TECHNICAL AND SCIENTIFICAL REPORT, STAGE 4 (2021)
PROJECT 1

Design, modelling and in-service simulation of distributed configurations of sensors and visual servoing systems on complex autonomous systems (CAS-SI, CAS-ARP, CAS-VAM), intended for personal medical and social assistance technologies, in / out of hospital and at home.

4th Stage

Testing, by simulation and real-time, in laboratory mode, of the integrated technologies of medical-social assistance and service of flexible precision manufacturing lines

Activity 4.1 *Real-time functional testing of the integrated sensory system. Dissemination of results*

Activity 4.1 Real-time functional Testing of the integrated sensory system. Dissemination of results

4.1.1 Human-machine interface for robotic arm control for people with special needs

Our goal is to extend the intelligent seat control interface presented in previous reports by adding the possibility for the user to control a robotic arm. Our approach to implementing this functionality is to create an intelligent and intuitive menu that helps the user switch from one mode of operation to another: the movement of the wheelchair and the control of the robotic arm. This interface also contains a button for a predefined movement, which we call "Parking". This action will withdraw the robotic arm to a position where it cannot collide with the surrounding obstacles. The user can select this action while using the interface, but this action will be performed automatically when the user exits the robotic arm control menu.

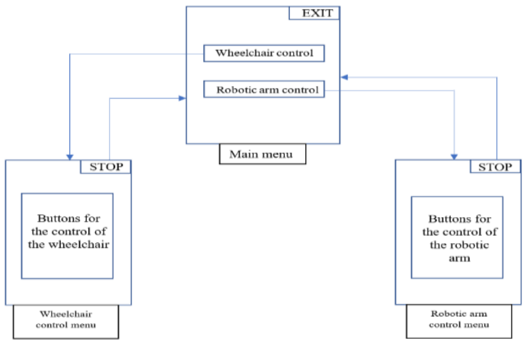


Fig. 4.1.1. User interface diagram

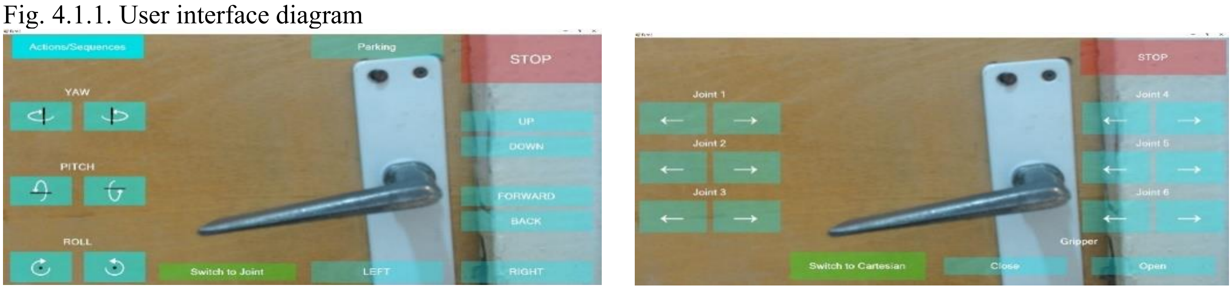


Fig. 4.1.2. Cartesian mode user interface (left) and "Joint" mode (right)

All interface controls are correctly labelled so that the wheelchair user can distinguish each button and its role.

On the final effector of the robotic arm, we mounted a webcam so that the user has a clear view of the direction of the robotic arm without having to change the look between the interface and the current position of the arm (Fig. 4.1.3). In addition, webcam images are displayed as the background for the interface. The buttons have a transparent colour so that the two components, the buttons and the wallpaper, do not interfere, providing a clear view for the user.

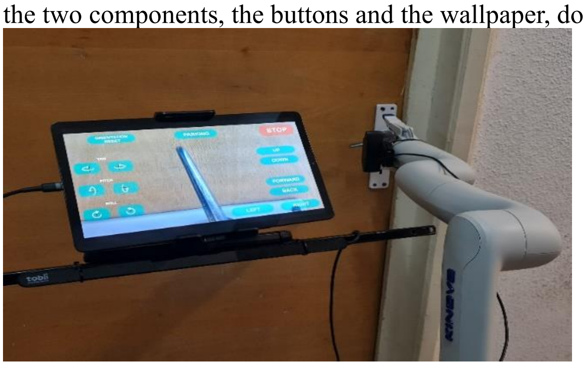


Fig. 4.1.3. Webcam mounted on the final effector and the image displayed on the interface

In the current development phase, the robot arm can be used to help the user in the usual fundamental interactions, such as opening the doors, holding a book to read or holding a bottle of water (Fig. 4.1.5).

Fig. 4.1.5. Daily activities with the help of the robotic arm attached to the wheelchair

4.1.2 Simulation of the movement of the mobile platform in environments with static obstacles by applying the potential algorithm on a three-dimensional space scanned using a LIDAR device

With the help of a LIDAR device (Velodyne LiDAR Puck 16), a series of three-dimensional spaces were scanned, located inside the Faculty, containing static obstacles (structural elements of the building, alveoli and entrances, access roads to other areas of the building.

Records were obtained, and tests were performed for several scenarios: movement in the hall of the department (figure 4.2.1), identification of passage areas from one space to another space (such as access roads, doors - figure 4.2.2), or moving in a foyer-like space (figure 4.2.3). In addition, the area made acquisitions for real-time local navigation (figures 4.2.1 and 4.2.2), and mapping data - zonal assets were merged into a mapped region, resulting in a map of the space on where the mobile platform moved (figure 4.2.3). Because the use of a location in absolute coordinates of the platform is defective (using a GPS device will lead to significant location errors due to the very weak GPS signal), it was preferred to use the LIDAR and a compass sensor. Provides information on the orientation of the mobile platform, as well as with an inter-scan processing algorithm, which determines the meaning and amplitude of the movement of the mobile platform in space.

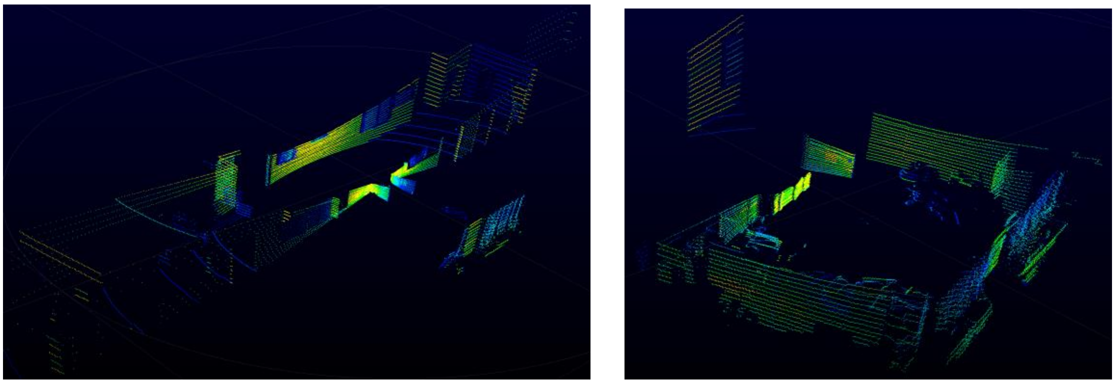


Fig. 4.2.2 – Switching from one space (left image - hallway) to another area (right image - laboratory)

Figura 4.2.3 – Three-dimensional space scanned with the Lidar LiDAR Puck VLP-16 device

The recordings were imported into the Simulink Matlab environment. In addition, the project's control algorithm based on the artificial potential field method proposed by Activity A 4.1 was implemented in the Simulink Matlab environment. The trajectories of moving the mobile platform in an autonomous regime were generated, imposing different points (start, destination) for different scenarios. Two of the trajectories obtained by applying the control algorithm based on the artificial potential field method for mapped regions are represented in Figures 4.2.5 and 4.2.6.

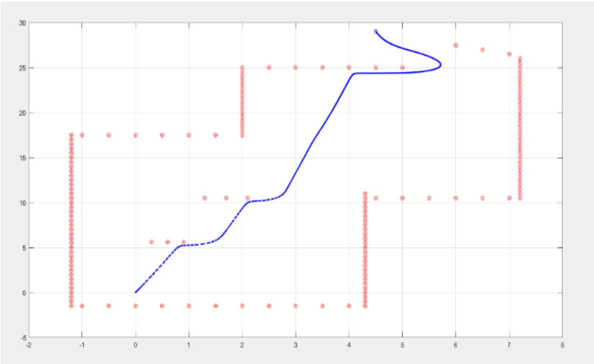


Fig 4.2.5 – The trajectory of the platform mobile in the autonomous regime between points Ps_1 și Pt_1

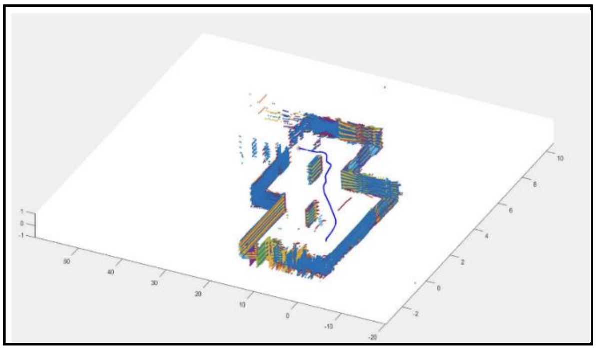


Fig 4.2.6 – The trajectory of the platform mobile in the independent control between points Ps_1 și Pt_1

4.1.3. Fuzzy control of the Kinova Gen3 lite assistance robot for people with personal needs

Intelligent and autonomous robotic wheelchairs are a combination of the robotic arm and the automatic movements of the algorithms that allow the user to use the wheelchair for intuitive navigation and more. These systems seem ideal for people with locomotor disabilities, but there is a lack of such systems on the market. Undoubtedly, many types of research have been done, and many prototypes have been built, but this type of compound is not so widely used.

Thus, there are not many projects in this category that are among the most challenging systems developed. Composing algorithms and using robotic manipulators is a difficult task for a single person. There are not many teams working on creating this type of system.

The proposed robotic chair is a mobile robot that can transport a person. It is equipped with several sensors to avoid obstacles, build maps, locate, detect people, etc. It is also equipped with motor controllers and other actuators for motion control.

Kinova Gen3 lite support robot

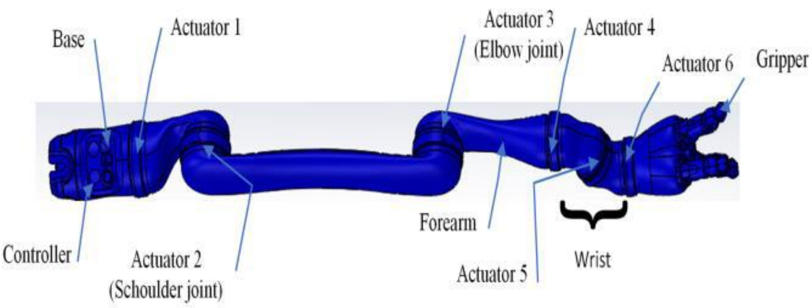


Fig. 4.3.1 The main components of the KINOVA Gen3 lite robot. CAD simulation

Fuzzy control has been developed for the arm attached to the electric wheelchair, which we consider more suitable for a person with locomotor disabilities. We also present some 3D simulation tests. The controlled robotic arm has a level of redundancy (arm with 6 degrees of freedom without taking into account the degrees of the hand), which we consider effective in manipulations in the open environment.

The control system developed in our previous research, in which we studied an ideal continuous arm, allows the introduction of fuzzy methods to implement regulators. The fuzzy analysis will be done if the desired position is stationary. The paper's starting point is developing a fuzzy control law that starts from conventional dynamic control through the formation of relationships. A closed-loop control system has been proposed to obtain the desired position using the mathematical model of the robot as:

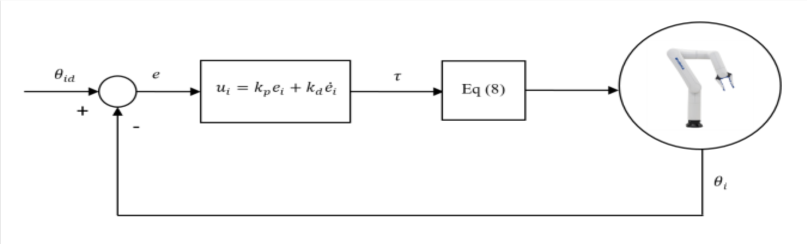


Fig. 4.3.4 Closed-loop control system to obtain the desired position of the robot arm

Simulation tests. The inertial reference system for the robot's movements is considered the reference system at the level of the mobile base of the wheelchair. The simulation results are suggestively illustrated in Figs. 4.3.5, which can track the initial, final and intermediate positions, respectively.

We consider that the initial position of the robot is raised to the maximum vertical position. Next, the robot is controlled to move to an intermediate position where it takes the glass. The robot is then manipulated to move to the final position (desired position), namely, bringing the glass to the person.

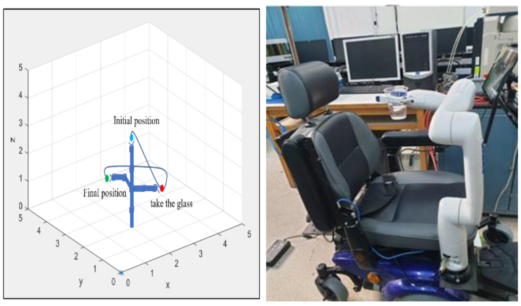


Fig. 4.3.5 Test 1: The robot brings a glass to the person in the wheelchair

The second test simulated and performed on the physical robot consists in inserting a plug into the socket. The simulation results are illustratively illustrated in Figure 4.3.6, which can follow the initial and final positions. The simulation conditions are similar to those of the first test.

