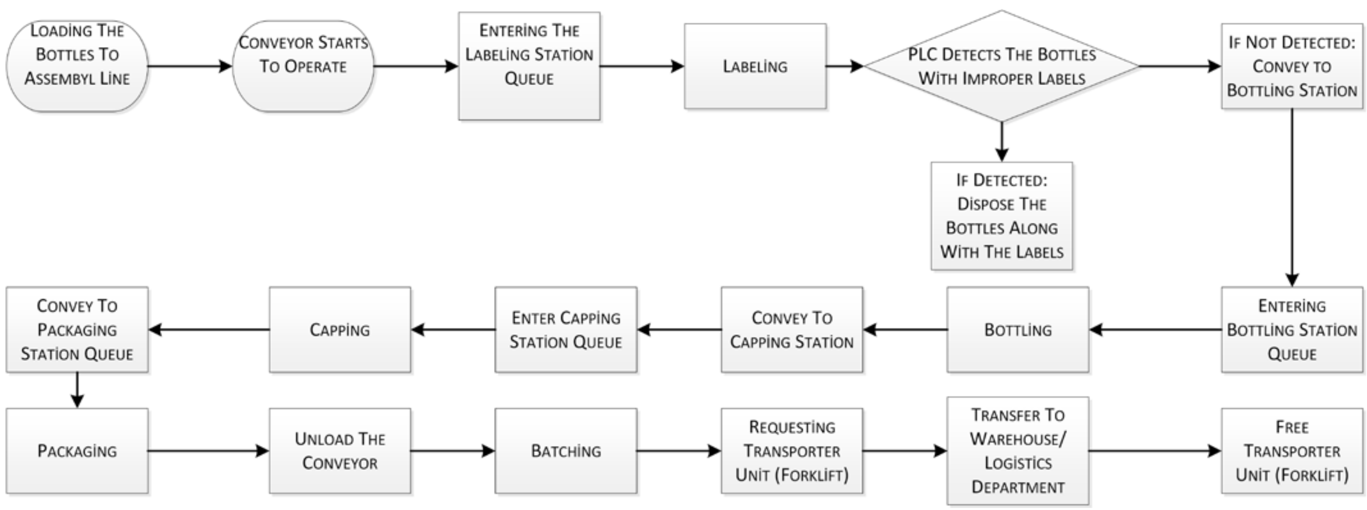

Fig. 2. Detailed process flow at filling facility

cause its surface also gets covered with glue, making repeated label application impossible,
- during the bottling stage, aluminium cans and/or plastic bottles are filled with lubricants, which are delivered from the production facility through tubes,
- during the capping stage, the machine seals bottles with the appropriate bottle caps,
- at the packing and batching station, after the completion of a group of products, (the number varies from product to product), the conveyor delivers products to the packaging machine, packing them in cardboard first, and then wrapping them with plastic material,
- during the last stage, transferring, the completed products are transported to the logistics department or warehouse to await freight transport to the final destination.

3. Proposed method for labelling process improvement

The aim of the proposed method consists of the following aspects:
- solving problems with label application at the labelling stage, which will reduce waste of labels and bottles, e.g. before the application of a previously recognized defective label, a bottle will be frozen to improve the quality of label sticking,
- providing a robust monitoring algorithm, which recognizes defective labels before they are stuck onto bottles. Thus, bottles will not be wasted. In this case, robust means that this monitoring system is accurate and is not sensitive to external disturbances of the process.

The method described above will increase the total economic production quantity (EPQ). Here, it must be emphasized that the algorithms within this method are complete and optimized solutions that are ready for implementation in the existing PLC supervisory control system. Moreover, these proposed solutions are cheaper than others, e.g. installation of a climate control system in the filling facility or of an automatic storage machine, which would be more costly. However, the technical specifications and parameter values of these solutions are not official, and they are not given in this paper.

