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TOPSIL FLEXIBLE CELL FOR THE SORTING OF CBRN BOTTLES

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Abstract: *The integration of industrial robots into flexible manufacturing cells plays an essential role in more and more manufacturing fields. In this paper the possibility of using a flexible manufacturing cell in the military domain is analyzed. The present work highlights the importance of designing a flexible cell for CBRN (Chemical, Biological, Radiological and Nuclear) weapons that is intended for handling and sorting vials with hazardous substances, thus significantly reducing the risk of human factor contamination.*
Keywords*: flexible cells, industrial robot, CBRN, human-artificial partnership, technological humanism*

1. INTRODUCTION

Over time, industrial robots integrated in flexible manufacturing cells have significantly expanded their fields of use, making them indispensable in modern production processes.

Advanced technologies have also begun to play a crucial role in the defense sector, where modern militaries use technological innovations to improve their capabilities, reduce the risks of human intervention and support conventional technology.

This paper presents the possibility and importance of designing and implementing a flexible manufacturing cell developed by industrial robots within the CBRN weapon to reduce and replace the human factor in certain operations involving the use of harmful substances, thus leading to decreased risks of contamination and endangerment of military personnel.

The present scientific paper illustrates the 3D principle design of a flexible cell that aims at handling and sorting the vials according to their color, thus separating harmful from non-harmful substances and allowing the human factor to accurately monitor the process remotely, without contamination or other risks.

2. CURRENT STATUS

Chemical, Biological, Radiological and Nuclear emergencies are those involving CBRN agents (e.g. toxic and hazardous chemical substances/materials, chemical and biological warfare agents, toxic radiological materials, etc.) [1].

The military field has started to increasingly use synergy with robotics, and the CBRN military is a prime example as they are increasingly using robots and robotic technologies in their operations to streamline and lower the risks.

Most of the robots used by the CBRN army are four-legged, tracked or wheeled robots for mining, demining, handling hazardous substances and many other operations involving human factors risks. Because military operations are very complex and diversified, many of these robots are designed to be serial-modular construction so that they can be configured according to the need of the application for which they are deployed.

The industrial robots frequently used in flexible manufacturing cells are ABB robots (Figure 1).



Fig. 1. ABB Robot flexible cell [2]

They are easy to integrate and reprogram for various operations and product types. In such cells, they are used for part handling (loading/unloading at CNC), transfer between stations, palletizing, assembly, and sometimes for processes such as welding or inspection, helping to reduce cycle times and increase production flexibility and repeatability.



Fig. 2. Crawler robot for CBRN applications [3]

An example of the robots used in the CBRN missions is the CBRN tracked robot (Figure 2), which is a medium-sized tracked robot used for both Chemical, Biological, Radiological and Nuclear threat detection and Improvised Explosive Device (IED) recognition and neutralization. Due to its size and the type of propulsion system it uses, it can take part in operations in confined spaces as well as in difficult rough terrain conditions.

Collaborative robots (Figure 3) are also frequently found as elements of flexible manufacturing cells, as they can work safely near operators and easily adapt to product or process changes. They are used primarily in operations such as assembly, light part handling, machine tending, packaging, or visual inspection.

Flexible cells in which operations within them are performed by robots are called "robot cells" [5].

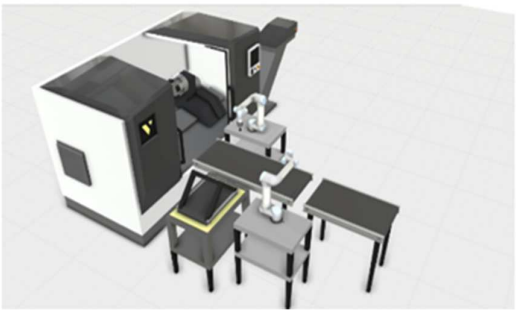


Fig. 3. Flexible cell with collaborative robots [4]

According to Figure 4, robotic flexible cells are often used in tasks involving risks to human factor health, in areas involving pressing, cutting, hot forming, high temperatures, hazardous substances or other processes that may cause injury or other harm to the human factor.