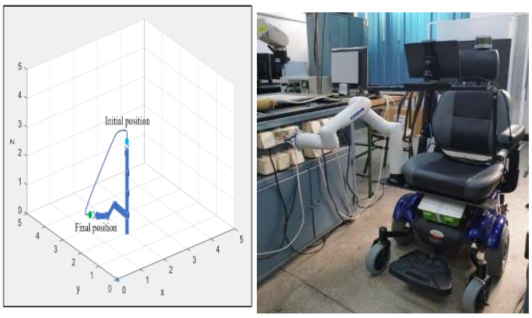
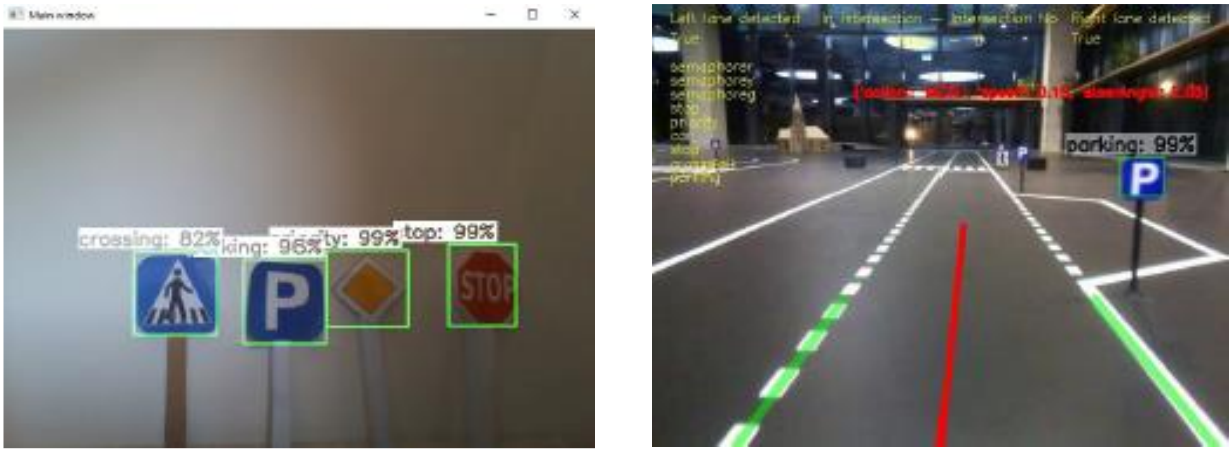


Fig. 4.3.6 The robot inserts a plug into the socket

4.1.4. Testing, by simulation and real-time, in laboratory mode, of the sensor system for the mobile platform

Another alternative for testing the sensory system was the participation of a team of students, under the tutelage of project team members, in the Bosch Future Mobility Challenge, 2021. Bosch Future Mobility Challenge is an international technology competition organized by the Bosch Engineering Center

from Cluj, Romania. The first competition was organized in 2017-2018. The main objective of the competition is the development of autonomous driving algorithms and their implementation on the vehicle at a 1/10 scale. The competition has a clear timeline, which spans six months. During this time, the team must prepare four technical documentation to present how the required steps have been reached in defining responsibilities, scheduling tasks, problem-solving tactics, algorithms and approaches used to implement the chosen solution, and results and encountered problems. As results to be obtained: autonomous driving algorithm including keeping the lane in the direction of travel, the logic of crossing an intersection, detecting signs, avoiding collision, throughout the mobile platform moving. After the presentation and passing of the fourth technical documentation, two weeks of training and elimination rounds (TER) are scheduled. A maximum of two members of each team is allowed to participate in the TER.



a) b)

Fig.4.3.1 a) Deep learning model that detects traffic signs (pedestrian crossing, parking, priority, and stop sign), b) Image processing algorithm on the real racetrack, detection of road signs, lane lines and calculating the turning angle

Activity Category: A2 – Industrial research

Expected results

Functional testing results

-New products integrated in hybrid technologies; structures for offering research services on integration in hybrid technologies (presentation in the erris platform of the partner institutions in the consortium);

-Integrated solutions in hybrid technologies for mobile platforms will be included in the joint RDI program correlated with the institutional development plan of each partner in the consortium;

CONCLUSIONS. The detailed scientific report highlights the scientific solutions that Project 1's team offers for the 3rd Stage requests. In the detailed scientific report uploaded on the P1 Project's platform (http://cidsactech.ucv.ro/data/_uploaded/Documente/RAPORT%20CIDSACTEH%20P1%202020%20UCV.pdf), can be viewed the research solutions/ results related to the 4th Stage. Priject 1 „Conducerea inteligentă şi distribuită a 3 sisteme autonome complexe integrate în tehnologii emergente către asistare personală medico-socială şi deservire de linii de fabricaţie flexibilă de precizie".

DISSEMINATIONArticles (ISI or BDI) - http://cidsactech.ucv.ro/index.php/Publicatii

BDI – IEEE XPLORE

1) *APF-based Control for Obstacle Avoidance in Smart Electric Wheelchair Navigation*, Liviu Florin Manta; Cristina Floriana Pană; Dorian Cojocaru; Ionel Cristinel Vladu; Daniela Maria Pătraşcu-Pană; Andrei Dragomir, 22nd International Carpathian Control Conference (ICCC),DOI:10.1109/ICCC51557.2021.9454660, 2021 (being indexed)

2) *Fuzzy Control of the Robotic Arm for a Smart Electric Wheelchair to Assist People with Movement Disabilities*, Cristina Floriana Pană;Daniela Maria Pătraşcu-Pană;Ionel Cristinel Vladu;Liviu Florin Manta;Florina- Luminiţa Besnea Petcu;Ştefan Irinel Cismaru;Andrei Costin Trăşculescu, 2021 22nd International Carpathian Control Conference (ICCC) DOI:10.1109/ICCC51557.2021.9454626 (being indexed)

3) *Human-Machine Interface for Controlling a Light Robotic Arm by Persons with Special Needs*, Andrei Dragomir; Cristina Floriana Pană;Dorian Cojocaru;Liviu Florin Manta, 2021 22nd International Carpathian Control Conference (ICCC) DOI: 10.1109/ICCC51557.2021.9454664 (being indexed)

4) *Interdisciplinary technical competitions – a case study*, Andrei Dragomir, Liviu Florin Manta, Alexandru Mariniuc and Dorian Cojocaru, EAEEIE 2021 - 30th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE), ISBN 978-1-7281-9327-4/21/ 2021 IEEE (being indexed)

TECHNOLOGICAL AND RESEARCH SERVICES OFFER STRUCTURE PRESENTATION WITH ERRIS PLATFORM LINKS INDICATION

TECHNOLOGICAL AND RESEARCH SERVICES

Name

- *Assisted the design services of the people with disabilities mobile platforms.*
- *Interfacing and integration services of the sensory systems in leading architectures for the people with disabilities mobile platforms.*

Link: https://erris.gov.ro/Computer-Aided-Design-CAD--C

PROJECT 2

"Modeling, simulation and implementation of distributed configurations of sensors and visual servoing systems for hybrid technologies for reusable products on flexible, precision, laboratory (mechatronics lines) and industrial manufacturing lines, with complex integrated autonomous systems"

Stage 4 (2021)

Testing, by simulation and in real-time, in laboratory mode, of the integrated technologies of medical-social assistance and service of precision flexible manufacturing lines

Stage summary

At this stage, only one activity was carried out, according to the Plan for the realization of the component projects:

Activity 4.2: Real-time laboratory testing of the complex autonomous systems SAC-ARP and SAC-VAM

This activity continued the experiments started in stage 3, activity 3.8, regarding the valorization of the test results in order to optimize the management of the assembly / disassembly lines assisted by collaborative robotic platforms from the SAC-ARP and SAC-VAM categories. For this activity, tests were performed to allow the validation of procedures for driving a mobile autonomous robot that can provide parts transport operations as an auxiliary to the assembly / disassembly operations performed on the flexible laboratory line.

In addition, scientific papers have been developed for the dissemination of final results and a patent proposal has been submitted.

Technical and scientific description

Activity 4.2: Real-time laboratory testing of complex autonomous systems SAC-ARP and SAC-VAM.

4.2.1. Test system configuration

In stage 3.8 was presented the autonomous robot Robotino, which was used in experiments that validated the functional capabilities that allow it to be used as auxiliary equipment in servicing the mechatronic laboratory line for assembly / disassembly operations. We present in summary the tests that were performed and the results obtained.

We used in tests the ROBOTINO mobile robot (fig. 1), produced by Festo Didactic, a product that is compatible with the project objectives for use in advanced applications in the fields of autonomous mobile robot systems. Using an omnidirectional actuator, the Robotino moves quickly forward, backward and sideways and also rotates in place. Three robust industrial DC motors with optical rotary encoders allow speeds of up to 10 km / h with high reliability.

The base frame contains nine infrared distance sensors and numerous mounting options. An analog inductive sensor and two optical sensors are additionally included, allowing Robotino to recognize and follow predefined paths). Robotino comes with an extensive image processing system, which uses a stereo / RGB-D camera unit to perceive the environment independently and can navigate freely in it. These stand-alone functions can be seamlessly integrated into programs based on workflow analysis.

Tests were performed to allow the validation of procedures for driving a mobile autonomous robot that can provide parts transport operations as an auxiliary to the assembly / disassembly operations performed on the flexible laboratory line. The basic functional modules tested in phase 3.8 are: i. The route creation function; ii. Current position playback function; iii. Obstacle avoidance function; iv. Mapping function.

Fig.1 Robotino 4 – Festo Didactic

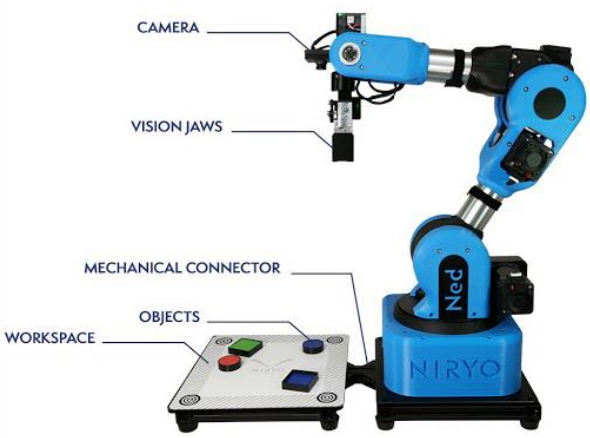


Fig. 2. Ned – Nyrio Didactic

The control of the robot's position is given by the existence of an odometer through which the position is calculated, which has as input data the coordinates from which the robot starts moving and provides as output data the current position of the robot. Wheels rotation is measured at the highest possible time resolution. At all times the distance traveled by the vehicle is calculated according to the speed of rotation of the wheels. This leads to the actual position compared to the initial position. This method produces good local performance.

In addition, the obstacle avoidance function was tested and validated. This can be used when there is a fixed obstacle in the robot's workspace; with the help of obstacle coordinates, the robot can avoid them by calculating the shortest path it can take. The function can also be used dynamically, bypassing obstacles that appear randomly in the workspace, operation that can be done by taking data from distance sensors, in number of 9, placed circularly on the surface of the robot.

Because Robotino does not have the ability to manipulate objects, the association of the mobile robot with a fixed robot called Ned produced by Nyrio was used to test the support of the assembly / disassembly lines. Ned is a 6-axis collaborative robot (cobot) arm designed for Education and Research (fig.2). Ned is designed to reproduce all the movements required in the most advanced uses in industry 4.0, with a precision of 0.5mm and a repeatability of 0.5mm. This cobot takes advantage of the capacities of the Raspberry Pi 4, with a 64-bit ARM V8 high performance processor, 2GB of RAM and an improved connectivity. It use ROS (Robot Operating System) Melodic, an open-source solution created for robotics.

Fig. 3. IMRP - didactic robotic system of SAC-ARP type

Combining the two didactic robots (Robotino 4®, Niryo Ned®) in a single equipment called Intelligent Mobile Robot Platform (IMRP) - see fig. 3 - is a didactic robotic system that can be considered a laboratory version of a SAC-ARP (Complex Autonomous System - Personal Robotic Assistant) that can be used for manipulating and moving objects.

The Intelligent Mobile Robot Platform offers the possibility to create and implement different behaviours of a system which can be used in different actions. The possibility of programming in specially created software applications (Robotino Factory for Robotino 4® and Niryo Studio for Niryo Ned®) makes IMRP a favorable environment for learning and simulation of industrial processes within the laboratory. Communication was established using Modbus TCP communication protocol, Modbus TCP APIs, and a programmable logic controller. Thereby, IMRP can be commanded externally (ex. from an HMI (Human-Machine Interface) and can be programmed to execute difficult tasks in various ways, such as obstacle avoidance, transport of objects, fine object manipulations or precise movement.

4.2.2. Programming working modes of mobil robot using Robotino Factory

To make it clear how to program various operations, we present a simple example of a program that will make the mobile robot advance and change its direction of movement when it detects an obstacle in front of it. This program can be realised in two steps.

We will rename “Step1” block with “Forward”. We want the robot to move forward while the infrared proximity sensors will not detect an obstacle. So, we will create a new function block by pressing the line highlighted in the green box then by pressing the button highlighted in the red box. We will rename the newly created “Step2” block with “Rotate” and we will obtain a scheme as shown in fig.4.

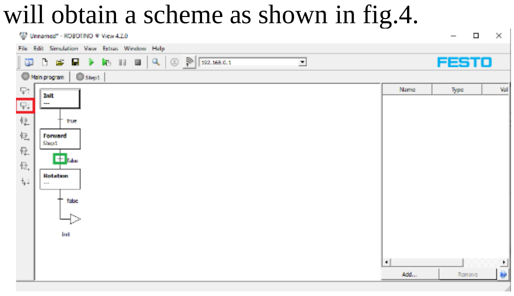


Fig. 4 Execution of the step Forward

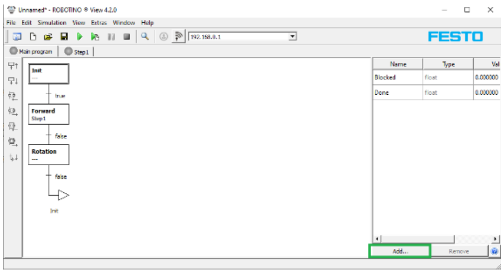


Fig. 5 Adding two float variables

We will now declare two float variables by pressing the “Add...” button highlighted in the green box as shown below. We will name the first variable “Blocked” and the second one “Done” (fig.5). We want to start the “Rotation” movement when the sensors detect an obstacle. So, when “Blocked” value will be 1, we will Move from “Forward” function block to “Rotation” function block. To do that, we will swap de “false” condition below “Forward” function block with “Blocked”. This is a simple condition meaning that if “Blocked” is true (or 1), the next function block will begin. We will do the same thing with “Done”, replacing the “false” condition below “Rotation” function block with it. The “Init” jump highlighted in the red box with shows that the program we are going to create will make an endless loop between these 3 function blocks.

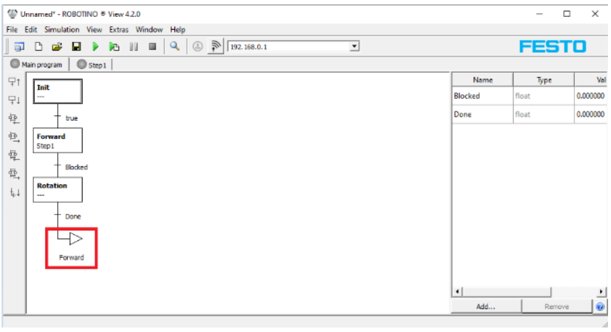


Fig. 6 Stopping a phase in an iterative process

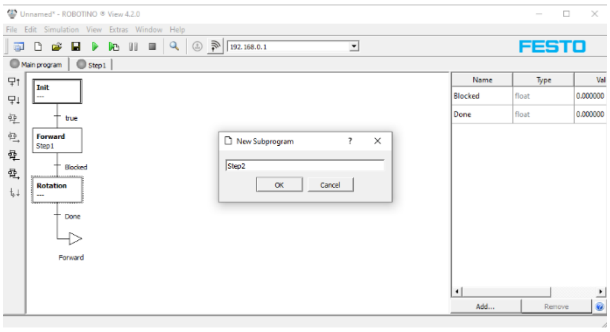


Fig. 7 Transfer to the next step of the program

If we want the program to stop after one iteration, we need to replace “Forward” with “TERMINATE” (fig.6). We can see that the function block named “Forward” already has a workspace called “Step1”. We will create another workspace for the “Rotation” function block by double clicking the block. For the sake of this example, we will call the new workspace “Step2”. We will do the same thing for “Init” function block, and we will call its workspace “Step0” (fig.7). So far, we decided that when started, the system will start moving forward and rotate when an obstacle is detected by the front infrared proximity sensors if the condition “Done” is false.