3.1. Robust method for detecting defective labels

The method for detecting a defective label is comprised of three steps:
- first, the label's glue temperature is measured by a non-contact temperature sensor (e.g. the FLIR A310 – forward looking infrared – thermal imaging camera), if the temperature is higher than desired, the label is marked and information about the label's increased temperature is sent to the freezing system, after which the algorithm goes to the second step,
- during the second step, the label's glue density is measured by laser sensors, and if the glue density is below the lower limit, the label is removed, and information about the removed label is sent to the supervisory computer,
- finally, an image of the bottle with the applied label is generated using a CCD camera, and after that, a binary image containing a striped pattern of the label surface area is recognized. Some image recognition algorithms are used here, and if the label surface quality is lower than desired, the bottle is removed.

For ideal assessment of a label's glue, a liquid density sensor should be applied. However, this must be a non-contact sensor. Moreover, the liquid density is very sensitive to changes in temperature. Thus, the measurement of density and temperature should be closely coupled. All of the sensors (temperature and density) described above should operate online and in real-time without delay. They must provide stable and reliable measurement, even in a system with a high degree of agitation or disturbances.

Image processing of labels on bottles is the last and most complex step of label inspection. Here, the dynamic compensation algorithm is used to filter out shadows, tints and reflections on the background area of the label surface. The dynamic compensation algorithm is es-

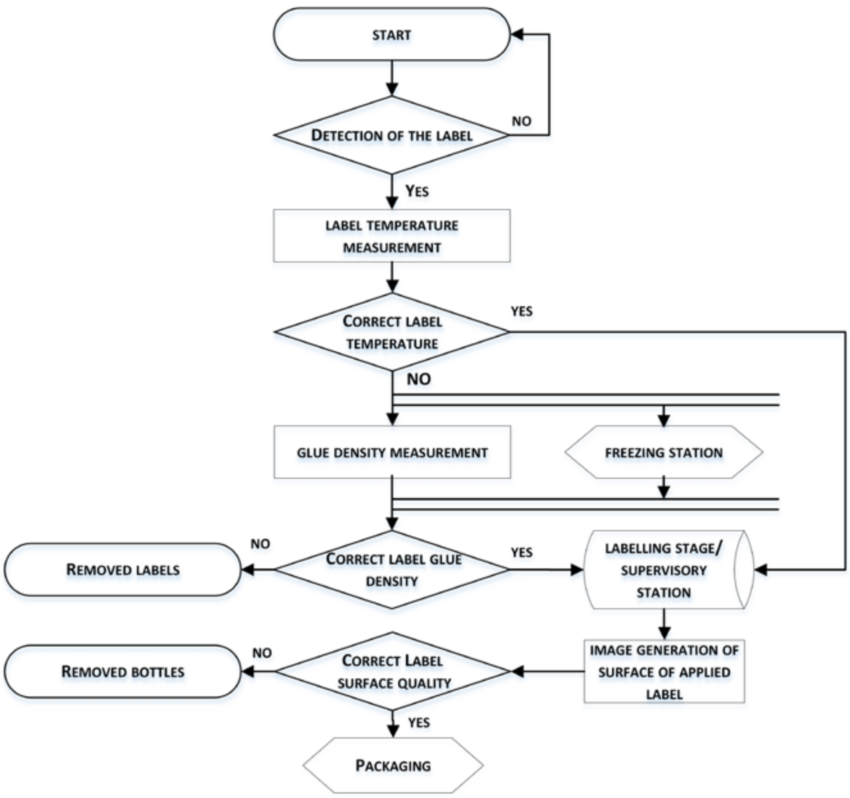

Fig. 3. Scheme of label defects detection

pecially useful in the case of highly reflective labels. Thus, the image processed by this algorithm contains less shadow area, making the image easier to analyse for defects. The Matlab® Image Processing toolbox can be used in order to design the dynamic compensation filter and obtain the image recognition algorithm [10]. The recognition algorithm is extended by a tool for setting vertical and horizontal inspection of the label surface. Here, the label quality is verified by detection of wrinkle defects on the leading edges of the label.