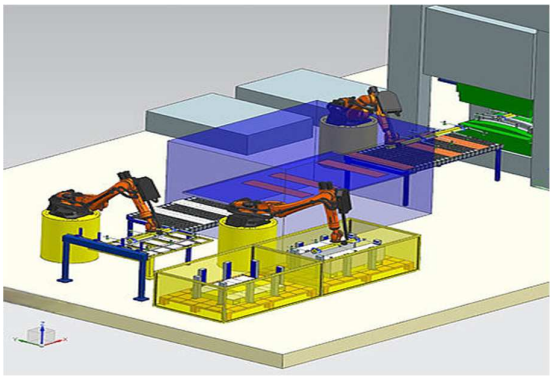


Fig. 4. Press cell, hot forming [6]

Despite the existence of more and more robotized technologies to serve the military field, so far in specialized literature there is no mention of the existence of flexible robotized cells exclusively dedicated to the sorting or handling of CBRN vials.

3. PURPOSE OF THE WORK

This paper presents the development of an advanced mechatronic system, which integrates an industrial serial-modular robot to configure a flexible manufacturing cell for handling and sorting of CBRN vials. The purpose of the flexible system is to identify and separate the vials according to color, distinguishing between those containing toxic or hazardous substances and those with non-hazardous substances. The technological process begins with the selection and design of an industrial robot, of serial-modular construction, capable of handling vials of various sizes, thus ensuring precision and speed of execution. The color recognition system uses advanced sensors integrated with the robot control system to enable fast and accurate classification of CBRN bottles. The gripper is designed to be adaptable and to ensure a precise/safe grip without the risk of breakage or leakage of the bottles. The materials in the robot's organic component must be

resistant to chemicals and comply with operational safety standards. The testing and optimization of the system aims to ensure accuracy, flexibility and safety, while complying with the rules for handling hazardous substances. The ultimate goal is to streamline the sorting process and reduce the risk of illness/accident to human operators. By flexibly automating the process of identifying and separating vials according to color and content, the system eliminates the need for direct involvement of human operators in the handling of hazardous substances, thereby reducing exposure to chemical, biological, radiological or nuclear risks.

4. SYSTEM COMPONENTS

Each system component was individually designed in the 3D CATIA environment, ensuring accurate and detailed modeling. Components, such as the industrial robot, gripper, sensors, color recognition camera and transport system, were designed according to technical and functional specifications.

After finalizing the individual designs, all components were assembled into a complete virtual assembly in the CATIA environment. This virtual assembly process allowed the verification of the geometrical compatibility between the components, the simulation of relative motions and the identification of possible interferences or collisions. Following this step, structural adjustments and optimizations were performed to improve the overall functionality of the system, thus ensuring an efficient and safe deployment under real operating conditions.