4.2.3. Programming working modes of cobot robotic arm using Niryo Studio

The example below presents how to calculate some fixed positions which will help in building a simple program.

After connecting the manipulator robot to the access point, we need to calibrate it by pressing “Auto Calibrate” button highlighted in the picture below (Fig 8).

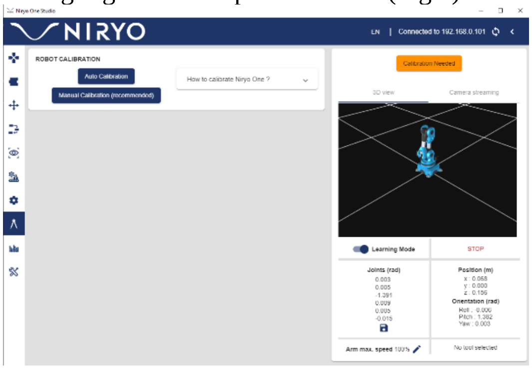


Fig. 8 Autocalibration

Fig. 9 Arm command

After the calibration is successfully completed, we will click on the button framed in the red box from the picture below to get to the position’s configuration menu. First, we will select the standard gripper as shown in the green box. After selecting the gripper, we can choose to move the robot in its default position (0,0,0,0,0,0) by pressing the button “Move Joints” highlighted in the light blue box or we can choose to manually move the robot in a desired position by pressing “Learning Mode” framed in the orange box. If we decide that we want to manually move the robotic arm in a desired position, we need to press the “Learning Mode” button again after the position was established and press “Set to current” as shown in the blue box for the joints values to update accordingly to the new position (Fig. 9). If we want to adjust the position virtually, we can modify the joint parameters manually or we can adjust the parameters by modifying the sliding bars as shown in the brown box. After we successfully decided on a certain position, we can save it by pressing the button marked by the mauve box.

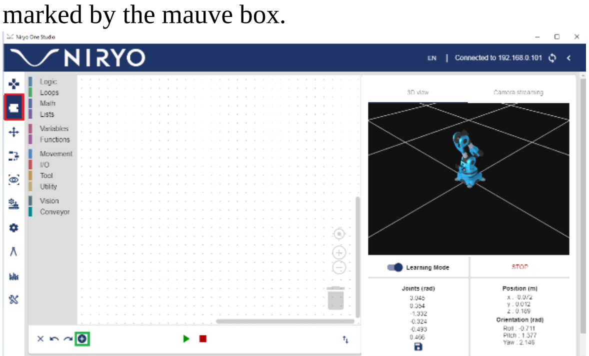


Fig. 10 List of functionalities

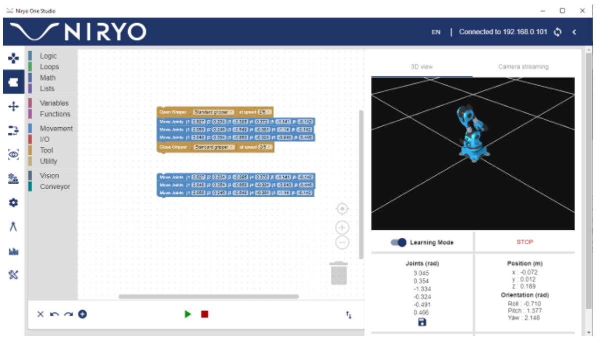


Fig. 11 Repeating the process

For this exercise, we will save 3 positions and we will name them Pos1, Pos2, Pos3. Next, we will open the workspace by pressing the button highlighted in the red box in the picture below in which we will create our custom program. In the left side of the workspace, a list of functionalities can be seen from where we can pick the utilities, we need to develop our program. By pressing the green marked button, we can import a position we saved earlier (Fig. 10)

For this example, we want the robotic arm to close its griper, reach Pos1->Pos3->Pos2 and open its gripper 5 times in a row and Pos1->Pos2->Pos3 3 times in a row, and we want to repeat this process 2 times. For that, we will first add our positions to the workspace by pressing the button highlighted in the green box. Then, we will drag and stick the pieces together. Now, we will press on "Tool" button and we will drag the "Open gripper…" and "Close gripper…" blocks to the workspace and stick them to the positions as shown above. We now have 2 distinct blocks (Fig. 11). We want the first block to be executed 5 times in a row, the second block to be executed 3 times in a row and the whole process to be repeated 2 times. For that, we will press on "Loops" and we will use "repeat x times…" block. Before entering the loop, we will use another block named "Change tool to…" from "Tool". We will stick the pieces together as shown in the picture below (Fig. 12) and by doing this, we finished our program.

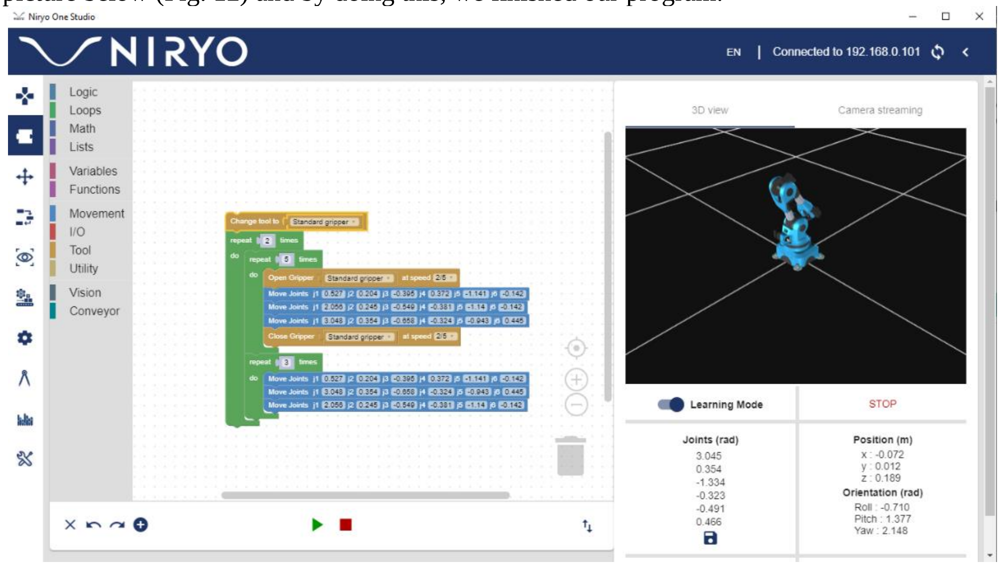


Fig. 12 Program ending.

4.2.4. Extern control of IMRP

For remote controlled operations, the design of a human-machine interface structure (HMI) was considered. This entity has been named Interface for Command, Control and Collection of Information (ICCCI) for a Flexible Product Assembly Line. This interface was included in the structure of the existing HMI interface at the level of the flexible assembly / disassembly line of the laboratory (SMART Flexible Assembly System) which represents the validation support of the results obtained within the CIDSACTEH project (fig.13). ICCCI serves three objectives:

a) command - of the software application made in Matlab® called IBVSViewer (see RTS 2020 - stage 3)

b) control - the robotic arm that serves the flexible assembly line of the products and respectively of the intelligent IPRM platform (Robotino base and Ned gripper);

c) information collection - obtained following the process of analyzing images purchased with a video camera.

As such, all the steps necessary for the visual guidance of an assembly / disassembly process (videoservoing) can be monitored through ICCCI, ie: video camera calibration, object detection, object validation and object coordinate determination (positioning). In addition, the structure of the HMI interface is original and intuitive, as it allows the simultaneous display (see fig. 14) of the assembly and disassembly processes implemented at the flexible laboratory line (vertically) and the stages of the IBVSViewer software application algorithm for the assembly process (horizontally).

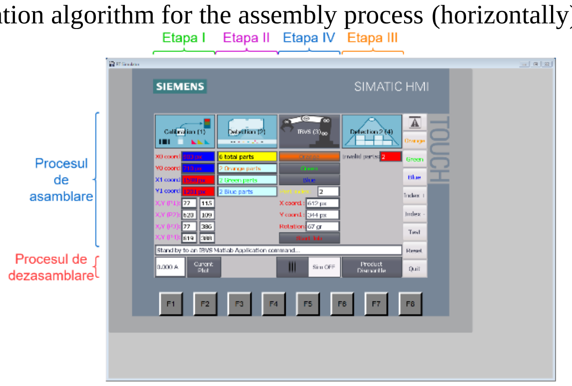


Fig. 13 ICCCI - afișare în HMI

Fig. 14 ICCCI - afișare in simulator

We mention that a patent proposal entitled: "Interface for command, control and collection of information for a flexible product assembly line" has been filed.

CONCLUSIONS

The scientific report highlights the solutions that the Project 2 work team offers for the requirements of Stage 4 (2021). In the detailed Scientific Report uploaded on the P2 project platform (http://cidsacteh.upb.ro) , you can view the solutions and results for research related to Stage 4. Project 2 "*Testing, by simulation and in real-time, in laboratory mode, of the integrated technologies for service of precision flexible manufacturing lines*".

STAGE 4 results

1. Procedures for driving an autonomous mobile robotic platform in the environment with obstacles, for parts transport operations at the mechatronic assembly / disassembly laboratory line
2. Procedure for testing the reproducibility of the positioning performance of the mobile robotic platform
3. Precision evaluation procedure of the robotic assembly / disassembly processes
4. Human-machine interface for command, control and information collection for a flexible product assembly line (possible patent).

PERFORMANCE INDICATORS ACHIEVED

Activity 4.2.

- Report of assessment the performance of an Intelligent robotic platform made by associating two collaborative robotic units (cobots)
- Instruction Guide for using a mobile robotic platform that emulates the functions of a complex Autonomous System - Personal Robotic Assistant
- Reports with the results of testing complex autonomous systems in simulation mode.

DISSEMINATION

Published papers in 2021

Papers în Journals (ISI)

1. J.I.R. Cojocaru, D. Popescu: "Image Analysis Algorithm for Image Based Visual Servoing of a Robotic Assembly Line", U.P.B. Sci. Bull., Series C, Vol. 83, Iss. 1, 2021, pp.41-52.
2. R. Dobrescu, S. Mocanu, O. Chenaru, M. Nicolae, G. Florea, Versatile Edge Gateway for improving manufacturing supply chain management via collaborative networks, International Journal of Computer Integrated Manufacturing, Vol. 34 Iss. 4, 2021, pp: 407-421, WOS:000617980200001, ISSN: 0951-192X
3. O. Chenaru, S. Mocanu, R. Dobrescu, Using predictive maintenance to enhance antifragile performance of manufacturing systems, Journal of Industrial Manufacturing, manuscript JIMS-D-21-00510 (in evaluare).

Papers published in the volumes of international scientific events:

1. G. Cristescu, O. Chenaru, R. Dobrescu, "A holonic approach of manufacturing systems modeling and simulation," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), 2021, pp. 238-242, doi: 10.1109/CSCS52396.2021.00046.
2. M. Crăciunescu, D. Baicu, Ş. Mocanu, C. Dobre, "Determining on-shelf availability based on RGB and ToF depth cameras," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), 2021, pp. 243-248, doi: 10.1109/CSCS52396.2021.00047.
3. V. Mihai, C. Dragana, D. Popescu, L. Ichim, "Condition Monitoring of Manufacturing Production Lines Using Fractal Analysis of Energy Consumption Datasets," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), 2021, pp. 249-253, doi: 10.1109/CSCS52396.2021.00048.
4. A. V. Olteanu, M. Nicolae, "Using advanced V2X communication technologies in self-organized VANETs," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), 2021, pp. 254-259, doi: 10.1109/CSCS52396.2021.00049.
5. R-A. Luchian, G. Stamatescu, I. Stamatescu, I. Fagarasan, D. Popescu, "IIoT Decentralized System Monitoring for Smart Industry Applications," 2021 29th Mediterranean Conference on Control and Automation (MED), 2021, pp. 1161-1166, doi: 10.1109/MED51440.2021.9480341.

Note: The underlined authors are part of the UPB team for the CIDSACTEH project

We mention that the 4 papers were presented in a special section entitled *Intelligent Manufacturing Systems* from the 10th *International Workshop "Interdisciplinary Approaches in Fractal Analysis"* - IAFA 2021, held as a satellite of the *23rd International Conference on Control Systems and Computer Science* (CSCS 23) organized by the Faculty of Control and Computers. At the end of this session, a synthesis report was presented on the results of the CIDSACTEH research project.

WORK PLACES SUPPORTED BY PROGRAM, INCLUDING NEW HUMAN RESOURCES

The project team that contributed to the researches in Stage 4.Project 2, consists of 11 (eleven) researchers (included in the Project 2 staff list). These include two young full-time researchers (PhD students) employed by the UPB partner, in the position of Research Assistant.

PRESENTATION OF THE STRUCTURE OF THE OFFER OF RESEARCH AND TECHNOLOGICAL SERVICES WITH THE INDICATION OF THE LINK TO ERRIS PLATFORM

RESEARCH AND TECHNOLOGICAL SERVICES

Name - *Precision and reversible flexible manufacturing line, served by SAC-ARP (Autonomous complex system - Personal Robotic Assistant) and SAC-VAM (Autonomous complex system - Autonomous Mobile Vehicle)*

Description - Testing and validating the performance of a mobile robotic platform that emulates the functions of a complex Autonomous System - Personal Robotic Assistant. The implementation of the service is based on two new products: Procedures for driving an autonomous mobile robot in an obstacle environment (see http://cidsacteh.upb.ro/index.php/ro/demonstratii) and Human-machine interface for command, control and information collection for a flexible product assembly line (see http://cidsacteh.upb.ro/index.php/ro/activitati/20-imagini).

Equipments– *SMART Flexible Assembly System , Producator: ASTI Automation SRL*

Link to ERRIS platform: https://erris.gov.ro/PRECIS-UPB

Research services: Position L9:Innovative Products and Processes to Increase Life Quality
Equipments: Positions SMART Flexible Assembly System

PROJECT 3

The intelligent control, of the of the Complex Autonomous System -SAC-ARP Personal Robotic Assistant and Complex Autonomous System -SAC-VAM Multidirectional Autonomous Vehicle integrated in medical-social assistance and line service technologies flexible manufacturing of precision, laboratory (mechatronics lines) and industrial, with advanced techniques and navigation based on high-performance sensors and visual servoing systems

Stage 4 Objectives

The integration of complex autonomous systems SAC-ARP and SAC-VAM in hybrid technologies serving flexible precision, laboratory, mechatronics, P / R, Festo MPS200 manufacturing lines

Activity 4.3 The control structure is designed for the system composed of:

- Flexible cell, CF, with 6-DOF ABB RM IRB120 - station used for assembling, disassembling and repairing parts as follows: with buffer, handling, processing and transport capacity. CF is a controlled assembly / disassembly unit PLC Siemens S7-1200 PLC, which deals with the supply of workpieces for product type 1 workpiece and disassembly, repairs for workpiece type 2;
- A / DML 6-WS Hera & Horstmann ML - based on a mechatronic laboratory system, used for assembling and transporting workpieces with verification and storage facility. A / D / RML, is characterized by a modular structure. The hardware structure consists of 2 PLC controlled subsystems / modules with specific tasks for all stages of manufacturing
- SAC ARP is a system composed of the PeopleBot WMR robot equipped with a 7-DOF Cyton 1500 RM equipped with the VSS eye in hand system, used for recovery and transport / return of the disassembled workpiece / reprocessed components (to the warehouse).