The Grafcet algorithm proposed for detection of label defects is presented in Fig. 3.

4. Stateflow monitoring model for the labelling process

The monitoring system for the labelling machine can be described by states and events for further recognition of defective labels. This system is known as the discrete event drive system (DED). The algorithm for classification of labels in the manufacturing process is provided in the Matlab® software by a tool for modelling and control of this system called the Stateflow® toolbox [10]. After that, the Simulink PLC Coder software is used to generate hardware-independent structured text from Stateflow® charts. As a result, it is possible to compile and deploy the proposed algorithm to programmable logic controller (PLC) and programmable automation controller (PAC) devices by using PLC-oriented tools [11]. Moreover, the Simulink PLC Coder provides optimizations that reduce the memory used by the PLC controller and increase the execution speed of the generated structured text. Finally, the Simulink PLC Coder can simulate the algorithm prior to structured text generation and package the results into a test harness that is generated by the algorithm code. The workflow of the Simulink PLC coder is presented in Fig. 4. The main goal is to propose an optimization algorithm for recognition of defective labels.

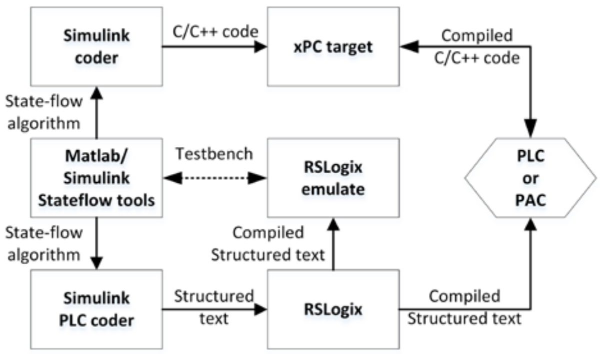

Fig. 4. Workflow of the model-based design [10]

The Simulink PLC coder (Fig. 4) generates structured text for the target PLC controller and provides verification support including test benches. The structured text of the control algorithm meets the standards of IEC 61131-3 e.g. for Rockwell Automation [11]. The Structured Text is generated in PLCopen XML, which is supported by widely used integrated development environments (IDEs) [10]. The Simulink PLC Coder also generates test benches in order to verify the structured text using PLC and PAC IDEs and simulation tools [10]. IDE support includes 3S-Smart Software Solutions CoDeSys, Rockwell Automation® RSlogix™ 5000, Siemens® SIMATIC® STEP® 7, Omron Sysmac Studio, and PLCopen XML [11].

4.1. The Stateflow label defects detection model

Stateflow® is a compressive tool for representation of event-driven (reactive) systems and includes designing and modelling of digital control algorithms [10]. In anevent-driven system, finite states are used to represent machine operations. The machine performing these operations is called a finite state machine (FSM). In a FSM, the relationships between inputs, outputs, and states are represented by truth tables, and the behaviour of an FSM is described by the conditions of transitions between states [3].

Label defects detection and the decision-making algorithm are presented by agraphical chart which represents the FSM. States (e.g. *labelling, freezing, packaging, surface_quality, temperature_sensor,* and *density_sensor*) and transitions (e.g. *label, temp, density*, and *surface*) form the blocks of the algorithm in the FSM (see Fig. 5).

Label validation according to glue temperature and density is implemented in the event algorithm by the Simulink models. The *freezing* station is designed by using Matlab functions. The history junction (H) records the activity of substates (e.g. total amount of removed bottles and labels) within the main finite states. Label surface validation is realized by using a complex image processing function. All transitions are conditioned by internal Boolean conditions according to the limits of main process parameters (e.g. [*temp<temp_limit*]). The solution of this algorithm concerns switching between states in the desired order and according to defined logical conditions. The process's modes of operation are modelled as states and represent the logic for switching between modes using transitions and junctions. The algorithm starts from the default state (*label detection*), then *temperature_sensor* state is activated. After that, if the glue temperatureand density are below the limit, the *labelling* state is activated, and if not, the *parallel_processes*state is activated. This state provides two states: *freezing* and *density_sensor* in a parallel configuration. Thus, the *labelling* state is activated again if the glue parameters meet the logical conditions for desired temperature and density. All defective labels are removed by activating the *removed_labels* state. During the