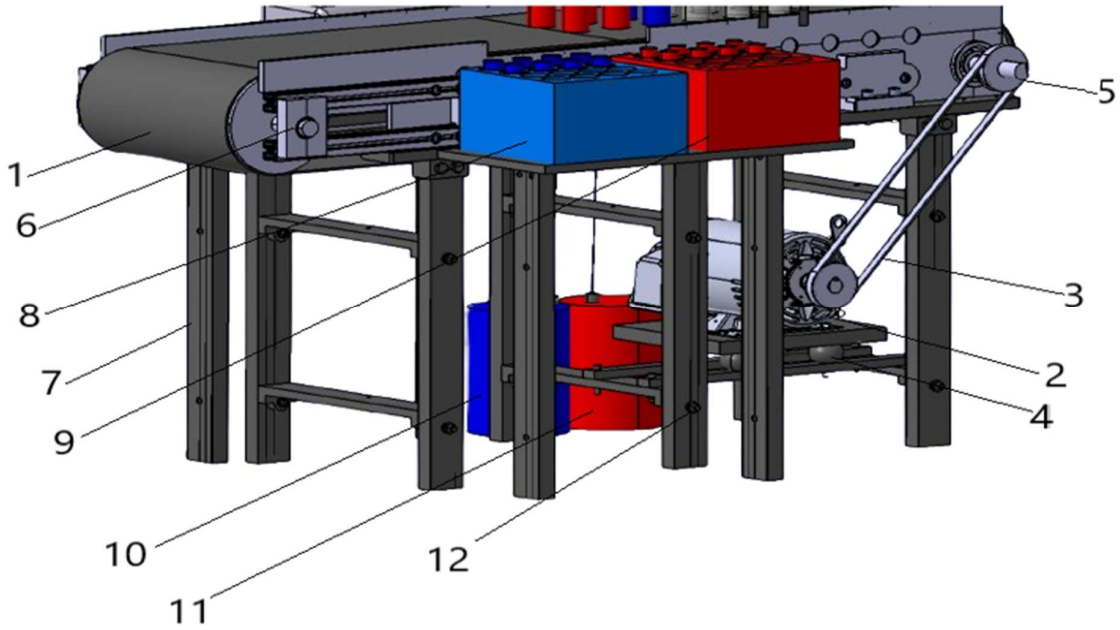


Fig. 5. Legend CBRN components (own contribution)

Figure 5 marks the components at the bottom of the CBRN flexible vial sorting cell as follows:
1. Conveyor belt,
2. Three-phase AC motor,
3. Transmission belt,
4. Vibration drum,
5. Drive drum,
6. Stretching system,
7. Support legs,
8. Blue vial storage box,
9. Red vial storage box,
10. Container for non-toxic substances,
11. Container for toxic substances,
12. Fixing screws.

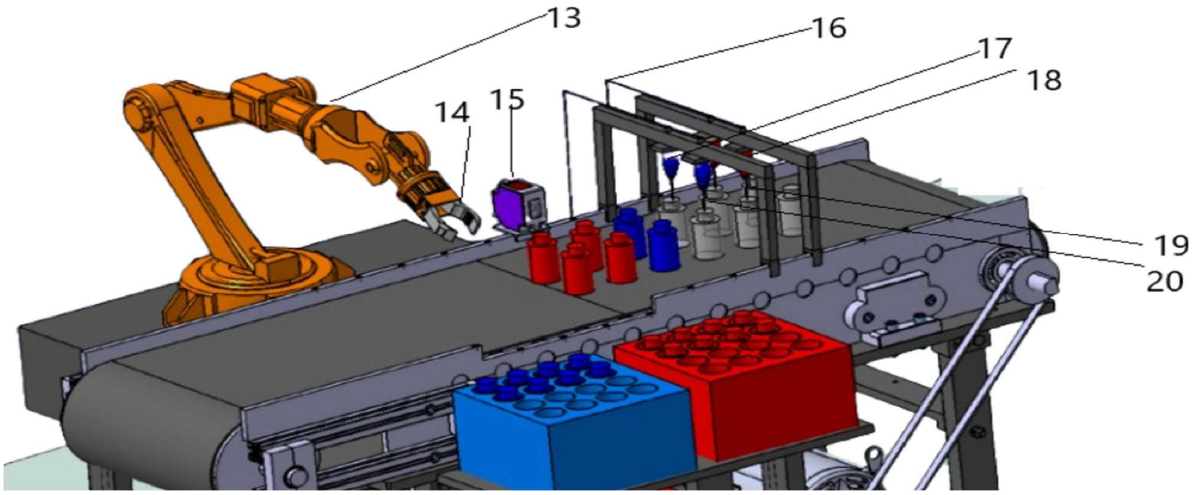


Fig. 6. Legend CBRN cell components (own contribution)

In Figure 6 the components in the upper part of the flexible CBRN vial sorting cell are labeled as follows:
13. Robotic arm,
14. Gripper,
15. Color sensor,
16. Piping for liquid transportation,
17. Filling system for non-toxic substances,
18. Filling system for toxic substances,
19. Toxic substance filling line,
20. Filling line for non-toxic substance.

The entire assembly is housed in transparent side walls (Figure 7), designed to provide full visibility of the robotic work area while maintaining an adequate level of physical separation between the operator and the potentially contaminated environment. These walls serve to prevent accidental exposure of personnel to CBRN agents by creating a structural barrier that limits direct access to the operational area.