The proposed control structure is a hybrid, distributed and centralized / decentralized architecture, with two main features:

- Distributed structure, through separate PLCs for each of the 2 subsystems, to automate the respective areas with visualization or operation facilities.

- Centralized / decentralized architecture, in which CF PLC (Siemens S7 1200), in addition to the role of local control, acts as a master PLC for central control of both subsystems of the entire ML A / D / R process, and operating facilities, thus coordinating and control tasks with synchronization of SAC operations. The system is equipped with a KTP 700 hardware interface (HMI) that provides the function of viewing running tasks and operator control.

In addition, scientific papers were developed to disseminate the final results.

1. The control structure The control structure is designed for the A / D / RML assembly / disassembly / reprocessing line, which is shown in Figure 1. The basic components of the assembly / disassembly / reprocessing line are:

- Flexible cell, CF, equipped with ABB RM IRB120 6-DOF manipulator. This machining station is used for assembling, disassembling and repairing parts.

- Mechatronic assembly / disassembly / reprocessing line A / DML 6-WS ML - based on a mechatronic laboratory system, used for the assembly and transport of workpieces with verification and storage facility;

- SAC PeopleBot WMR equipped with a 7-DOF Cyton 1500 RM used for recovery and transport / return of the disassembled workpiece.

The A / D / RML line represents a system characterized by a modular structure. The hardware structure consists of 2 PLC controlled subsystems / modules with specific tasks for all stages of manufacturing.

- CF is a controlled assembly / disassembly unit PLC Siemens S7-1200 PLC, which deals with the supply of workpieces for product type 1 workpiece and disassembly, repairs for workpiece type 2;

- The 6-WS Hera & Horstmann ML line of stations is also a PLC controlled subsystem (Siemens S7-300 series) which has a predefined role as a logistics unit that assembles individual workpieces, transports between modules and stores the processed parts in place of final storage.

- The hardware and software structure based on PLC is a hybrid, distributed and centralized / decentralized architecture, with two main features:

- Distributed structure, through separate PLCs for each of the 2 subsystems, to automate the respective areas with visualization or operation facilities.

- Centralized / decentralized architecture, in which CF PLC (Siemens S7 1200), in addition to the role of local control, acts as master PLC for central control of both subsystems of the entire A / D / R ML, process and operating facilities, thus coordinating and control tasks as a synchronization of SAC operations that includes a KTP 700 hardware interface

(HMI) that provides process monitoring and visualization of the current process status as well as operator control.**Flexible cell (CF) with ABB IRM**

- CF is an integrated workstation equipped with an ABB IRB120 robot, shown in Figure 1, which consists of the following major components:
  - manipulator with 6 degrees of freedom 6-DOF ABB IRB120 MRI with electrical outlet;
  - PLC Siemens S7-1200 series-CPU 1214C;
  - HMI Siemens KTP700, Color Basic PN;
  - Siemens SCALANCE XB005 switch;
  - Conveyor belt with Sinamics V90 servomotor;
  - Compact storage and unloading units corresponding to each five-part workpiece to be assembled.

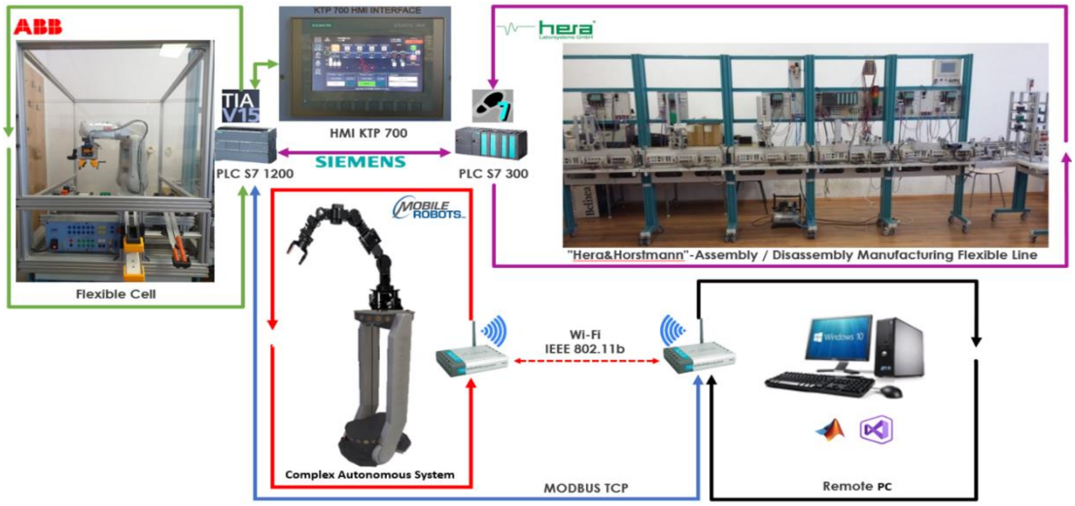


Figura 1 Control structure of A/DML Hera&Horstmann, FC with ABB IRM and CAS with PeopleBot WMR and Cyton 1500 RM.The Profinet communication link is used to interconnect and control all the CF devices mentioned above. For the CF hardware structure, the following Profinet profiles are applicable:

• Profinet-IO, distributed I / O (remote I / O), in which user data on field devices is periodically sent to the control system process model. This can be considered an advanced Profibus protocol on the TCP layer. Profinet-IO is used to connect HMI, CPU PLC and ABB robot controller (Figure 2);

• PROFI unit - implemented for drive application scenarios, covers from simple frequency converters to intelligent servo drivers. This Profinet profile is used in the flexible cell station to control the conveyor belt with Sinamics V90 servomotor (Figure 2).ABB Robot Controller has the hardware capability to communicate with third party devices through the Profinet protocol. For this, a dedicated AnybusCC Profinet slave board (DSQC 688) is inserted into an expansion board above the main computer unit in the ABB robot controller. This Profinet Anybus device, DSQC 688, requires the DSQC1000 robot controller (mainframe). With the Profinet Anybus Device option, the ABB Robot controller can act as a slave module in the Profinet network.

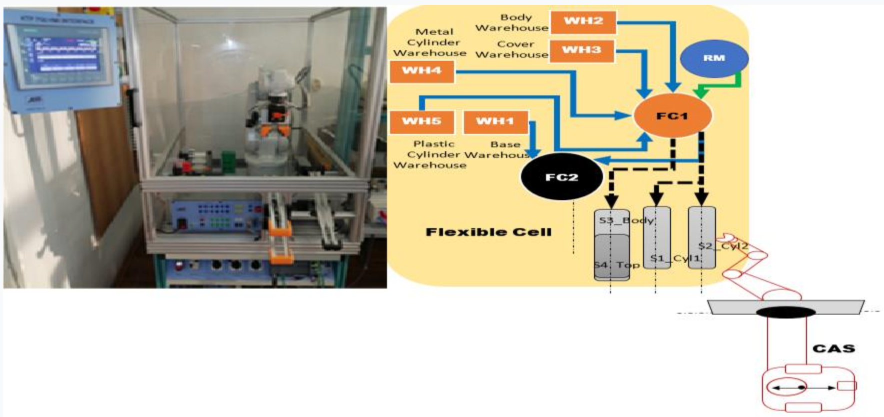


Figure 2. Flexible Cell Station with 6-DOF ABB IRB120.

The mechatronic line (ML)

The flexible mechatronic line (Figure 3) includes six individual workstations with different tasks, each task ensures the performance of operations for different stages: transfer and transport, pneumatic workstations, conveyor belt, sorting unit, test station and warehouse.

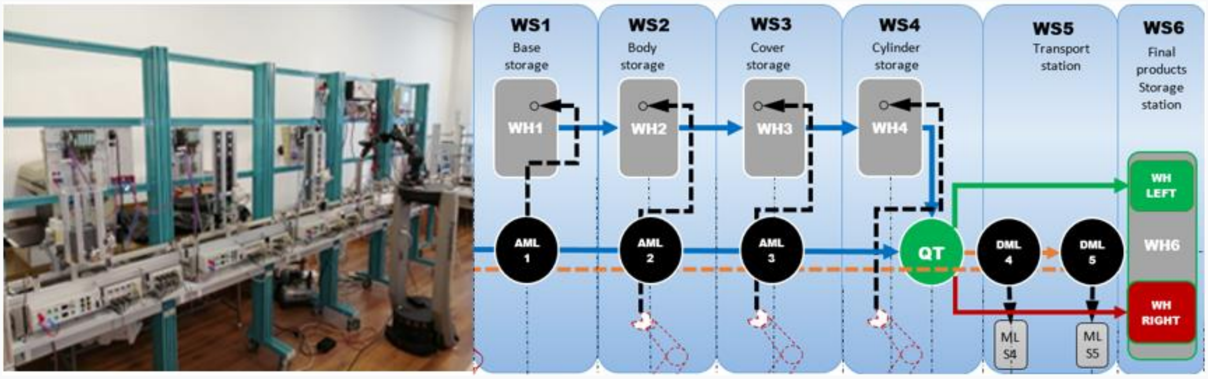


Figura 3 A/DML Hera&Horstmann ML with symmetrical final product storage.

The hardware structure of SAC

The SAC, shown in Figure 4, consists of the following elements: a Cyton 1500 RM 7-DOF manipulator equipped with a visual VSS eye-hand servoing type using a high-definition camera, both being connected to a computer via USB and synchronous communication with A/D/R ML via Wi-Fi. RM is placed on the SAC ARP Peoplebot, which is a WMR with two drive wheels and a freewheel (2DW / 1FW). SAC ARP is used to transport recoverable parts taken by Cyton 1500 RM to the appropriate warehouses if the assembled part has not passed the quality test and has been disassembled or repaired.

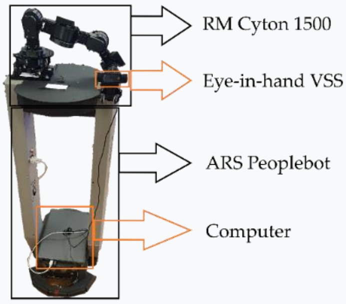


Figure 4. The CAS composed of ARS, RM, *eye-in-hand* VSS, and a computer.

The SAC control is performed wirelessly using a router that is placed inside the WMR, through dedicated functions from ARIA (Advanced Robotic Interface for Applications) that run on the same computer to which Cyton RM is connected.

Visual servoing VSS *eye in hand*

VSS eye-in-hand is a system in which the video sensor is placed on the last link of the RM, also known as the final effector. For this type of VSS, 2D image information is used to control the robot's movement in the workspace. Object tracking and robot positioning are done using the comparison between current visual characteristics, extracted from images captured by the camera and the desired visual characteristics. The difference obtained is used to minimize the error between the current position of the part and the anticipated location. Also, eye-in-hand VSS indicates that the RM movement also induces the movement of the mounted camera. One of the most used components in detecting and classifying objects is called image moment. These image moments are commonly used in the fields of robotics due to their efficiency and simplicity in implementation. The moments of the image contain information about the region of interest, the coordinates of the center of gravity of the piece and the positioning of the image.

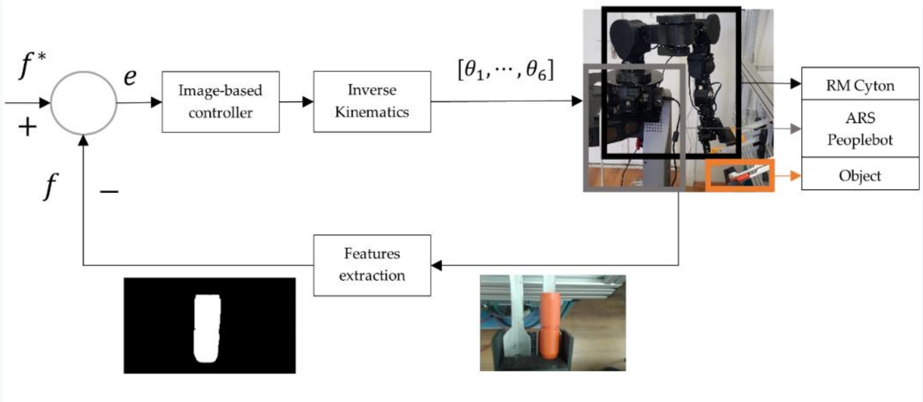


Figura 5. Closed-loop control of the RM Cyton based on eye-in-hand type VSS.

The control architecture of SAC

The mobile part of the A / D / R ML, called SAC, consists of an autonomous robotic system (ARP), Peoplebot WMR equipped with 7-DOF Cyton 1500 RM and an eye-type VSS system, for lifting parts from CF in the case of a repair / disassembly process and transport them to the appropriate storage depots (Figure 6). The control of the moving part is based on 3 control loops:

1. Control loop for synchronization between CF Modbus PLC and Cyton RM;
2. Cyton RM control loop with eye-in-hand VSS for precise positioning to pick up objects from the FC and place them in storage;
3. PeopleBot WMR control loop based on sliding mode control to track trajectory in set time with obstacle avoidance (Trajectory Tracking Sliding Mode Control (TTSMC)).

All three control loops communicate through a computer that contains GUI and ARP commands, eye in hand VSS, Cyton 1500 RM and manages synchronization with CF. Specific software packages and libraries were used with Microsoft Visual Studio to drive the entire system. As can be seen in Figure 12, the communication between Cyton RM, eye in hand VSS and computer is done with USB connections, while the communication with and CF is done wirelessly using a TCP / IP protocol. Coordination between control loops was achieved using the open-source library specialized in image processing, OpenCV and defined command input, functions from Aria Mobile Robots, a synchronization with the FC Modbus PLC, all combined in Microsoft Visual Studio with the language C ++ programming.

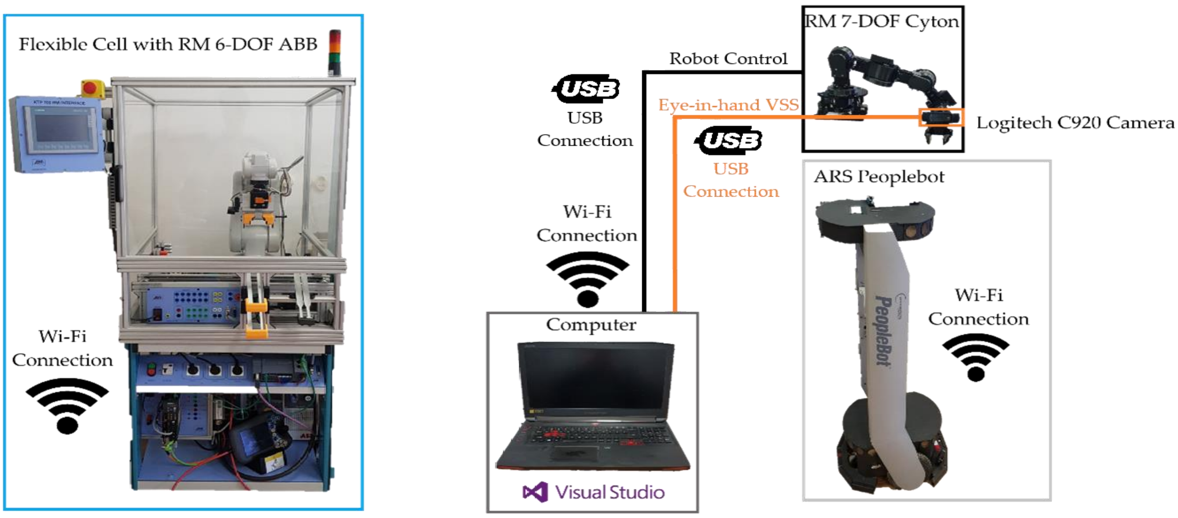


Figura 6. Communication block set of the computer between the FC, ARS PeopleBot WMR equipped with the Cyton RM and *eye-in-hand* VSS.