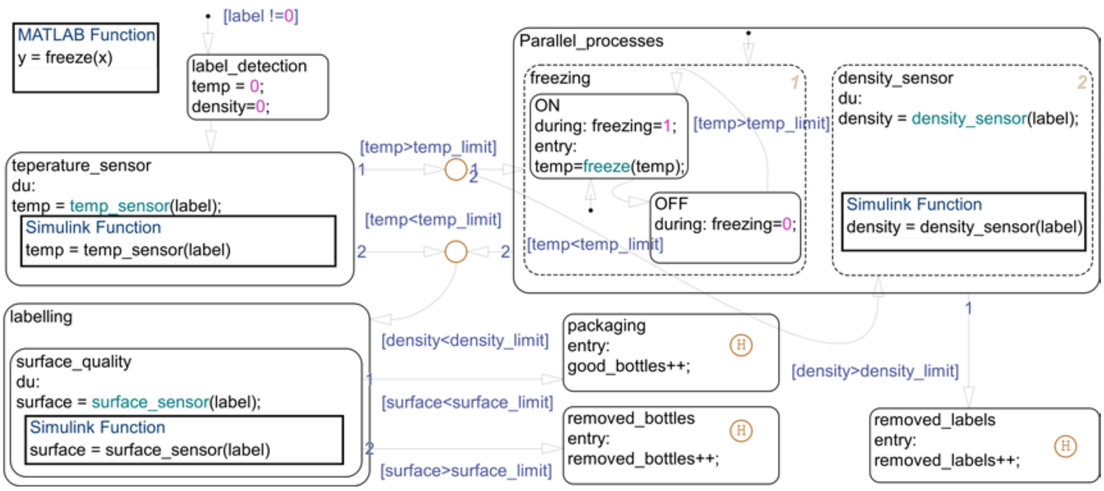

Fig. 5. Chart of the process algorithm

labelling state, label surface quality is validated, and the*surface_quality* state is activated. The outputs from the *surface_quality*state provide and activate the *packaging* or *removed_bottles* state depending on defined logical conditions.

5. Testing of the algorithm using the Simulink C Coder and PLC

In order to implement the Stateflow® algorithm in PLC or PAC memory, the flow graph is transformed to C/C++ code. The Embedded Coder™ software enables generation of real-time code directly from the flow graph. The C source code generated for the label defects detection model is needed to perform a simulation and tests. The generated code is optimized before the testing process. For example, the parallel states of freezing and density validation, with conditional transitions, are presented within the following C code:

```
/* Outputs for Function Call SubSystem: '<S1>/Parallel_processes.density_sensor.density_sensor' */
  /* Gain: '<S2>/Kd' incorporates:
   *  Sum: '<S5>/Diff'
   *  UnitDelay: '<S5>/UD'
   */
  /* During 'density_sensor': '<S1>:26' */
  /* Simulink Function 'density_sensor': '<S1>:29' */
  rtb_Kd_e = (rtb_randomlabels -
          label_defects_detection2_DWork.UD_DSTATE_d) *
   label_defects_detection2_P.Kd_Gain;

  /* Update for UnitDelay: '<S5>/UD' */
  label_defects_detection2_DWork.UD_DSTATE_d = rtb_randomlabels;
  label_defects_detection2_B.density = rtb_randomlabels + rtb_Kd_e;

  /* End of Outputs for SubSystem: '<S1>/Parallel_processes.density_sensor.density_sensor' */
}
```

The main advantage of automatic code generation is the elimination of errors that may accrue during manual writing.

