SCIENTIFIC AND TECHNICAL REPORT, STAGE II (2019)

PROJECT 1: **Activity 2.1:** Modeling and simulation of the sensors selected in Step 1

At this activity the modeling and simulation of the use of selected sensors were performed, namely: DJI Guidance, LIDAR, Kinect and Tobii eye tracker 4c. In the case of simulating the use of DJI Guidance, for the complex autonomous system intended for the technologies of personal medical-social assistance, intra / extra hospital and home made within the present research project, the Guidance Core controller and 4 Guidance sensory elements were used. The local schematic of the connections is shown in the figure below:

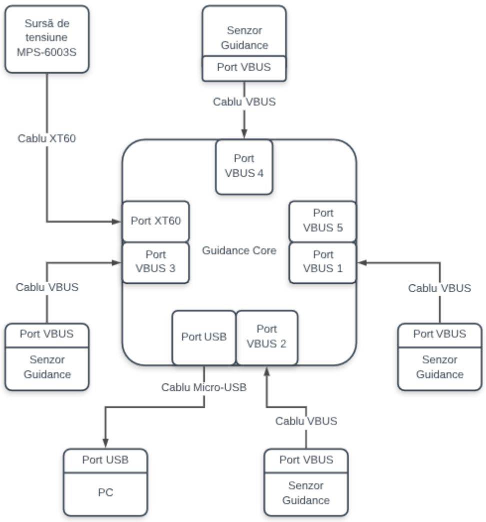


Figure 2.1.1 Local diagram of the connections

In the case of simulating the use of LIDAR, the data is provided by the Velodyne LIDAR under the following structure:

VelodyneVLP16Data18									
X	Y	Z	intensity	laser_id	azimuth	distance_m	adjustedtime	timestamp	vertical_angle
Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
X	Y	Z	intensity	laser_id	azimuth	distance_m	adjustedtime	timestamp	vertical_angle
0.01151305...	4.71177211...	-1.2625193...	4.0	0.0	14.0	4.878	104838287...	628782463.0	-15.0
0.04580262...	17.4952750...	0.30538220...	34.0	1.0	15.0	17.498	104838287...	628782466.0	1.0
0.01517746...	5.43501502...	-1.2547769...	4.0	2.0	16.0	5.578	104838287...	628782468.0	-13.0
0.05185823...	17.4779371...	0.91598390...	67.0	3.0	17.0	17.502	104838287...	628782470.0	3.0
0.01905385...	6.42177676...	-1.2482724...	3.0	4.0	17.0	6.542	104838287...	628782473.0	-11.0
0.04390874...	13.9765426...	1.22279507...	42.0	5.0	18.0	14.03	104838287...	628782475.0	5.0
0.02586826...	7.80071962...	-1.2355194...	3.0	6.0	19.0	7.89800000...	104838287...	628782477.0	-9.0
0.03476412...	9.95914741...	1.22283699...	22.0	7.0	20.0	10.034	104838287...	628782479.0	7.0
0.03645139...	9.94524563...	-1.2211308...	2.0	8.0	21.0	10.02	104838287...	628782482.0	-7.0
0.02773689...	7.56761723...	1.19860087...	50.0	9.0	21.0	7.662	104838287...	628782484.0	9.0
0.05290883...	13.7792634...	-1.2055382...	1.0	10.0	22.0	13.832	104838287...	628782486.0	-5.0
0.02295731...	5.71891389...	1.11165320...	2.0	11.0	23.0	5.82600000...	104838287...	628782489.0	11.0
0.07325335...	17.4878469...	-0.9165072...	54.0	12.0	24.0	17.512	104838287...	628782491.0	-3.0

Simulink application was used to represent the data in the three-dimensional space. Below is shown the block diagram made in Simulink, as well as the functions implemented by them.

Figure 2.1.10 Data representation in three-dimensional space

In the case of simulating Kinect usage, the device provides 2D data from images obtained on the visible spectrum and 3D data acquired by a time-lapse camera on the IR spectrum. The mapping is provided as a point cloud represented in polar coordinates and contains the distance from the sensor to the nearest obstacle in the respective polar direction. In the case of simulating the use of the Tobii eye tracker 4c, the test is designed to measure the accuracy and precision of the sensor in correlation with a particular subject. In this regard, we have defined the surrounding areas around specific target points, to determine the position of the eye gaze reported by the sensor, while the subject is convinced that he / she is looking at the target point. Thus, if the gaze is within a neighboring area for 0.5 seconds, the algorithm marks the appropriate target as "subject view", changes the target color, and records the average viewing position during 0.5 seconds.