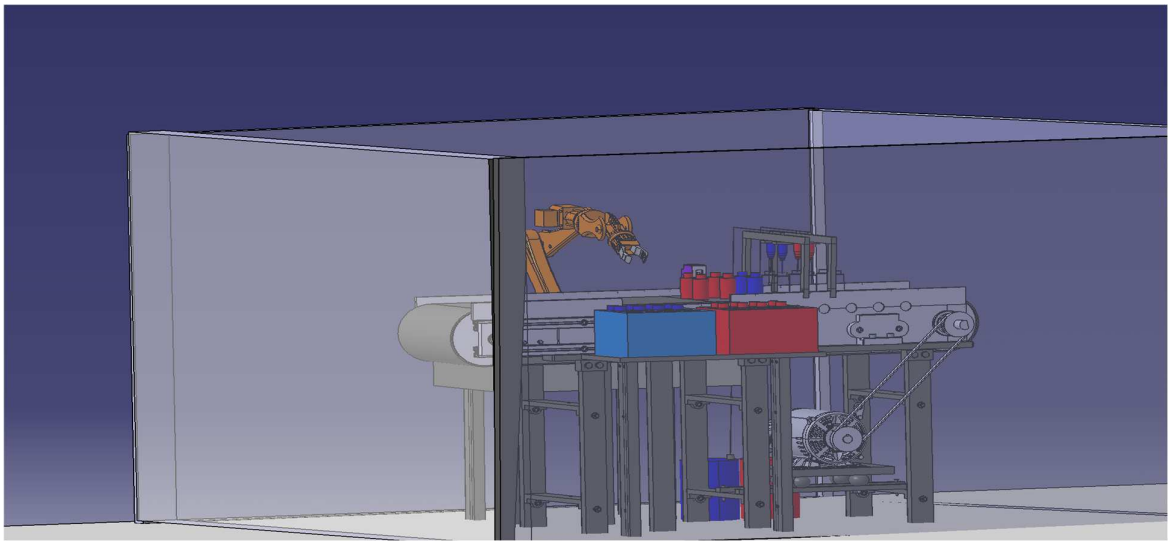


Fig. 7. Safety glass panels (own contribution)

The transparent panels are made of resistant materials, such as polycarbonate or laminated glass, which provide mechanical protection and structural stability in working conditions specific to CBRN environments. These walls have the advantage of allowing permanent visual supervision of the process without the operator having to enter the isolated space.

The human operator can position themselves wherever they deem necessary (Figure 8) to monitor the process, thanks to the transparency of the walls and complete visual access to the robotic work area. The flexibility of positioning is complemented by remote control systems, which allow the operator to monitor and intervene in the process without physically approaching the potentially contaminated space or the moving mechanisms.

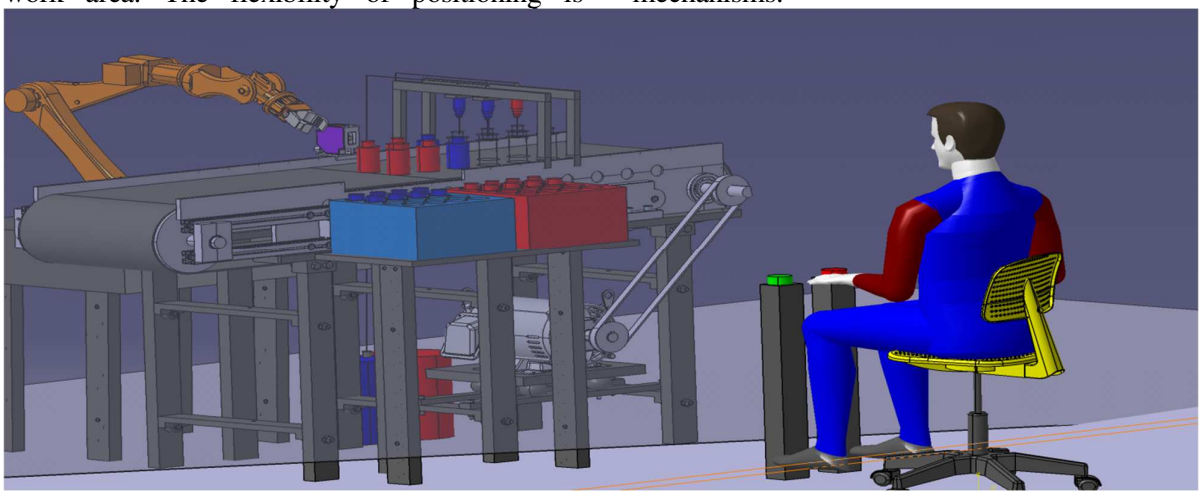


Fig. 8. Human operator (own contribution)

5. SYSTEM DESIGN

The CBRN flexible vial management cell, implemented on a conveyor belt, is an advanced system designed to ensure efficient, accurate and safe handling of toxic and non-toxic substances.

