Smart Inventory 4.0: Advanced version

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Abstract: The Authors of this paper had first conceptualized and then developed the automated picking plant described in the paper "A 4.0 Automated Warehouse Storage and Picking System for Order Fulfillment", presented by the Authors to the WCE 2021 IAENG Congress and awarded with the "Best Paper Award of the 2021 International Conference of Manufacturing Engineering and Engineering Management". In the perspective of the continuous improvement of Industry 4.0 they have brought to this first system the significant functional improvements object of this paper. In particular, having found that the loading of the goods in the individual boxes was carried out by the Operators in this factory by using ladders on which they climbed, without the necessary PPE and carrying the load manually, with the consequent risk of falling from such heights (3-6m) to cause even serious physical damage, the Authors first studied and then implemented an automatic loading system. A second problem was then highlighted for the storage of special products such as Food and Pharma, that, unlike what happens in the Beauty Sector (for which the plant was designed), need to remain in specific conditions of temperature and relative humidity. The paper describes how, in this new version, the two parameters are monitored in each single box by means of appropriate sensors that send alerts to the centralized control system when these parameters are outside the preset threshold. In this way, prompt remedial intervention is possible, avoiding the deterioration of the contents of the boxes and the consequent economic damage deriving from their alienation. All this is made possible at acceptable costs thanks to the technologies offered by Industry 4.0 such as modern robotics and Data Centralization via IIoT for monitoring and control.

Keywords: Automated storage and retrieval system, Automated warehouse, Automated picking

I. Introduction

Following the increased awareness of the safety of Those who work in Companies, as also recently reported by the Italian Premier Prof. Draghi (Oct 2021), the Authors examined the behavior of the Employees when loading this type of systems; an operation that the Authors observed being performed with exposure to risk (Operator with goods in his arms, climbing precarious stairs, often without any PPE as harnesses or lanyards). It was therefore decided to study an automation system for this activity, designed in such a way that the Loaders do not have to climb to the top, but carry out the operation always remaining at ground level. Doing so avoids the possibility of serious injuries (fallen from a height of 5-6 meters could easily affect the physical state of the Operator, sometimes permanently, sometimes even causing death). A further problem has arisen in Sectors such as Food & Beverage and Medical, in which it is necessary to maintain the temperature and relative humidity levels within predetermined ranges. A sensor system has therefore been developed, that continuously detects these parameters and, via Industrial IOT, transmits the data to the Operations center where, on a monitor, it is highlighted each warehouse location which takes on a different color, in relation to compliance with the thresholds set as control limits. When these are exceeded, an acoustic signal intervenes to call the attention of the Operator in charge of the alert event. It was installed inside the drawers of the warehouse, for a capillary data collection. So, a statistical process control system has been set up for each drawer, therefore a control card of the monitored parameters is generated.

II. Literature Review

The picking plant object of this case study is described in detail in the paper "A 4.0 Automated Warehouse Storage and Picking System for Order Fulfillment" (produced by the authors Lucia Cassettari, Fabio Currò, Marco Mosca, Roberto Mosca, Roberto Revetria, Stefano Saccaro, Gabriele Galli) and presented at WCE 2021 where it was awarded as the Best Paper Award in the "Manufacturing Engineering and Engineering Management" Section [1].

Please refer to the original paper for the literature review and references, which are omitted in this paper in order to avoid duplication.

A second series of articles have been considered in this extension, that deal with how picking is a fundamental element of efficiency and effectiveness for any Company. Han at al. have shown, for example, that by modifying withdrawal policies, increases in the flow of 10-15% are obtained. According to R. De Koster, T. Le-Duc, and K.J. Roodbergen in the article "Design and control of warehouse order picking: a literature review" of 2006, picking reaches as much as 55% of all warehouse costs. The picking activity is therefore

treated very carefully, and various models are proposed to improve performance. It is in fact suggested to adopt automated warehouse systems.

The focus is mainly on the research phase of the products and their picking. About the loading of the warehouse, the literature is much less rich. In fact, systems capable of finding randomly arranged products are studied in depth rather than self-loading systems for shelves. An example is the work done by Francis et al. "Facility layout and location: an analytical approach. Prentice-Hall, Englewood Cliffs" from 1992, in which the Authors discuss about 4 storage policies. The last is the shared one, which allows a product to occupy the place previously assigned to another. This randomness allows shorter loading times but, on the other hand, it requires more advanced systems to search for products.