The last stage of code validation is to test the fully implemented code in the PLC hardware and, after that, to compare the results with the original simulation results. Hardware-in-the-loop (HIL) simulation makes it possible to run simulations of all stages of process automation control in real-time using the original C code and a real PLC controller. For this purpose, real-time communication between MATLAB/Simulink and the industrial controller (PLC) is established. Then, input/output signals are scaled due to analog-digital/digital-analog conversion(A/D, D/A). The entire system of the HIL test is presented in Fig. 6.

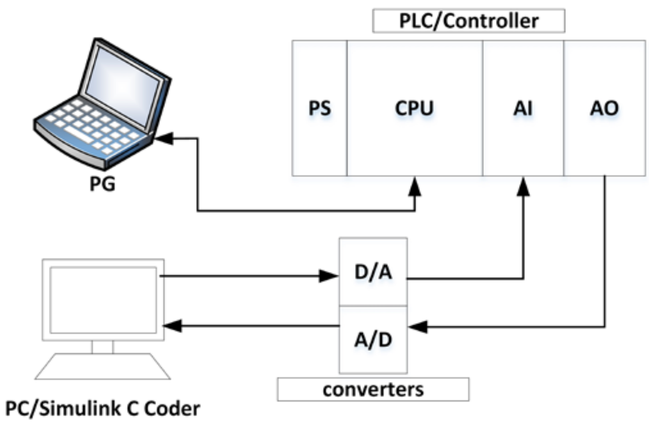

Fig. 6. Connection between the PLC and PC/Simulink C coder during HIL simulation

The experimental setup consists of: a PLC with PS, a CPU, and analog input/output modules (AI and AO), A/D and D/A converters, a PC with Matlab, and a PG station for programming the PLC. The results of the HIL tests will be used to validate the simulation model in another work.

6. Forecasting the benefits of the proposed model by using ARENA Simulation Software

By presenting a method for improvement of the labelling process and a robust monitoring model for the labelling machine, we aim to optimize three different outputs. First, the number of defective labels and bottles will be reduced. Second, costs resulting from the disposal of defective labels and bottles will be reduced. Third, the total production time will be optimized. These three outputs will help to assess the benefits of the Simulink/Stateflow model introduced in section 4. The statistical data of the labelling/bottling/capping and packaging processes before the application of the robust monitoring model are presented in this section.

6.1. Data Collection, Assumptions and Data Analysis

A detailed analysis was carried with the primarygoal of characterizing the performance of the system in different scenarios at the plant. To create a model for the simulation software, a chronometer was used to measure the time performance of the machines. Each step was observed 30 times in order to achieve reliable and descriptive statistical results. Statfit software was used to determine "the goodness of fit". Detailed information regarding machine operation times before implementation of the Simulink/Stateflow robust monitoring model is provided in Table 1.

A number of assumptions were made. First of all, production starts at 8 AM. Secondly, the times of transportation by forklift from the filling department to the logistics department were observed. The results of these observations were between 4.46 and 5.05 minutes, therefore, the transport time was assumed to be 5 minutes. Thirdly, the system doesn't stop until it reaches the desired production quantity, meaning that breakdowns, breaks, or any other disturbances are ignored and not included in the simulation model. Fourthly, detection of defects with the help of the PLC system is only defined for the labelling machine. The defectiveness rate on other machines is ignored since the rate is lower than 3%. Fifthly, the simulation is used for 2 different types of products (which have different batch sizes), and each of these simulations has an ending condition, which is the generation of, respectively, 500 (Product A) and 1000 (Product B) completed final products. Finally, the production (model) stops when the desired production quantity has been achieved, which means thatthe model doesn't requirewarm-up time.

In such a state-of-art lubes plant, production flow is carried out via tubes and conveyors. The personnel mainly inspect the flow of the system. Therefore, the following data are considered to be deterministic. Firstly, after observation of the conveyor's speed, it was noted that a bottle was loaded onto the conveyor system of the filling facility every 1.5 minutes. Secondly, the first in first out rule, FIFO (first input; first output), is applied for all queues on the conveyor line. Thirdly, the cost for disposing of a bottle with a label stuck onto it is 1.1€. Machine operation times were considered to be stochastic after chronometric observations were made.