The vials are color-coded for quick and accurate selection: red vials indicate the presence of toxic substances, while blue vials are for non-toxic substances.

Figure 9 shows the rollers made of high-quality stainless steel, which play a crucial role in ensuring the smooth and continuous operation of the conveyor belt.

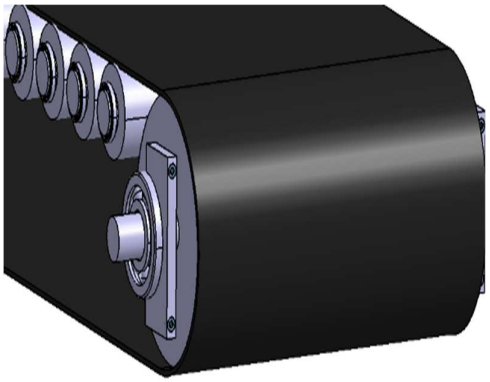


Fig. 9. Conveyor belt support rollers (own contribution)

These rollers are strategically positioned along the conveyor system to support and guide the belt during its movement. Each roller is equipped with precision bearings at both ends, which significantly reduces friction and allows for effortless rotation, thereby enhancing the overall efficiency of the system. One of the key features of these rollers is their quiet operation, which makes them ideal for use in environments where noise reduction is important. In addition, their modular design allows for quick and simple installation or replacement, minimizing system downtime.

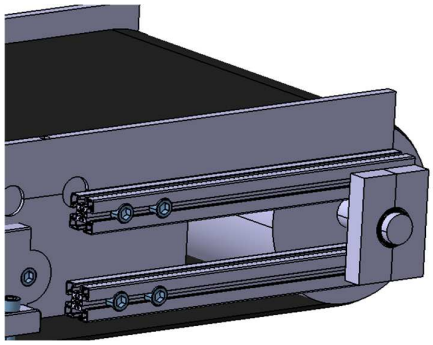


Fig. 10. Belt stretching system (own contribution)

According to figure 10, Bosch profiles [7] have been used for the stretching system because they give a very high flexibility, thus making it possible

to easily move the mobile system to the left or to the right so that the belt can be stretched to its maximum, resulting in a proper and optimal operation.

During operation, the belt is exposed to different types of loads - tension, bending, fatigue, creep, impact, etc. It is exposed to various weather conditions such as sun, rain, cold or frost. Due to the combination of the above factors, the belt is a highly loaded element of the conveyor [8].

The belt used in the transportation system is made of high-strength rubberized material, (Figure 11), specially chosen for its grip and flexibility.

The outer surface of the belt has a high degree of adhesion, which facilitates gripping and stabilization of the transported objects, preventing them from slipping during transportation.

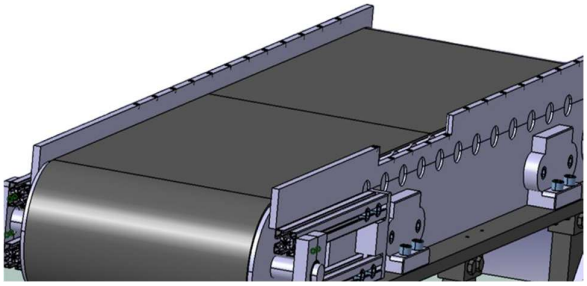


Fig. 11. Conveyor belt (own contribution)

Due to the controlled elasticity of the material, the belt can absorb mechanical shocks caused by load variations or frequent stops and starts of the system without compromising the overall functioning.

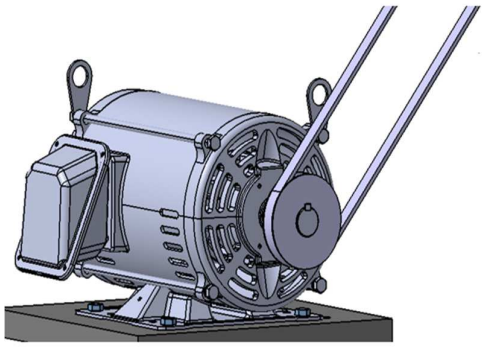


Fig. 12. Motion transmission (own contribution)

Figure 12 illustrates the mechanism for transmitting the motion from the electric motor to the gear drum, realized by means of a gear belt between the two components. This constructive solution allows an efficient transmission of the motor speed, ensuring the drive of the gear-wheel drum. Once set in motion, the drum causes the conveyor belt to move continuously, ensuring a constant flow of ampoules to the sorting area. The mechanism is sized and calibrated to guarantee a uniform transmission of motion without shocks or speed variations, thus contributing to the stability of the system.