The warehouse design itself is also the subject of more study. Eynan and Rosenblatt and Wen et al. have studied the influence of the system design, for example the length and height of the shelves and the horizontal and vertical speeds of warehouse cranes, such as overhead cranes and other means, on the optimal storage policy.

The 2014 article "Optimal Storage Assignment for an Automated Warehouse System with Mixed Loading" published by Tokyo University of Science, deals with an automated system with a mixed loading system. The Authors point out that manufacturing industries are converting to small-batch and highly varied productions. This makes a change of policies necessary since, in the case of dedicated positions, shelves would be lacking and therefore more and more spaces would be needed. Starting from this point, we can see the need for systems not only for picking, but also for automatic loading.

Another element that emerges from the existing literature is the importance of the data, which Clive Huby defines as the new oil. Only a measurable system can be improved, so the value of the data is clearly enormous. Linked to the warehouse there is the DWH (Data Warehouse), which is discussed in the article "An Approach for Implementation of Cost-Effective Automated Data Warehouse System" of 2020. Through their analysis it is possible to evaluate trends and send timely alarms in case of values detected outside the set parameters. The Authors analyze different solutions to evaluate the results and the most suitable system is a No-SQL DWH, which allows the Company to effectively manage the Big Data produced in the warehouse.

Thanks to Industry 4.0 technological developments, it is possible in real-time to have a control of the parameters and remotely, from any authorized device, to be able to view the trends and intervene promptly.

As many Authors, including Jay Lee, Hung-An Kao, Shanhu Yang explain in their 2014 article "Service innovation and smart analytics for Industry 4.0 and big data environment", Companies need for rapid decision making in order to cope with an environment increasingly more competitive. The same also happens for the control of the parameters in the Warehouse, both for limits imposed by law on perishable goods and imposed by the Market to remain competitive.

Parameter control is studied in different areas and this testifies to the importance it assumes in the quality of the product. Examples are the article "A review on sensor based monitoring and control of friction stir welding process and a roadmap to Industry 4.0" of 2018 and the article "An approach of developing solution for monitoring the status and parameters of technological equipment for the implementation of Industry 4.0 "of 2020. In the latter the Authors emphasize how fundamental the quality of the products sold is and this derives from the quality of the individual processes and materials. Since raw materials, semi-finished and finished products are stored, for more or less long periods, based on the type of work and on the type of Company, the Warehouse must be well designed in the processes and monitored in the parameters, such as temperature and humidity, so that they are optimal.

III. CONCEPT

In this new version, the system is equipped with product loaders, i.e. tanks inside the drawers within which the Operator can place the products, without particular effort, when they are picked up from the pallets located on the storage racks, normally behind the warehouse (instead of having to insert them one by one into the drawers at a height), and then entrust the full loader to an automated replacement system, which exchanges them with empty tanks, regardless of the height at which the destination drawers are positioned (from the first on the ground at the top). This is achieved by means of an automated rear loading system, based on a single lift system, shared by the multiple columns of drawers, a system hereinafter referred to as the "automatic loading tower".

This tower is configured as a solid steel scaffolding industrial structure on wheels, which moves on rails located at the rear and parallel to the warehouse, for its entire length. In this way, the tower is easily positioned by the Operator by sliding on the rails in correspondence, from time to time, to the column of drawers involved in the replacement. The function of the tower is double and consists both in the automatic extraction of the drawer loader to be replaced and in the replacement of the same with a full loader. The positioning of the tower in correspondence with the column is foreseen both manually (simple, fast and error-proof handling as the system consists of rails and mechanical blocks that guarantee perfect alignment) and, if deemed appropriate by the Company, can be equipped with motorized automation.

In summary, the variants with respect to the system previously in use, provide for the use of special product

loaders for the drawers and an automatic loading tower (which can be positioned by the Operator and activated by him at ground floor level by means of a button control, that allows for drawer selection). In particular, the Authors wish to emphasize that the system automatically identifies the unloading drawer (traffic light logic according to the progressive unloading) and communicates the request to replace the loader to the Operator.