All the three control loops communicate through a computer that contains GUI and ARP commands, eye in hand VSS, Cyton 1500 RM and manages synchronization with CF. Specific software packages and libraries were used with Microsoft Visual Studio to drive the entire system. As can be seen in Figure 12, the communication between Cyton RM, eye in hand VSS and computer is done with USB connections, while the communication with and CF is done wirelessly using a TCP / IP protocol. Coordination between control loops was achieved using the open-source library specialized in image

processing, OpenCV and defined command input, functions from Aria Mobile Robots, a synchronization with the FC Modbus PLC, all combined in Microsoft Visual Studio with the language C ++ programming.

Figure 7 illustrates the desired and actual trajectories of the PeoplePot ARP obtained with the command given by the closed loop TTSMC to switch from CF to storage and back to CF in the desired time. In (a) the complete path is shown, in (b) separately on the X axis, (c) separately on the Y axis, (d) the angular trajectory so that the differences between the actual and the desired trajectory can be more easily perceived. There are 2 observable deviations, one after a 90 ° rotation to advance to the depot, as shown in Figure 7 (c) and 7 (d) between seconds 40 and 56 on the X axis, and the second again after a 90 ° rotation to move back to the FC, shown in Figures 7 (c) and 7 (d) between seconds 78 and 90 on the X axis.

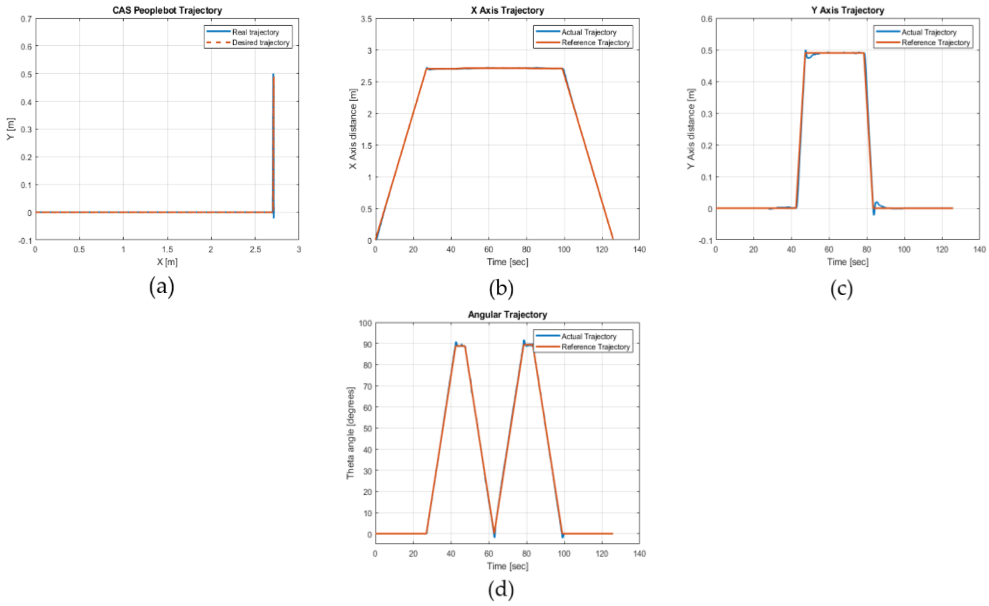


Figura 7. Desired and real trajectories of ARS PeopleBot based on Trajectory Tracking Sliding Mode Control: (**a**) complete trajectory, (**b**) X axis, (**c**) Y axis, and (**d**) angular trajectories.

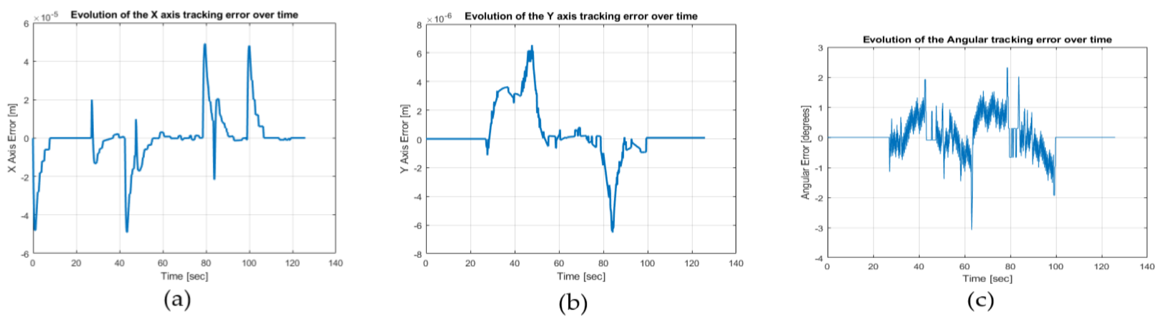


Figura 8. (a) X axis and (b) Y axis tracking errors in absolute coordinates, (c) angular tracking error expressed in radians per second for ARS PeopleBot.

The proposed and validated control structure at this stage, is easy to implement, does not require additional equipment to the usual ones in the manufacturing systems and ensures the assembly or manufacturing system the fulfillment of the imposed performances. SAC ARP is equipped with high-performance algorithms for tracking the trajectory in a set time and avoiding obstacles. The use of VSS eye in hand for the positioning of the RM Cyton mobile manipulator, which is equipped with SAC ARP, leads to a considerable reduction in the positioning errors of the parts, in a priori unknown conditions. The proposed SAC ARP solution, having the two major advantages demonstrated, is an emerging technology that can be used in the industrial environment with very small adjustments.

2. The research services structure offered The research services structure offered, regarding SAC-ARP integrated in the hybrid technology for servicing flexible precision, laboratory, mechatronics, P / R, A / D manufacturing lines is available at https://eeris.eu/?&sm=module.org.erris.app.infra&ddpN=3245192760&we=a5ba74f6d75889ea8c62a266f3e019f6&wf=dGFCall&wtok=598efa9b52e5b548b3eb15710f55b335b924c1fc&wtkps=JY3bEkMwFEX/Je+MOLk5vibE0aiiSTCj038v+rYe1l7bosBPREAWvWN1RFki45vapDRHguFoXPRvM1bE1y2mKaV5aMkfjyLjuhJ9K7N+hWEM11Yj8xMF+y8JZIJzfUeR7ek5xovhPCBeEgAYB7qRZItWQWm0IVK2LBoSl3dqe3eDQvaa3Tp2+Rz6vAvBx9wuS35/sfr7Aw==&wchk=4252aaa4ab28b8b1fdb3db7fd9588b0e3f8b9349 .

The services structure offered is made of two research services:

- Research for the Autonomous Complex System - Personal Robotic Assistant platform to ensure the medical and social assistance in the hospital and at home
- Research for the Autonomous Complex System- Multidirectional Autonomous Vehicle platform for personal assistance in/out the hospital and rescue in rough terrain

and two technological services:

- Hybrid flexible manufacturing systems control technologies for precision flexible assembly/manufacturing lines for laboratory or industrial use, integrating the Autonomous Complex System -Multidirectional Autonomous Vehicle
- Hybrid flexible manufacturing systems control technologies for precision flexible assembly/manufacturing lines for laboratory or industrial use, Hybrid flexible manufacturing systems control technologies for precision flexible assembly/manufacturing lines for laboratory or industrial use, integrating the Autonomous Complex System - Personal Robotic Assistant.

PROJECT 4

Real-time modeling, simulation and control of production lines assisted by complex autonomous systems (SAC-ARP, SAC-VAM) integrated in hybrid technologies of flexible precision manufacturing, laboratory (mechatronics lines) and industrial, for reusable products

Stage 4(2021)

The real time implementation, in laboratory regime, of the integrated technologies of medical-social assistance and service of flexible precision manufacturing lines. Integration of complex autonomous systems SAC-ARP and SAC-VAM in hybrid technologies serving flexible precision, laboratory, mechatronics, P / R, Festo MPS-200 manufacturing lines;

STAGE SUMMARY

The researches of Stage 3 respond to the research objectives related to activities 3.13, 3.14, 3.15, 3.16, from the realization plan of the complex project, and finally led to the implementation and laboratory testing of the real-time management of the Integrated System for Flexible Manufacturing (SIFF), served by complex autonomous systems, SAC-ARP and SAC-VAM.

In this stage, the hardware structure of the production system was finalized, respectively the completion of the existing system, intended for flow manufacturing, with a flexible cell equipped with ABB industrial manipulator. Thus, the production system becomes an integrated system for flexible manufacturing, in which manufacturing is done through two parallel flows: manufacturing in flow and manufacturing in the cell. The production system now has seven stations, equipped with industrial robotic systems - ABB manipulator, FANUC manipulator in which products are assembled or disassembled in order to recover components. The implementation / testing research required the establishment of a production planning procedure on the two flexible manufacturing systems working in parallel. A generalized algorithm for optimizing production planning was developed and tested on the laboratory system. Thus, at the end of this stage, the following indicators are reached: 1) Flexible precision manufacturing line with integrated complex autonomous systems; 2) Client / Management Application software package for optimized production planning, for two flexible manufacturing systems working in parallel, 3) SAC-VAM control, Pioneer 3-DX mobile robots (2DW / 1FW) equipped with 6-DOF Arm Manipulator and SAC-VAM, mobile robots (2DW / 2SW) equipped with 6-DOF Manipulator, integrated in handling / transport / storage operations of components recovered from the SIFF disassembly station.

Activity 3.13

Testing of the software platform for synchronization of flexible precision LA / D production lines, integrated in hybrid manufacturing technologies, and the visual servoing system of SAC-ARP and SAC-VAN, under the LabView / Matlab / Visual C ++ platform

3.13.1.Integrated Flexible Manufacturing System (SIFF)

The SIFF hardware structure

SIFF is a flexible production system obtained by developing the SMART ASTI mechatronic line with a new production station, a disassembly station, a SCARA robotic system and mobile robots. Thus, a system of 7 interconnected stations with two parallel production processes was obtained, in station or in flow.

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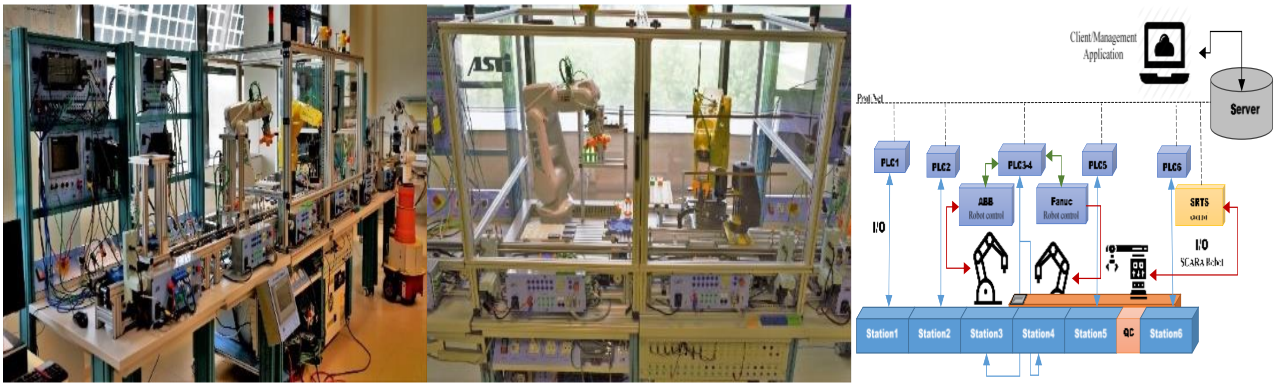


(a) (b) c)

Figure 1. a) SIFF equipped with the robotized systems; b) robot ABB robot (left), robot FANUC si SCARA (right); c) The local control of the workstations and the communication with the Cloud The interaction with the Client-Server/ Management Application

The mechatronic system is designed for assembly by flexible manufacturing and recovery of components by disassembly. In stations: 1, 2, 4, 5, 6 functionally connected in the order of tasks for the successive assembly of components, a complete assembly cycle of a certain product is performed. To adapt line flow manufacturing technology to flexible flow manufacturing (FFF), the system was equipped with the SCARA transport system which was designed to serve the production flow through handling, transport or repositioning operations. In FMC from station 3, equipped with ABB robotic manipulator and with its own component depots, a complete assembly cycle can be performed. In this case, the overall flow production on the mechatronic line is transformed into flexible cross-manufacturing, using a combination of flexible cell / station manufacturing (FMC) and flexible flow manufacturing (FFM). The flexible cell functions as an independent system for flexible manufacturing, operating in parallel with the mechatronic line dedicated to simple assembly and / or flexible manufacturing. The mechatronic system connects the flexible manufacturing in flow with that in the cell, in the quality control station (QT). Flexible production is performed on both systems in parallel and independently, with mutual conditioning only at the initiation of the quality control process.

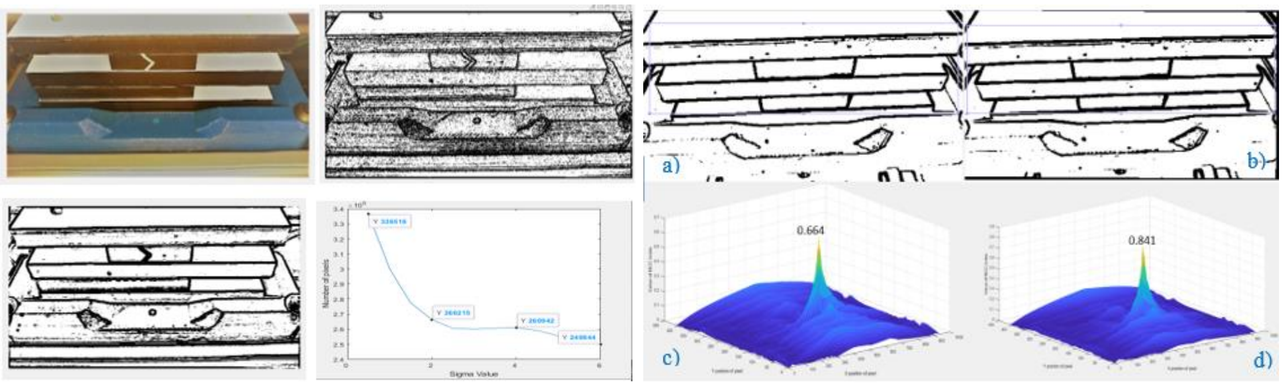
3.13.2. Integrated flexible manufacturing

The control structure

Production control is structured in two parts. A local, decentralized control, represented by PLCs that, based on the information provided by the sensors and based on the production parameters and task diagrams, send commands to the execution elements. The control algorithm of SIFF is also based on global control represented by a Server Application, interfaced with the Client Application, which sends to the PLCs the parameters of the current production. Through the Server Application, based on the customer's order, a sequence of tasks is created for each product. Each sequence of tasks and production information is stored in a query of production orders. From the query, the stations receive a production order after completing the previous order.