In addition, the use of the belt as a transmission element offers important advantages such as damping vibrations, reducing running noise and minimizing wear on mechanical components.

The entire drive system has been designed for continuous operation with low energy consumption and extended component life.

The vibration aspect of the engine is one that needs to be treated very carefully and for this reason the four elastic buffers have been added to further dampen vibration and shock (Fig. 13).

The pads serve to absorb shocks and reduce vibrations transmitted to the structure, making the system more stable, quieter, and more reliable. The circular design is used to distribute the load and vibrations more evenly and to better compensate for minor misalignments, protecting the motor and gear components and extending the life of the mechanism.

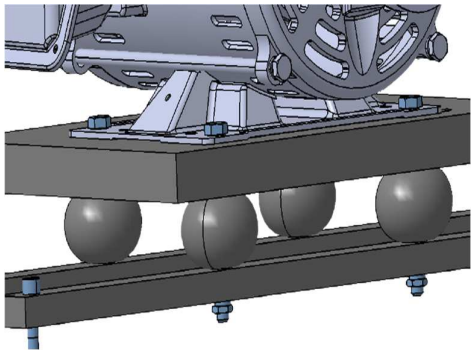


Fig. 13. Vibration damping pads (own contribution)

Vial selection is performed using the color sensor located on the side of the belt and fixed to a support plate (Figure 14).

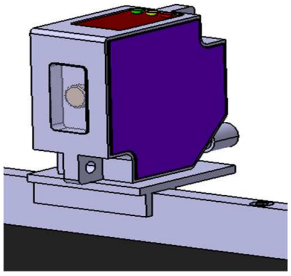


Fig. 14. Color sensor (own contribution)

The process starts with placing the vials on the conveyor belt, which is driven by a three-phase asynchronous motor, ensuring a continuous and controlled movement. The conveyor belt is equipped with guides and positioning sensors to keep the vials in proper alignment, thus preventing blockages and deviations from the optimal path.

Each vial is then routed to a specialized filling system, where separate units handle the loading of substances into the appropriate containers. Thus, toxic substances are transferred into red bottles and non-toxic substances into the blue bottles.

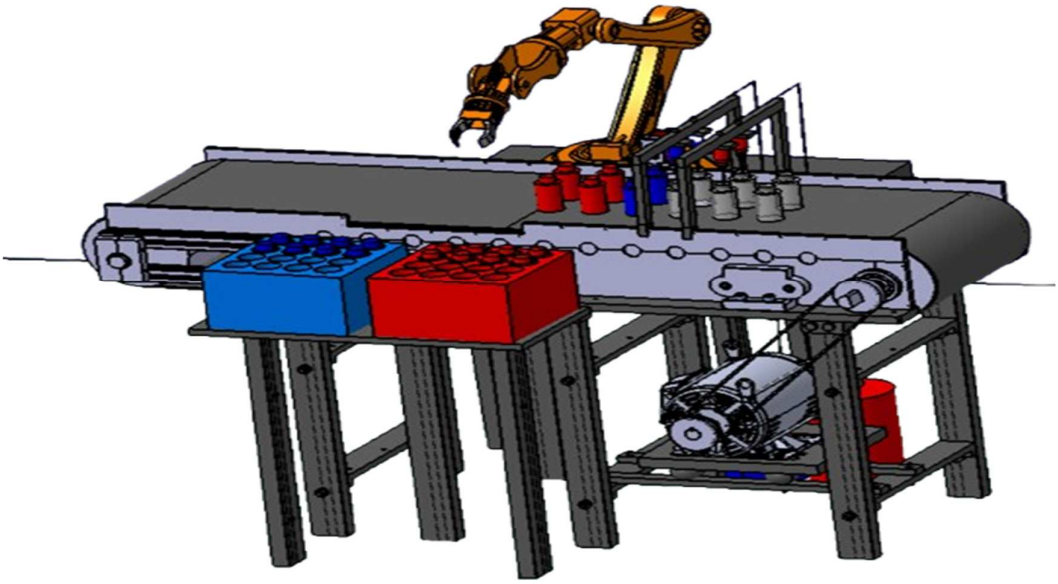


Fig. 15. CBRN cell - overview (own contribution)