A. Warehouse rear loading process

The Operator can choose whether to replace a drawer when it is empty or when it is partially empty:

- Place the loading tower in correspondence with the column of the drawer to refill;
- Moving a trolley on wheels He reaches the storage shelving behind the picking warehouse;
- Picks up the products and places them easily in the loader which is placed on the same trolley;
- Returns (with the trolley) to the base of the loading tower;
- Confirms to the tower (via keyboard located at the base) the number of the drawer that it intends to replace;
- Operate the tower (by using the same keyboard).

The loading tower is equipped with an automatic vertical sliding lift:

- Automatically positions the lift in correspondence with the selected drawer;
- Extracts the empty loader and presents it to the Operator;
- Automatically removes the loader from the trolley;
- By means of dedicated electronics, the loader is recognized;
- Place the checked loader in the empty drawer.

The system recognizes the full loader (plug and play) and makes it operational.

The picking process and the management logic remain completely unchanged.

IV. Environmental Parameters Monitoring

To solve the problem of punctual control of each single drawer, a special telemetry system has been studied which makes use of an appropriate electronic device equipped with 2 sensors for detecting the relative temperature and humidity inside each drawer respectively as shown in figure 1.

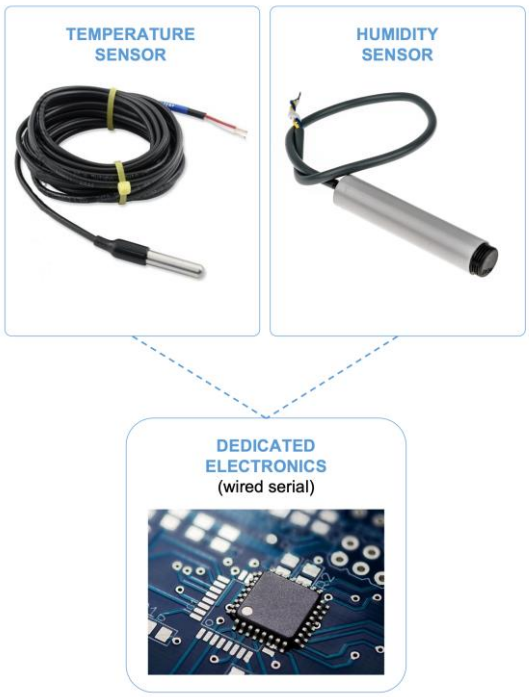


Fig. 1. Peripheral kit for data collection (Sensors / Electronics)

A software was then created for the real time monitoring of these parameters.
The software has been designed in such a way as to ensure that the device sends alert signals whenever an unwanted trend is generated in the progressive measurements of the two parameters or there is an increase in the variability of the same or whether the control limits are exceeded. Special thresholds can be preset for each single drawer.

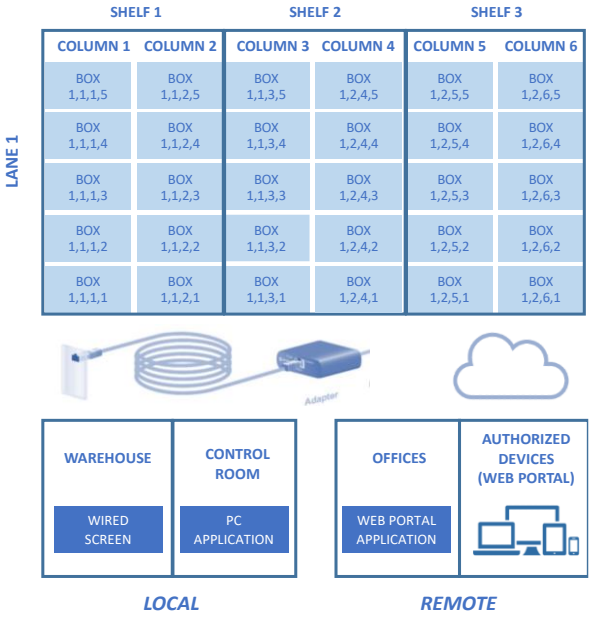
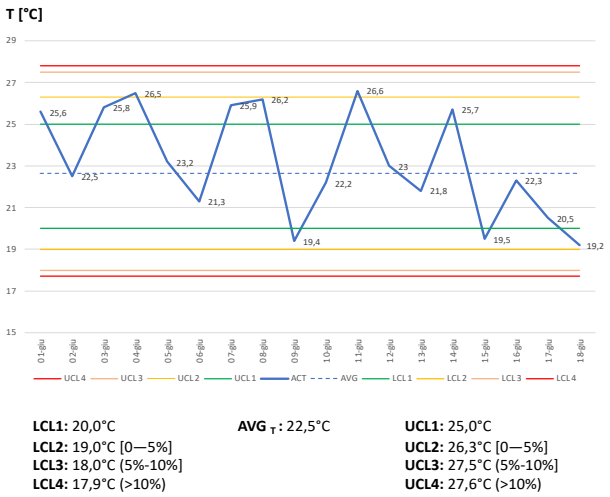