Table 1. Descriptive statistics of the operation times of machines before the implementation of the robust monitoring model

	Sample Size	Range	Mean	Variance	Excess Kurtosis	Std. Deviation	Coef. Variation	Skewness
Labeling	30	19	69.96	35.96	−11.784	59.971	0.08612	0.1291
Bottling	30	4	30.3	1.61	−12.124	12.689	0.04188	−0.08615
Capping	30	21	51.1	46.82	−12.221	68.428	0.13391	0.05072
Packaging	30	3	61.83	0.73	−0.38431	0.85959	0.0139	0.95634

Table 2. Detailed results of 10 replications after the implementation of the robust monitoring model

		Number Of Replication									
Unit	**Description**	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Simulation Outputs Of Product A Under 30% Defection Rate										
Number	Number Of Defected Labels	228	197	236	237	214	184	223	244	221	217
Euros	Cost Of Disposed Labels and Bottles	125.95	108.9	130.35	130.9	118.25	101.75	123.2	134.75	122.1	119.9
Minutes	Total Production Time	558.441736	542.957	558.7365	551.0397	539.9819	518.728	571.0567	566.7704	552.2564	558.9632
	Simulation Outputs Of Product A Under 25% Defection Rate										
Number	Number Of Defected Labels	162	149	155	166	171	147	177	147	144	206
Euros	Cost Of Disposed Labels and Bottles	89.65	82.5	85.8	91.85	94.6	81.4	97.9	81.4	79.75	113.85
Minutes	Total Production Time	500.288966	503.198	497.2145	503.6616	512.5845	491.7889	531.3535	498.6743	489.7158	551.6037
	Simulation Outputs Of Product A Under 2% Defection Rate										
Number	Number Of Defected Labels	16	9	9	7	12	8	14	9	15	14
Euros	Cost Of Disposed Labels and Bottles	9.35	5.5	5.5	4.4	7.15	4.95	8.25	5.5	8.8	8.25
Minutes	Total Production Time	398.080675	394.413	395.2622	392.726	395.2118	394.7517	398.2378	395.2784	398.2744	396.0148
	Simulation Outputs Of Product B Under 30% Defection Rate										
Number	Number Of Defected Labels	424	403	435	468	418	393	443	449	426	422
Euros	Cost Of Disposed Labels and Bottles	233.75	222.2	239.8	257.95	230.45	216.7	244.2	247.5	234.85	232.65
Minutes	Total Production Time	1093.880785	1063.92	1103.216	1104.154	1074.024	1047.443	1108.876	1108.52	1089.014	1076.287
	Simulation Outputs Of Product B Under 25% Defection Rate										
Number	Number Of Defected Labels	346	328	304	323	325	311	336	295	296	362
Euros	Cost Of Disposed Labels and Bottles	190.85	180.95	167.75	178.2	179.3	171.6	185.35	162.8	163.35	199.65
Minutes	Total Production Time	1007.281788	995.135	990.6528	996.2137	1012.036	989.4882	1022.921	985.4722	981.9551	1055.244
	Simulation Outputs Of Product B Under 2% Defection Rate										
Number	Number Of Defected Labels	27	15	22	20	21	16	22	19	24	24
Euros	Cost Of Disposed Labels and Bottles	15.4	8.8	12.65	11.55	12.1	9.35	12.65	11	13.75	13.75
Minutes	Total Production Time	784.022205	775.099	778.2257	774.8996	778.6259	775.2485	781.2348	776.8666	782.7499	779.8694

Table 3. The average results of 10 replications after the implementation of the robust monitoring model