Implementation of quality control (QC) functions

At this stage, a dedicated station was designed and implemented to verify the quality of the products. It was placed after workstation 5. Thus, two hypotheses were considered: all assembled components are stored in warehouses and components in warehouses do not show non-conformities. Four scenarios are possible that may arise as a result of the system decision: 1) Product type A declared good in terms of quality, in which case the product is stored in WS6; 2) The type B product declared good in terms of quality, in which case the product is stored in WS6; 3) Product type A declared non-compliant with the required quality standards, in which case the product is sent to WS7 for disassembly; 4) Product type B declared non-compliant with the required quality standards, in which case the product is transported by the SCARA robot to WS2, where it is disassembled by the ABB IRB 120 robot. The algorithm used to detect the defect uses the following image processing techniques: image filtering, edge detection, feature matching and normalized cross-correlation followed by the Gaussian filter for smoothing the two images. The research conducted focused on increasing the performance of contour detection in the image and increasing the performance of defect detection. The difference between the maximum value of the normalized cross-correlation index on which the MASC algorithm was not applied and the value of the cross-correlation index on which the MASC algorithm was applied is between 12% and 30%.



i) ii)

Figura 2. i) Influența parametrului Sigma- abaterea standard a filtrului gaussian, asupra numărului de pixeli detectați; ii) Rezultatele obținute cu privire la implementarea algoritmului MASC și aplicarea corelației încrucișate normalizate: a) imaginea prelevată b) imaginea prelevată asupra căreia s-a aplicat algoritmul MASC c) indicele maxim de corelație încrucișată pentru imaginea prelevată, d)indicele maxim de corelație încrucișată urmat de suprapunerea algoritmului MASC.

Task diagram of integrated flexible manufacturing

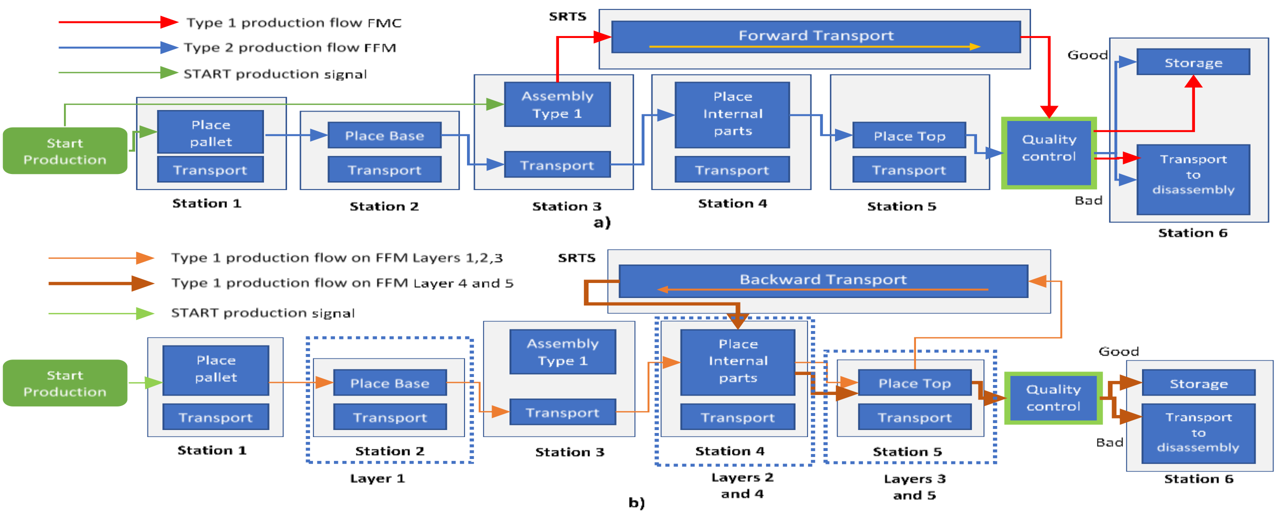


Figure 3. Diagram of tasks related to the two production flows: a) Production of Type 1_single Layers by flexible manufacturing in flow (FFM) and Production of Type 2 by flexible manufacturing in cell (FMC) FFM; b) Production Type 1 - multi_Layers by manufacturing flow (FFM)

SIFF allows the manufacture of two types of products: with several inner layers, called type 1, or with a single inner layer, called type 2. The inner parts of the product layer are placed based on the customer's requirement. For product type 1, several product configurations can be made based on layers. The production process is shown in Figure 3 as a load diagram. The control of the two production processes is based on a planning optimization algorithm. After assembly, the product reaches a quality control point, where it is checked for defects, using an automatic visual analysis process. Good products are stored in station 6 and defective parts are disassembled in station 7. For the type 1 product, the assembly process is different. Complete assembly is performed in station 3. In order not to interfere with the type 2 assembly, the type 1 product is transported to the quality control point by the SCAR system. If the product is defective, the product is transported back to station 3 by the SCARA system. Station 3 is a complete assembly / disassembly workstation that can operate independently or as part of the production line. The flexibility of the production system is given, in this situation, by the possibility of assembling two different products with distinct assembly orders, without the need to change the hardware configuration. The server, based on the volume of products requested by the customer, determines a planning of production tasks, based on the planning optimization algorithm. This information is sent to the SIFF's centralized control system.

3.13.4. PN models for flexible manufacturing system assisted by integrated robotic systems

PN models for flexible manufacturing in the cell (FFC)

PN models for flexible flow manufacturing

Only type 1 and type 2 products will be manufactured on FFM. Only type 1 products will be assembled on FMC. The transport of the finished products from FFM to the quality test (QT) is done by the SCARA system. On FMC, the assembly starts with a signal received from the server (Figure 6.a, Sync signal 1). When signals are received, the ABB robot is assigned to perform this task. After the assembly is completed in the FMC, the SCARA system transports the products to the QT station for verification (Figure 6.a, QT_location). If the product is defective, the SCARA system transports the product for disassembly.

On the FFM system, the type 1 typology will be launched in manufacturing (Figure 6.b). The product has a multi-layer assembly structure that is obtained through recurrent assembly operations. Recurrent assembly operations are controlled by CL1 (control model 1) and CL2 (control model 2), which have a predetermined start / stop state, depending on the product configuration launched in the factory. In the case of manufacturing with recurrent assembly operations, the transport of the product between stations is performed by the SCARA system. After assembly, the finished products that pass the quality test are stored in the warehouse of station 6. Defective products are transported to the next station for disassembly. The quality check is done for both type 1 and type 2 parts, as shown in the model.

Activity 3.14

Testing the software platform for synchronization of flexible precision LA / D production lines, integrated in hybrid manufacturing and navigation technologies based on advanced driving techniques for bypassing obstacles, locating and manipulating SAC-ARP and SAC-VAM, under the LabView platform / Matlab / Visual C ++

3.14.1. Generalized algorithm for optimizing production planning based on synchronization of flow manufacturing with flexible cell manufacturing

The generalized model of a station as a component part of flexible flow manufacturing

In the generalized model it was considered a station *k* of a flexible assembly line with $k \in [1, N]$ being the total number of stations of the system. A product p , $p \in [1, P]$ is produced on the considered system, with $T_{transIn_k}$ P the total production volume. In this system can be defined: $T_{transIn_k}$ the duration of transport in the assembly area; $T_{transOut_k}$ transport time at the exit of the assembly area; $T_{assembly\ k}$ assembly time in the station k. Thus, a cycle time can be defined for the production system of the form:

$$T_{cycle_p^N} = \sum_{k=1}^{N} \sigma_{k,p} T_{prod_k} + \gamma_p T_{transport} + \sum_{k=1}^{N} T_{stop_{k,p}} ,$$

where:

$\sigma_{k,p}$ the number of passes of product p through station k, γ_p the number of product returns for the product *p* $T_{transport}$ the transport time of the returned part, $T_{stop_{k,p}}$ waiting time of the product p located in station k by inserting a piece into the station *k+1:*

$$T_{stop_{k,p}} = \theta_{k+1,p} T_{prod_{k+1}} \tag{2}$$

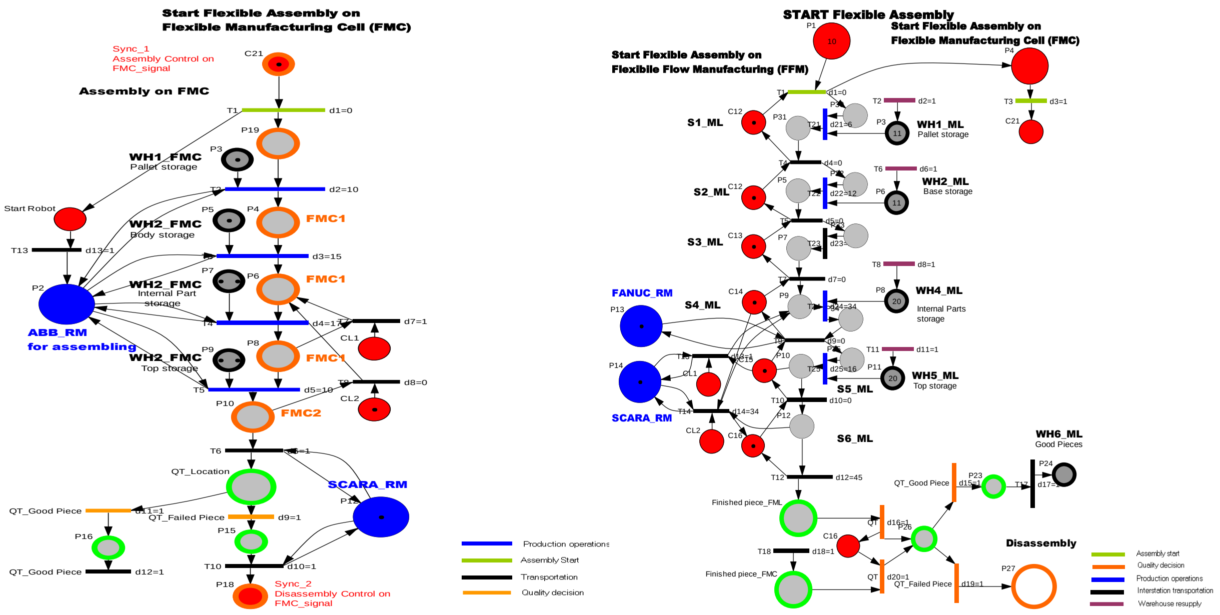
$\theta_{k+1,p}$ represents the number of parts inserted in the station *k+1.*

The generalized model of synchronization of manufacturing in the cell with manufacturing in flow

Based on the production system model can also be defined:

- production time in FFC:

$$T_{prodcell} = \beta\, T_{prod\,max} ,\ \beta \in N \ , \beta \geq 1$$



a) b)

Figure 6. Model PN model pentru asamblarea in a) FMC b) FFM

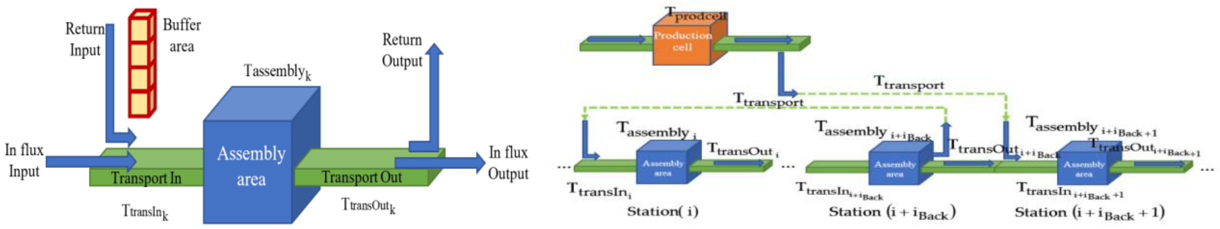


Figure 4. a) Modelul general al unei stații de lucru; b) Model general al fabricației flexibile in SIFF

- return transport time:

$$T_{transport} = \lambda T_{prod\,max}\,,\ \lambda \in \mathbf{N},\ \lambda \geq \mathbf{1}$$

- and cycle time in FFC:

$$T_{CycleCell} = (\beta + \lambda + 1) T_{prod\,max}$$

Based on the production times in FFM and FMC we define a form minimization function:

$$J_{IFMS} = \min\left(\left|\left(\sum_{r=1}^{\upsilon_1 - \eta} T_{CycleCell}\right) - T_{prodFFM}\right|\right)$$

Based on these, the number of type 1 products assembled on FFM is determined:

$$\eta = \frac{\upsilon_1(\beta + 1) - \upsilon_2 - N + 1}{\beta + 3}$$

The time between FFM and FMC is also determined as:

$$T_{sync} = c\, T_{prod\,max}$$

where:

$$c = \beta + 1 - \left(i + i_{Back} + \theta_{i,T1}\right).$$

Based on parameter c of FFM synchronization with FMC, the following task correlations result:

- production of the Type 1 part on the FFF begins with steps before production on the FFC.
- production on FFF and FFC start simultaneously
- the production of the type 1 part on the FFF starts with c steps after the production on the FFC starts.

3.14.2. Results of the implementation of the generalized algorithm for optimizing production planning on two parallel systems dedicated to flexible manufacturing

Based on the general model, it was considered a production of type 1 and type 2 parts for production, simultaneously on the two streams FFM and FMC. In the case of production, two distinct cases are obtained: process initialization and cyclic repetitive production. Thus, the task schedules for the initialization sequence and for the repetitive manufacturing cycles (Figure 5.a) and minimum durations for the variable “waiting time” (Figure 5.b) were obtained.

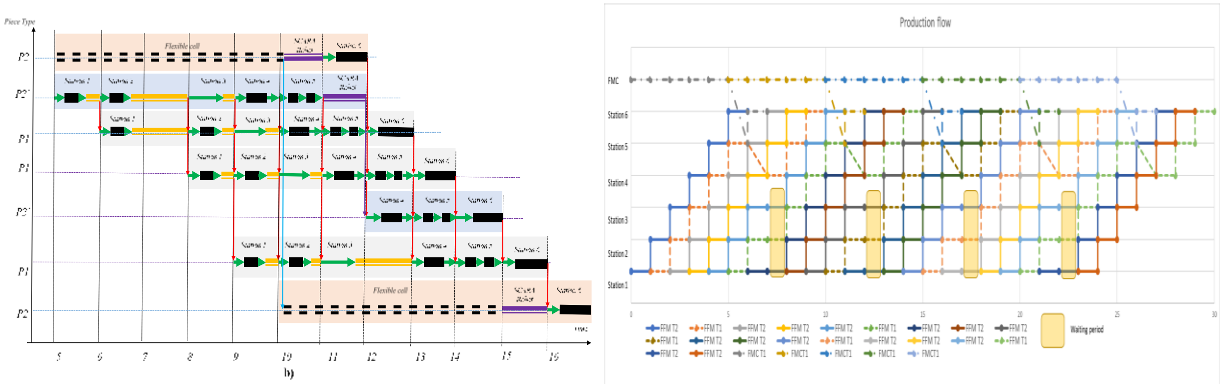


Figura 5: Planificarea taskurilor de producție: a) Producția repetitivă; b) : Fabricație flexibila cu evidențierea timpilor de așteptare

Activity 3.15, Activity 3.16

Laboratory testing of real-time control of flexible LA / D precision manufacturing lines, assisted in the reversible process of disassembly of SAC integrated in assistive technologies, SAC-ARP, SAC-VAM, mobile robots (2DW / 1FW) equipped with Manipulator 6-DOF Arm

3.15.2. Implementation and testing of the production optimization algorithm on SIFF equipped with SAC-VAM industrial robotic systems

SAC-VAM control structure for warehouse recovery / supply with components, based on an inventory optimization algorithm

Figure 6. Linia de fabricație flexibilă de precizie, de laborator, asistata în procesul reversibil de dezasamblare de SAC-VAM (2DW/1FW), robot mobil echipat cu Manipulator 6-DOF, cu conducere integrata în tehnologii de asistare

The recovery and replenishment process presented in Fig.6, Fig.7 is defined by the production and mobile robot parameters. In a non-optimized manner, the mobile robot receives a supply order when stocks in a workstation warehouse are below a set threshold. At the supply order, the mobile robot takes a predefined number of parts and transports them to the station warehouse.