Fig. 2. High level architecture for data collection and communication

Figure 2 illustrates the conceptualization of the system: each drawer to be controlled is identified by means of 4 positional parameters A; B, C, D being A the aisle on which the shelf identified by B faces, C the column of the shelf B in which the drawer is located and D the height location of the drawer.

By the Cloud, the data collected from each drawer are sent to the warehouse management monitor and to the control room, through a special App loaded on the server, accessible via the web portal from any authorized device. As a result of this innovative control method of the 2 parameters T and U monitored in each drawer of the warehouse (made possible by what Industry 4.0 makes available today in terms of sensors, electronics, IOT and Cloud), significant advantages are obtained in stock management, especially of perishable materials including, above all, those of Food and Beverage, Medical Aids and Pharmaceuticals. Among these advantages the Authors wish to highlight the safety for the warehouse Managers, who can thus avoid the deterioration of the stock, as currently occurs due to the persistence of the same in inappropriate climatic conditions. The result is an obvious improvement in the level of Customer service, as well as certain savings obtainable from the avoidance of deteriorated goods or the costs necessary to prevent this to happen (manual measurement by Operators). The new control system also allows (Figure 3) to generate a history of the maximum and minimum values of T and U of each drawer and to implement an adequate method of Statistical Process Control, that can be used to make corrections or improvements to the process, in consideration to that continuous improvement dictated by Industry 4.0.
Finally, please note that this new methodology was deliberately designed to be aligned with the dictates of the ISO 13485 Regulation, in order to apply to the many cases in which it is required.



LCL1: 20,0°C
LCL2: 19,0°C [0—5%]
LCL3: 18,0°C (5%-10%]
LCL4: 17,9°C (>10%)

AVG $_T$: 22,5°C

UCL1: 25,0°C
UCL2: 26,3°C [0—5%]
UCL3: 27,5°C (5%-10%]
UCL4: 27,6°C (>10%)

ACRONYMS:
UCL: Upper Control Limit; LCL: Lower Control Limit; AVG: average; AVG$_T$: average (target).

Fig. 3. Statistical Process Control (Temperature °C)

V. BENEFITS

The Authors wish to emphasize the benefits of the automated loading system, which are mainly reflected in the safety for the Operator who, due to the automation, remains located at ground level, therefore not exposed to any risk of fall. Another important factor is that the Operator is not required anymore to handle heavy weights, which can compromise is spine and generate muscular aches. Impact on safety is provided also for the users of the drugs stocked inside the warehouse, because the continuous control of humidity and temperature (with feedback to the HVAC- Heating Ventilation and Air Conditioning system) guarantees that the goods are correctly maintained and not subjected to overheating, even for short periods. Among the benefits it is possible underline also the speed of the operation and the control functions that make it error-proof and easy to use. This latter advantage is not negligible as it avoids the need for special training of Operators to enable them to govern it, but only the carrying out of some field tests under the guidance of an Expert Technician.

VI. CASE STUDY

Sunrise Company, settled in Cairo Montenotte (Savona, Italy), owned by the Sambin Family, is an important Distributor of medicines and medical devices, having as Customers several Hospitals in Northern Italy. In order to guarantee optimal conditions of relative humidity and temperature in the storage boxes of the products marketed, the Company has decided to adopt the control system designed by the Authors and described in the previous paragraph. The sensors and electronics, necessary for monitoring online and real-time U and T, were therefore mounted on each box in the warehouse. To better understand the ease of the control action (that can be performed at a glance) it is provided below (Fig. 4) a screenshot of the Software installed on the Server, which is accessible by any authorized device.