Product A			
Defectiveness Rate	Average Total Product Time	Average Total Number of Defective Labels	Average Cost Of
Defective Labels			
30% Defection	550.51	220.10	121.61
25% Defection	507.53	162.40	89.87
2% Defection	395.38	11.30	6.76

Product B			
Defectiveness Rate	Average Total Product Time	Average Total Number of Defective Labels	Average Cost Of
Defective Labels			
30% Defection	1086.64	428.10	236.01
25% Defection	1004.20	322.60	177.98
2% Defection	778.37	21.00	12.10

7. Experimental set-up

The Simulink/Stateflow simulation model was implemented and built using ARENA Simulation Student Edition Software Version 14.00.00000 from Rockwell Automation with the help of the conceptual model described in Section 2 . This section explains the outputs of the simulation model outputs and contains a discussion. Two different types of products were chosen from among the product assortment of the company. However it is important to note that all names have been manipulated for proprietary reasons. These two products will be called Product A and Product B. The features of these products and experimental results are given in this section.

7.1. Experimental results

Over 10 replications, the Simulink/Stateflow simulation model (robust monitoring model) observed the results of three outputs:

- average total cost of disposed products (Euros),
- average total production time for stated production quantity (minutes),
- total number of defective labels (number).

The simulation model's reaction toward these three outcomes was observed under three different defectiveness rates for labels: 30%, 25% and 2%. The defectiveness rate for labels causes instability in production schedules, therefore the simulation model experimented with these three values. The defectiveness rate for labels is known to be between 25% and 30%, therefore, these two values wereused. 2%, on the other hand, waschosen to see how much the plant can benefit on the outputs, if the problem were to be fixed. A 2% problem rate (possible risk-defect-danger) is used at the plant for operations which are considered to be almost risk-free. The experimental results of the system with the implemented simulation model are collected in table 2, and average results are presented in table 3.

Based on the results in Table 2, the robust monitoring model works properly and detects defective labels for three different defectiveness rates. The greatest accuracy is noted for the label defectiveness rate of 30%. However, the number of defective labels is different in each simulation performed for Product A and Product B. Each replication of the simulation gives a similar number of defective labels. The costs of disposed labels and bottles increase due to the amount of defective labels.

Finally, by using the robust monitoring model created using ARENA software, we can observe the difference before and after implementation of the proposed Simulink/Stateflow model in the production process. To describe the situation in detail, between 25÷30% of labels and bottles were being disposed of before, and the proposed simulation model shows that our improvement fixes the problem, and now the disposal rate is reduced to 2%. Thus, it forecasts the benefit of our model by simulating the process.

8. Summary

In order to survive in today's highly competitive and global market, all businesses, regardless of their size and scale, must have brisk and responsive problem-solving mechanisms, otherwise even small complications may result in catastrophic outcomes for companies. This paper's field of observation, British Petroleum's lubricant production plant, is a good example of how constant observation of subprocesses, measurement of both qualitative and quantitative results, and their benchmarking with the expected outcomes help companies to construct successful problem-solving frameworks.

Although the literature is full of research on manufacturing improvements, the use of programmable logic controllers in combination with data provided by chemical analysis is considerably rare. With the help of the proposed method for improvement of the labelling process, which recognizes defective labels before they are stuck onto bottles, the number of defective materials was reduced, costs resulting from the disposal were reduced, and the total production time was optimized. Furthermore, the solution proposed in this paper is much cheaper compared to alternative options of solving the problem, which include obtaining an automated storage and retrieval machine with a climate controlling feature.

It is important to note that the subject of this paper is based on a real-life scenario, however some data have been manipulated due to company anonymity. But still, the framework and the outcomes of this study can be helpful for future research. The model proposed in this paper provides three important outcomes:

a) total production time was optimized: because of the proposal of a quicker and more reliable monitoring system, the total production cycle time will be faster compared to the old one,
b) reduction of the number of disposed products: deviations from production plans will be considerably reduced due to the elimination of the source of instability,
c) reduction of costs: because of the improvement, costs resulting from the problem are noticeably reduced.

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