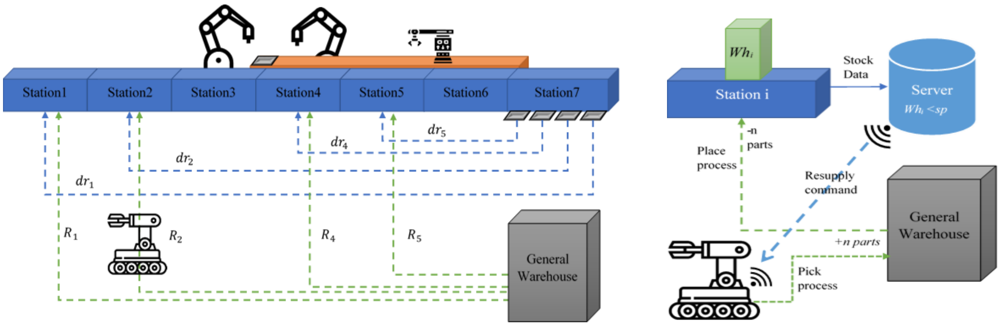


Figura 7. a)Traiectoriile CAS pentru aprovizionare/recuperare componente in magazii; b) Aprovizionare cu componente

The process steps can be viewed in general for a station i in Fig.7.a, where i represents the station number. The sourcing process depends on some parameters of the process and the mobile robot: • it is the processing period of the station and represents the time required for a workstation to finish a product; • represents the supply time and is to a large extent influenced by the time of taking over and placing the robot. The mobile robot is connected to the local network, communicating directly with the production server. The communication between the local server and the mobile robot is done using the local wireless internet network. All provisioning commands processed on the server are stored in the SQL database from where the mobile robot's internal processing unit reads it at a predefined time interval. The mobile robot also transmits the supply processing information back to the database for storage and other processes.

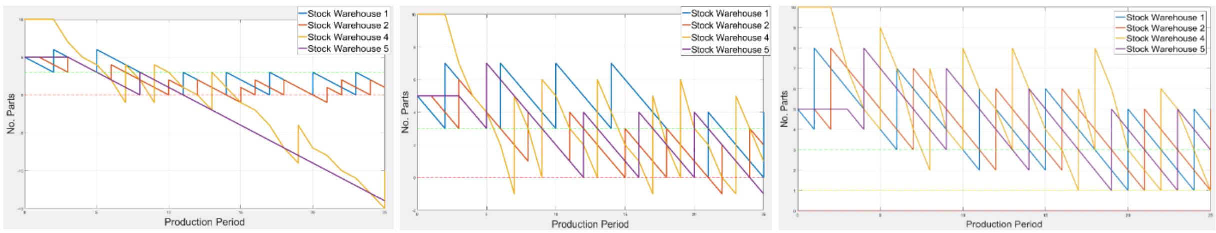


Figura 8. Evoluția stocului in magazii pentru a) aprovizionare insuficienta**;** b) supra-aprovizionare; c) stoc optimizat

The optimization function is defined according to the waiting time for supply and the difference between the stock in a warehouse and the stock demand for production between the production period j, which has values from 1 to N:

$$t_a = \min\left(\sum_{j=1}^{N}\sum_{i=1}^{N_w}\left(Tw_i\sigma_i\left(Wh_{i,j}\right) - D_{i,j+1}\right)\right)$$

After implementation and testing (Fig.8.a, b), it results that in the process of supplying the warehouses, the mobile robot introduces an additional waiting time that accumulates over time. This cumulative waiting time causes a decrease in the level of components in the warehouses compared to the ideal case (Fig.8.c). But even in the case of the introduction of a waiting time by the mobile robot, the level of stocks is kept above the minimum level, without implications in the production process.

CONCLUSIONS

The detailed scientific report highlights the scientific solutions that the Project 4 work team offers for the requirements of Stage 3. The detailed scientific report (http://cidsacteh.valahia.ro/p4/files/Report Stage3_extins.pdf) presents technologies management system of the **Integrated System for Flexible Manufacturing** as well as results of the test sequences of its real-time management, with the integration of algorithms for optimizing the flexible manufacturing and component stocks of SIFF warehouses. Algorithms and technologies have been developed / implemented / tested for the management of SIFF:

- product quality control (QC) based on a new image analysis algorithm;

- SAC-ARP, SAC-VAM control algorithms, mobile robots (2DW / 1FW) equipped with 6-DOF Arm Manipulator for optimizing component stocks in SIFF station warehouses;

- optimizing the planning of production tasks based on a generalized algorithm for optimizing flexible manufacturing;

- Testing the software platform for synchronization of parallel processes, dedicated to flexible precision LA / D manufacturing, integrated in hybrid manufacturing technologies;

- Testing the control structure for precision handling and positioning operations of the SCARA manipulator

- Testing the control structure of two parallel flows for flexible manufacturing, with the synchronization of arrival at the QT quality testing station

- Testing of the software platform for synchronization of flexible precision LA / D production lines, integrated in hybrid manufacturing technologies, and the visual servoing system of SAC-VAM, under the LabView / Matlab / Visual C ++ platform;

- Laboratory testing of real-time management of flexible LA / D precision manufacturing lines, assisted in the reversible process of disassembly of SAC integrated in assistive technologies, SAC-VAM, mobile robots (2DW / 1FW) equipped with Manipulator 6- DOF Arm

Functional test results;

- Results of laboratory testing of the management of flexible manufacturing lines, integrated in hybrid technologies, assisted by SAC-VAM and SAC-ARP
- Results of the laboratory testing of the quality testing process management, on a quality control station implemented in this stage;
- Results of testing the production optimization algorithm, implemented on the flexible manufacturing line with parallel, synchronized flows;
- Results of testing the quality control algorithm implemented in a dedicated station;
- Results of laboratory typing of the hybrid system management, flexible manufacturing line with two synchronized flexible and reversible manufacturing flows, served by SAC-VAM and SAC-ARP;

EXPECTED RESULTS

Within Stage 3 of project 4 the following results were obtained:

1. Validation by testing of the product quality assessment software implemented under the Matlab / Visual C ++ platform;
2. Validation by testing of the production optimization algorithm, implemented on the flexible manufacturing line with parallel, synchronized flows;
3. Validation by testing of the optimized management of the flexible manufacturing technology, with synchronized parallel flows, assisted in the reversible process of disassembly of SAC integrated in assistive technologies, SAC-ARP, mobile robots (2DW / 1FW) equipped with Manipulator 6- DOF Arm and SAC-VAM, mobile robots (2DW / 2SW) equipped with Manipulator 6-DOF

PERFORMANCE INDICATORS

1. SAC-VAM and SAC-ARP research services integrated in hybrid service technologies, on flexible precision manufacturing lines for A / D;
2. Hybrid technology of flexible manufacturing based on the software for synchronizing the management of two parallel processes of flexible manufacturing with synchronized execution, integrated in the system for flexible manufacturing;
3. Hybrid technology for flexible, precision manufacturing, A / D on laboratory (mechatronics) lines with integrated SAC-ARP and SAC-VAM;
4. Two new research jobs supported by the program. The UVT partner employs 2 new researchers in the field of Systems Engineering, in the position of Researcher in Automation, who are included in the staff list of the UVT partner

DISSEMINATION

Articles presented at national and international conferences in 2020:

1. *Optimal Control of Automated Resupply on a Flexible Manufacturing Mechatronics Line* , Octavian Gabriel DUCA, Eugenia Minca, Filipescu Adrian, Petrut Claudiu Bidica, Marius-Adrian Păun, 24rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania during October 8-10, 2020
2. *Improved Image Processing Algorithm for Quality Test on a Flexible Manufacturing Mechatronic Line*, Marius-Adrian Păun, Eugenia Minca, Adrian Filipescu, Octavian Gabriel DUCA, Adriana Filipescu, 24rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania during October 8-10, 2020
3. *Optimal control of a flexible assembly technology on a mechatronics line with integrated industrial robotic manipulators*, Octavian Duca, Eugenia Minca , Adrian Filipescu , Henri-George Coanda , Florin Dragomir , Adriana Filipescu, Journal: Sensors, Manuscript ID: sensors-981733, (*under review)*

4. *Image processing method based quality test on a smart flexible assembly mechatronic system with component recovery*, Paun Marius-Adrian, Eugenia Mincă, Duca Octavian, Gurgu Valentin, Journal of Science and arts, 2020, (*under review)*
5. *Manufacturing Technology on a Mechatronics Line Assisted by Autonomous Robotic Systems, Robotic Manipulators and Visual Servoing Systems*, Adrian Filipescu, Eugenia Mincă, Adriana Filipescu, Henri-George Coandă, Journal name: Actuators, Manuscript ID: actuators-991918, (*under review)*

Description - The real-time management structure of precision assembly / disassembly lines, integrated in hybrid manufacturing technologies, assisted in the reversible SAC disassembly process, integrated in assistive technologies. Flexible manufacturing line with two parallel production flows, synchronized, and served by SAC-VAM and SAC-ARP.https: //erris.gov.ro/Valahia-University-of-Targoviste
Services
Hybrid technology for flexible, precision manufacturing, assembly / disassembly on mechatronic laboratory lines with integrated SAC_ARP and SAC-VAM
Hybrid technology for flexible manufacturing based on the software for synchronizing the management of two parallel processes for flexible manufacturing, with synchronized execution, integrated in the system for flexible manufacturing; https://erris.gov.ro/Valahia-University-of-Targoviste ,

PROJECT 5

Component project: Pr.5 Intelligent driving, with advanced techniques and navigation based on high-performance sensors, video-biometric system and visual servoing system of the complex autonomous system SAC-SI integrated in the technology of assisting people with severe neuro-motor disabilities

Stage 4 (2021)

Objectives Stage 4. Laboratory testing of the driving structure and navigation structure (based on high-performance sensors) of SAC-SI integrated in the technology of assisting people with severe neuro-motor disabilities
Stage 4 – P5. The research finally led to the implementation and real-time testing of the driving structure, navigation and obstacle avoidance for the complex autonomous system SAC-SI, autonomous robotic system consisting of wheelchair and robotic manipulator with 7-DOF integrated in the technology of assistance for people with neuromotor disabilities. The research of Stage 4 respond to the research objectives related to Activity 4.5, from the realization plan of the complex project, and finally led to the validation by testing of the real-time management of the complex autonomous system SAC-SI. The research for implementation / testing required the establishment of a procedure for planning the trajectory of the complex CAS-SI system. An algorithm for passing through narrow spaces (door) of the complex CAS-SI system has been developed. During this stage, a software package necessary to control the complex CAS-SI system through narrow spaces (door) - based on laser and video sensors - was developed and tested in laboratory conditions. The laser sensor was used to detect the space required for maneuvers to pass through the door frame and the video camera was used to detect the door (using QR codes).

Activity 4.5. Real-time testing of the control, navigation and obstacle avoidance structure for the complex autonomous SAC-SI system integrated in the technology of assisting people with severe neuro-motor disabilities in laboratory conditions.**Performance indicators:**
- A control, navigation and obstacle avoidance structure was developed for SAC-SI integrated in the technology of assisting people with severe neuro-motor disabilities, tested in laboratory conditions;
- A structure of offer of research services regarding SAC-SI integrated in the technology of assistance to people with severe neuro-motor disabilities present in the *erris* platform of the partner institutions in the consortium was created:
UVT: https://erris.gov.ro/Valahia-University-of-Targoviste
UCV : https://erris.gov.ro/Computer-Aided-Design-CAD--C
In this activity, a control structure of a robotic platform with 2 driving wheels using a laser type sensor and a video camera (web) was tested, see figure 5.1.
An autonomous door crossing system becomes a very important module for the autonomous navigation of complex autonomous systems of the SAC-SI type, because when combined with the wall tracking modules, it ensures a complete navigation system for indoor environments.
The control of the two-wheeled robotic platform through a door, tracking a certain wall or following the corridor are skills used in the case of autonomous mobile robot navigation systems. In the real world there are few applications that take into account the movements of the mobile robot passing through narrow exits, requirements very common in the case of autonomous navigation systems.

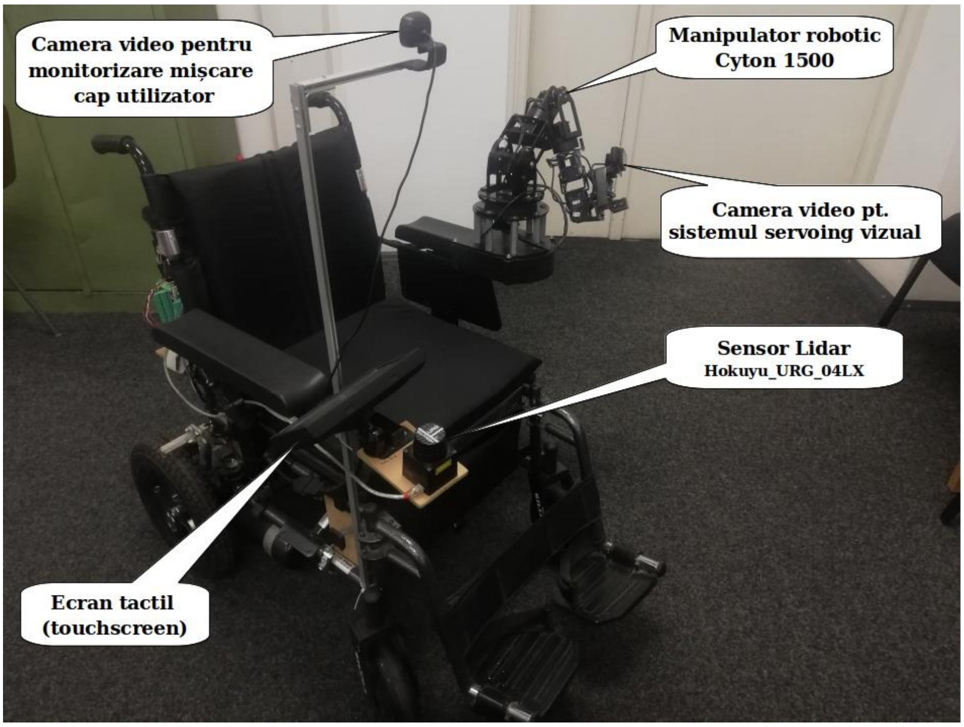


Fig. 5.1 The autonomous complex system SAC-SI integrated in assistive technology for people with severe neuromotor disabilities (front view).