According to Figure 15, after the filling stage, in the technological itinerary, the bottles undergo an automated visual analysis process, performed by a high-precision color sensor. This sensor can detect the exact shade of each bottle and identify any deviations from the pre-established standard. Following detection, the system automatically classifies the containers into categories corresponding to their colors, thus ensuring fast and error-free sorting. The collected data is transmitted in real time to a central control system, which monitors and coordinates the entire operational flow, synchronizing the analysis stage with the other processes in the technological itinerary.

To automate handling and sorting tasks, a serial-modular type SCARA industrial robot with 5 degrees of freedom (RRRRR) is integrated into the system, as shown in Figure 16. The robot's role is to pick up the bottles after they have been identified and classified by the sensor, lift them, and place them on conveyor belts or in areas dedicated to each color category. Thanks to its modular architecture and kinematics, the robot can adapt its movements in real time to variations in the position or size of the bottles, ensuring accurate and fast sorting. The integration of the color sensor with the SCARA robot allows for the creation of a fully automated process, reducing the need for human operator intervention and increasing the efficiency and safety of the entire production flow.

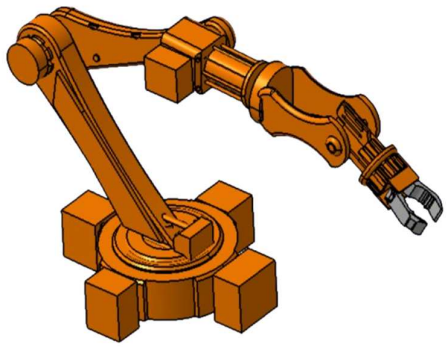


Fig. 16. Industrial type SCARA robot (own contribution)

SCARA-type industrial serial-modular robots are among the most widely used robots in

industry due to their inherent rigidity and high accuracy [9].

A horizontally rotating, selectively compliant articulated robot arm (SCARA) has four degrees of freedom (DOF), with two or three servo-controlled horizontal joints for the shoulder, elbow, and wrist [10], [11].

It is equipped with a specialized gripper designed to ensure safe and precise handling of the vials, regardless of their position on the conveyor belt. The gripper is mounted on an automatically controlled robotic arm, which acts on information received from the color sensor.

This sensor identifies the color of each vial that reaches the detection zone and transmits the signal to the robot control system. The robotic arm then picks up the identified vials and places them in the appropriate compartments: the red vials containing toxic substances are directed to a secure compartment specially designed for these materials, while the blue vials containing non-toxic substances are stored in a separate compartment for safe substances. The entire process is automated, helping to ensure fast, accurate and efficient sorting, minimizing the risk of contamination, human error and hazardous exposure, thus guaranteeing safe and controlled handling of sensitive materials.

6. CONCLUSIONS AND DISCUSSIONS

The present work demonstrates that the design of a flexible cell for color sorting of CBRN vials is feasible and can significantly reduce the risks to military personnel involved in such operations. Using advanced detection, transport, sorting and handling technologies can significantly minimize exposure to hazardous substance contamination. Automating the process associated with manual handling of CBRN vials eliminates the need for direct human intervention, thus reducing the likelihood of chemical, biological, radiological or nuclear accidents.

The designed flexible cell is scalable and can be adapted for different military scenarios as well as for different types of CBRN substances.

Its versatility makes it useful in a variety of operational contexts, from reconnaissance and collection missions to hazardous materials management in conflict or post-conflict zones.

The colors used in this paper are not standardized and do not comply with the color palettes established in the specialized literature, as the model presented is a cell for educational and demonstration purposes. The choice of colors was mainly oriented towards visual clarity and facilitating the understanding of operating principles, without seeking compliance with industry standards specific to robotics or CBRN environments.