Thanks to the use of the color code, which highlights normal conditions (green up to 3%) and critical conditions, in the event of progressive deviation from the threshold values, equal to +/- 3.1-5% (yellow), 5.1-10% (orange),> 10% (red), the monitoring and control Operations were extremely simplified for the Operator (as shown in figure 4).

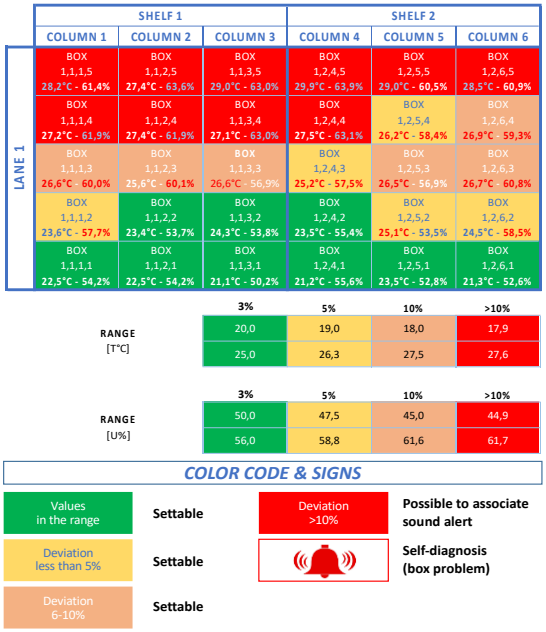


Fig. 4. Monitoring and Control Software (operative screenshot)

In the figure 5, which represents Sunrise implementation, it can be observed the flexibility of the system being adapted to the installed boxes by simply including the electronics in 3D printed enclosures, which fits (by interference) into the handle of each box.

Please note that, acting this way, the “environmental parameters monitoring” is applicable to any kind of warehouse (not only to the automated picking warehouse); in fact the system has already been required by multiple Companies, being in need of controlling such parameters due to the sensitivity of the stock to thermal shocks.

In a Company like Sunrise, which has always guaranteed the absolute integrity of the products to the Customers as pride of its management philosophy, this new feature allowed them to further improve this basic business principle, as well as to obtain the UNI ISO 13485 certification.

Previously, to preserve the integrity of the products in those cases in which faults in the air conditioning systems might have compromised such integrity, the Company proceeded to dispose of the products hypothetically being damage, taking on the related costs.

Fig. 5. Peripheral data collection, Sunrise implementation

VII. Conclusion

The new features introduced further improve the performance of a Plant that had, during years of Operations, proved to be capable for carrying out the tasks required by the business. On the other hand, the excessive ease of the Operators assigned to the loading phase, continuously generated a potential danger for the safety of the same, therefore the Authors, always attentive to Smart Safety issues, see [2], took moral responsibility to intervene with appropriate modifications to protect the Plant from visible or hidden risks. The request from multiple Companies in the Food & Beverage and Medical Sectors led the Authors to introduce a system for controlling the microclimate of each single location (i.e. box level) in the warehouse. Thanks to the Technology nowadays available on the Market, deriving from Industry 4.0, the Authors have been able to implement these innovations, allowing host Companies to increase the service level and to eliminate potential dangers. All this with a view to continuous improvement and, therefore, the Authors will remain vigilant on the Market to monitor any new Technological opportunity to make the system progressively more effective and efficient. The limits of the system proposed are still in the integration with the HVAC system, due to the fact that the control of humidity and temperature parameters is peripheral, in every single drawer, while the HVAC function is today centralized. Although the system already allows to prevent overheating, the energy management is still not optimized, in fact the HVAC is activated at the threshold of the critical drawers, so refrigerating all drawers through the surrounding environment. The objective of the research for the next future is to focus on a system of selective refrigeration, based on a central HVAC, but with local distribution.

VIII. SPECIAL THANKS

The Authors of the Paper feel the duty to thank the Properties, Managers and Operators of the "Fratelli Carli" and "Sunrise" Companies who, allowing for a constructive comparison on the possible improvements to be made to their systems, with the scope to make them more suitable to meet the their needs. Such availability made it possible to conceptualize the system described, which represents a sure step forward for the spread of picking 4.0 and environmental parameters monitoring to other Companies, with the benefits that derive from this.

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