The narrow space passage / movement algorithm consists of scanning the environment using a laser sensor and calculating the 6 points / positions that the mobile robot must reach. After reaching the last point, scan the environment again and calculate the next 6 points. This process is repeated until the mobile robot reaches the desired end point.

To determine the end point where the robot must reach, we need the "dial" where the door is. This information is obtained from a video camera that detects the door frame using a QR code (see Figures 5.2 and 5.3).

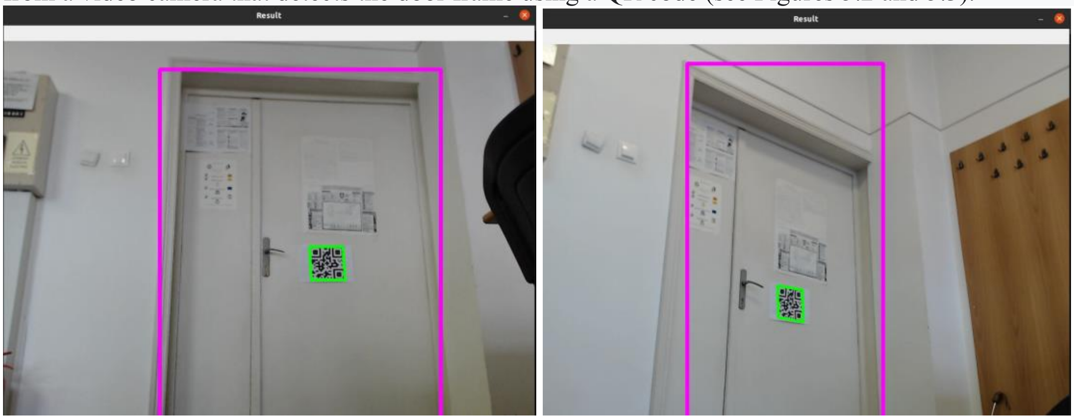


Fig. 5.2 Various images containing the door detected using the QR code

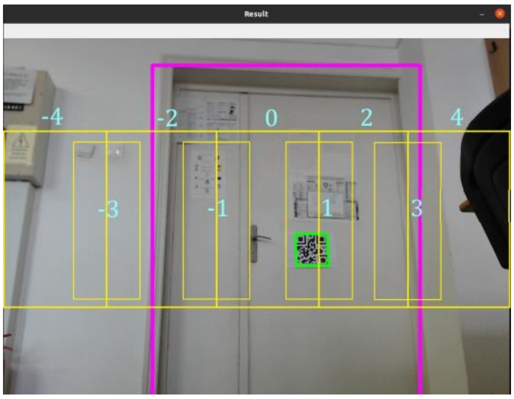


Fig. 5.3 Dividing the image into 9 quadrants   (in this example the QR code can be found in quadrant no. 1).

The scheme of the algorithm used to detect a door is presented in figure 5.4.

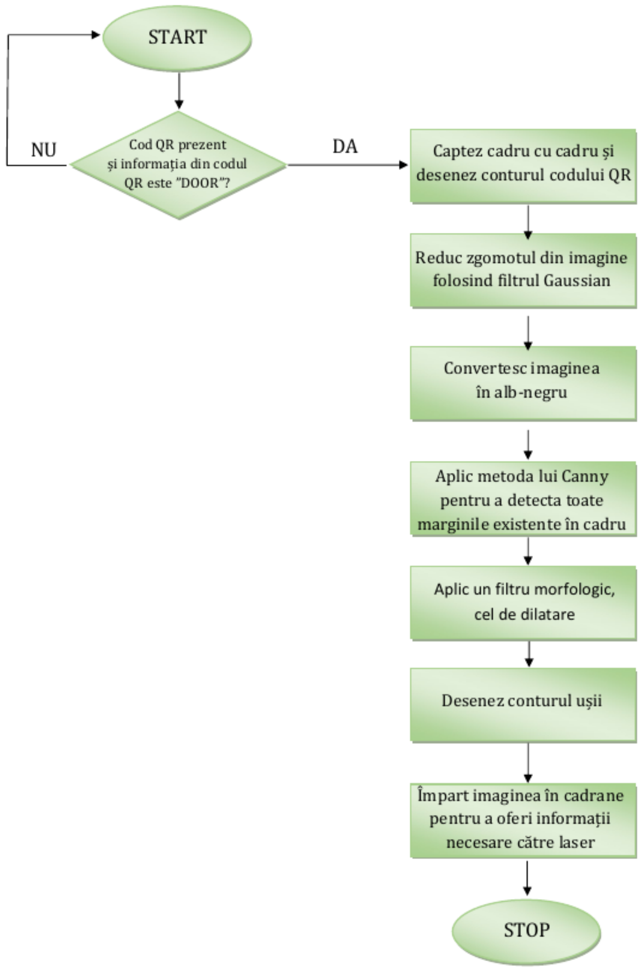


Fig. 5.4 The Logic diagram of the algorithm used to detect a door

To detect the space needed to move the mobile robot, use the laser sensor and the algorithm made in Matlab using a repetitive cycle of "for" type that "draws" several semicircles placed at a distance of 0.1m (from 0.3 m to 1 meter).

```
for arc = 0.3:0.1:1
    for i = 1:12
      for j = 1:43
        if arc == 0.3
            if citire_laser(j+((i-1)*43)) <= arc && citire_laser(j+((i-1)*43))> 0.2
              punct_fereastra(j, i) = 1; % fereastra ocupata
            else
              punct_fereastra(j, i) = 0; % fereastra libera
            end
        else
            if citire_laser(j+((i-1)*43))<=arc+0.2 && citire_laser(j+((i-1)*43))>arc-0.2
              punct_fereastra(j, i) = 1; % fereastra ocupata
            else
              punct_fereastra(j, i) = 0; % fereastra libera
            end
        end
      end
    end
```

The second repetitive cycle goes through the number of windows, 12 in number, using the "i" counter. What the third repetitive cycle goes through with the help of the counter "j" each window with the size of 15 degrees, which means a number of 43 readings. With the help of the "if" structure it is checked if there are obstacles inside the "i" window. If the window is occupied, the variable "window_point" is assigned the value 1, but if the window is free, the variable "window_point" is assigned the value 0. Next, the matrix "A" is used, inside which it is cumulated for each arc and each window the number of checked points and their type, free or occupied. A "degrees" vector is also defined, which contains the degrees of the window boundaries.

A(c, 1:12) = sum(punct_fereastra);
grade = [15 30 45 60 75 90 105 120 135 150 165 180];

The next step is checking matrix A to see which window has obstacles and which window is free. Occupied windows are assigned a value of 0 and free windows are assigned the value of the angle corresponding to the position, this can be seen in Figure 5.5.

Următoarea etapă realizează verificarea matricea A pentru a vedea care fereastră are obstacole și care fereastră este liberă. Ferestrelor ocupate li se atribuie valoarea 0, iar ferestrelor libere li se atribuie valoarea ungiului corespunzător poziției, acest lucru se poate observa în figura 5.5.

A =

15	30	45	60	75	90	105	120	135	150	165	180
0	30	45	60	75	90	105	120	135	150	165	180
0	30	45	60	75	90	105	120	135	150	0	0
0	30	45	60	75	90	105	120	135	0	0	0
0	0	45	60	75	90	105	120	135	0	0	0
0	0	45	60	75	90	105	120	135	0	0	0
0	0	45	60	75	90	105	120	135	0	0	0
0	0	0	60	75	90	105	120	135	150	165	0

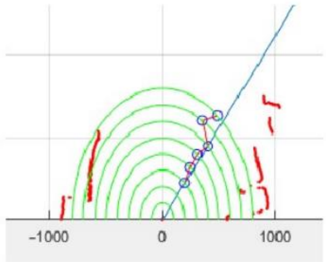


Fig. 5.5 The A Matrix associated to the presented graphic

The following are some examples of concrete cases

A =

15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180
15	30	45	60	75	90	105	120	135	150	165	180

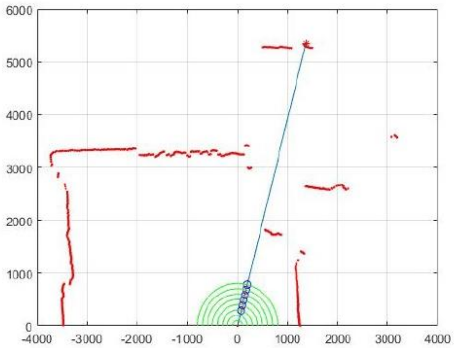


Fig. 5.6a On the mobile robot trajectory there are no obstacles

A =

15	30	45	60	75	90	105	120	135	150	165	180
0	0	45	0	75	90	105	120	135	150	165	180
0	0	0	0	75	90	105	120	135	150	165	180
0	0	0	0	75	90	105	120	135	150	165	180
15	0	0	0	75	90	105	120	135	150	165	180
15	0	0	0	75	90	105	120	135	150	165	180
15	30	0	0	75	90	105	120	135	150	165	180
15	30	0	0	75	90	105	120	135	150	165	180

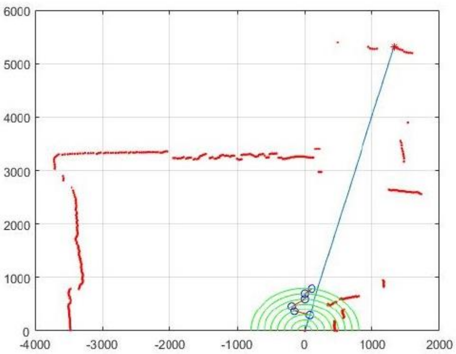


Fig. 5.6b On the mobile robot trajectory there are obstacles

Next, there some experimental results are presented. For these results, the size of the SAC-SI mobile robot was taken into account, as well as the range of the laser sensor used.

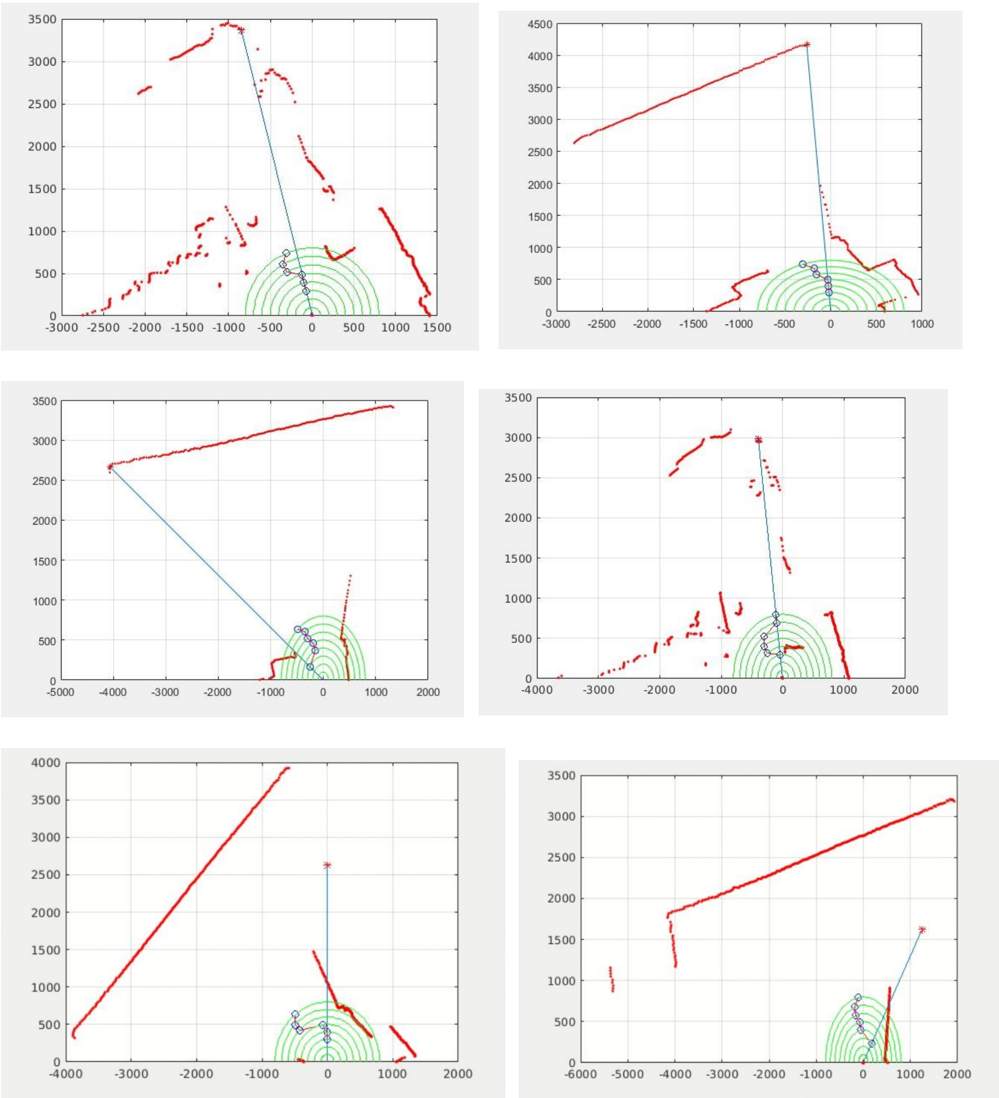


Fig. 5.7 Rezultate experimentale – ieșirea pe ușă a robotului mobil

CONCLUSION

The scientific report highlights the solutions that the Project 5 work team offers for the requirements of Stage 4. In the detailed scientific report uploaded on the P5 project platform (http://www.cidsacteh.ugal.ro), you can view the solutions and results research related to Stage 4."

„The results of the laboratory testing of the intelligent driving structure, of the navigation structure (based on high-performance sensors) and of the driving structure based on real-time visual servoing systems of SAC-SI integrated in the technology of assisting people with neuro-motor disabilities severe".

„***Rezultatele testării în laborator ale structurii de conducere inteligentă, ale structurii de navigație (bazată pe senzori performanți) şi ale structurii de conducere bazată pe sisteme servoing vizuale în timp real a SAC-SI integrat în tehnologia de asistare a persoanelor cu dizabilităţi neuro-motorii severe*".**

The Results for Stage 4

1) An algorithm for passing through narrow spaces (door) of a robotic platform with two driving wheels has been developed. During this stage, a software package necessary to drive a robotic platform with two drive wheels (SAC-SI type) through narrow spaces (door) – based on laser and video sensors – was developed and tested in laboratory conditions. The laser sensor was used to detect the space required for maneuvers to pass through the door frame and the video camera was used to detect the door (using QR codes).

2) A structure of offer of research services regarding SAC-SI integrated in the technology of assistance to people with severe neuro-motor disabilities present in the erris platform of the partner institutions in the consortium was created:

UVT: https://erris.gov.ro/Valahia-University-of-Targoviste

UCV : https://erris.gov.ro/Computer-Aided-Design-CAD--C

Director proiect complex
Prof. Dr. Ing. Adrian FILIPESCU

30.09.2021