In an educational context, the emphasis is on highlighting functions, components, and operational flows, which is why the colors were selected to contribute to a clear and immediate perception of the structure of the whole.

Therefore, the color coding used in the model should not be interpreted as a reference for real or industrial applications, but as a visual tool intended to support the learning, demonstration, and technical communication process.

The serial-modular design of the cell also allows for the integration of new technologies or components in the future, thus ensuring high adaptability to the ever-changing industrial requirements of the military system. Although the implementation of such a flexible cell may involve significant initial costs, the benefits in terms of operational efficiency, personnel safety, and the possibility of automating critical processes fully justify the investment.

At the same time, it is important to emphasize that this cell is only an intermediate stage in a much broader technological itinerary, which, in its mature variants, should include an extensive set of robots, conveyor belts, handling systems, and a sequence of operations specific to a fully automated flexible cell. Thus, the configuration presented is a demonstrative starting point, with the role of validating the modular concept and highlighting the potential for further expansion.

In conclusion, the flexible cell represents an innovative and efficient solution for the management of CBRN flasks, with significant potential for improvement and integration into modern military systems. With further research and development, this technology can make a substantial contribution to increasing the safety

of the military and improving the efficiency of operations involving hazardous substances and beyond.

7. FUTURE RESEARCH DIRECTIONS

The flexible cell will be integrated with military mobile robots to form a complete system for selecting and sorting CBRN substances. The development of communication interfaces between flexible cells and other military systems, enabling centralized management of CBRN materials, is essential for the safe and efficient operation of the entire system.

Future research directions will include testing the system under extreme and varied conditions to assess its performance, efficiency, and reliability in diverse and unpredictable operational scenarios.

Simulation of complex military operation scenarios will also be used to identify and correct any vulnerabilities in the system, while exploring the advantages of modular design, which allows rapid adaptation to different types of missions and operations.

Future research directions will focus on the development and integration of additional robots, the optimization of functional routes, the automation of material handling through conveyor systems, and the implementation of complex operational scenarios characteristic of modern industrial and military environments.

Expanding the current architecture involves setting up a collaborative network of autonomous equipment that interacts coherently within the same cell, enabling intelligent transfer of parts, synchronization of tasks, and real-time adaptation to process variations or mission requirements.

Another key aspect in the evolution of the concept is the integration of emerging technologies, such as advanced sensors for contaminant detection, predictive monitoring algorithms, automated diagnostic systems, and standardized communication protocols between robotic modules. These technologies can contribute to increased operational autonomy, reduced human intervention, and enhanced safety in sensitive applications, including in the CBRN field.

Attention will also be paid to the development of efficient energy solutions, such as solar batteries, to take over a larger share of energy consumption and increase the autonomy of the system in the field. At the same time, methods of securing flexible cell systems against cyber-attacks or other types of threats will be investigated through the implementation of encryption and authentication protocols, so that data integrity is ensured and the system is used exclusively by authorized military personnel.

Partnerships with military and research institutions will be proposed to ensure the development and implementation of flexible cells in accordance with the actual requirements of the various armed forces. Artificial intelligence factors will be tested for the implementation of a predictive maintenance system capable of anticipating the need to replace or repair components by continuously monitoring their performance before any defects affect the functioning of the system. For the operation of the cell, training programs will be developed for military personnel, which will include virtual simulations, conducted through virtual reality (VR) or augmented reality (AR) platforms, as well as practical field exercises, allowing direct interaction with the flexible cell under controlled conditions. In addition, an intuitive and easy-to-use interface will be developed to enable non-engineering personnel to operate the system efficiently. Thus, the simulations will provide the opportunity to practice complex operational scenarios without exposing personnel to real risks.

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Celula flexibilă *Topsil* destinată sortării flacoanelor CBRN

Rezumat: Integrarea roboților industriali în cadrul celulelor flexibile de fabricație joacă un rol esențial în tot mai multe domenii de producție. În această lucrare se analizează posibilitatea utilizării unei celule flexibile de fabricație în domeniul militar. Lucrarea de față reliefează importanța proiectării unei celule flexibile destinate armei CBRN (Chimice, Biologice, Radiologice și Nucleare) care este destinată manipulării și sortării flacoanelor cu substanțe periculoase, reducând astfel semnificativ riscul contaminării factorului uman.

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