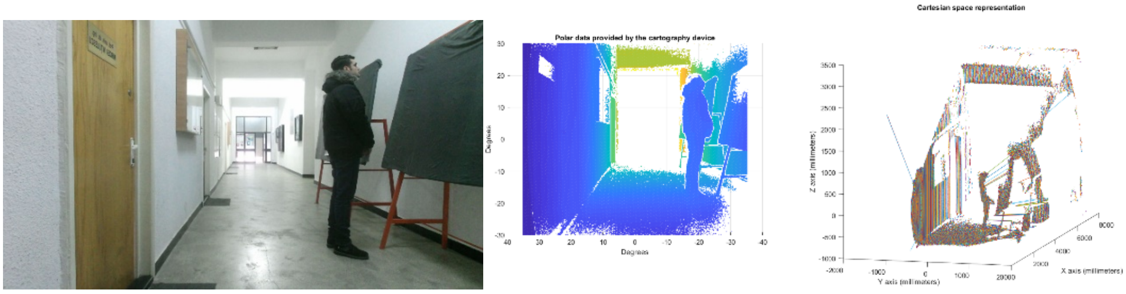


Figure 2.1.11 Left image: 2D image sharpened on the visible spectrum. Central image: depth data acquired by the cartographic device in polar coordinates; the center of the image represents the center of the polar coordinate system. Right image: depth data from Cartesian space coordinates (point cloud).

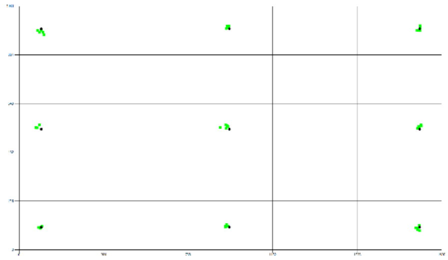


Figure 2.1.14 Eye gaze data recorded for a test, subject A. Good accuracy and good accuracy can be observed

One test consisted of:

- A screen with 9 target points is displayed (black dots in fig.3);
- The subject must look at each point for at least 0.5 seconds, in a random order, at least 5 times;
- For each point a neighboring area is defined; after looking more than 0.5 seconds at a point, the target point changes color to allow the user to know that 0.5 seconds have passed; at the same time, the data regarding the eye gaze extracted by the eye tracking device are recorded;
- The test ends automatically when the user analyzes each target point at least 5 times.

The tests were conducted for several subjects - at this stage of the research project, the subjects were members of the team; In the future, we will perform tests on persons with severe mobility impairments, to obtain their feedback (only for the valid operating conditions, described as follows).

For each subject, the tests were repeated under different operating conditions: outdoors (sunlight at different angles in relation to the sensor / subject, partly cloudy); interior (natural light, fluorescent light, incandescent light, different light intensities). Data analysis showed that the sensor is not suitable for outdoor operation in direct sunlight (coming from any angle) and when it is partially cloudy - the test provided erroneous data or even missing data (the sensor lost sight of the eyes).

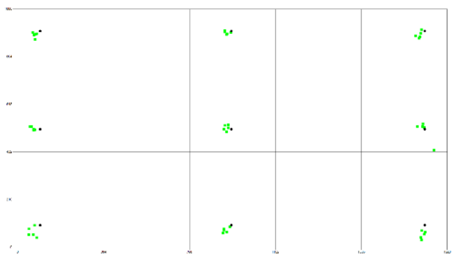


Figure 2.1.15 Tracking data of the eyes recorded for subject B under the same conditions as the data recorded for subject A and presented in fig.3. It can be seen that accuracy and precision are less good.

Activity category: A2 - Industrial research: Expected results, Selected sensor models and simulation results

Activity 2.2:Modeling and simulation of the sensory system defined in Step 1.

At this activity, the data fusion system was provided by the global sensory system with the general scheme presented in the figure below.

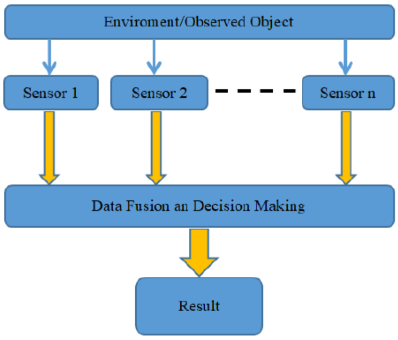


Figure 2.2.1 Generic data fusion system.

The model of the proposed sensory system for wheelchair (mobile platform) is composed of Kinect video acquisition system and Lidar VLP-16 system for laser scanning.The Kinect video system is positioned in front of the movement direction, in the middle of the seat, scanning an angular sector of 120 degrees horizontally and 80 degrees vertically.The experiments performed for object detection were performed using the KITTI data set. The association between the RGB-D images obtained with the Kinect camera and the cloud points obtained with LIDAR was based on an updated version of the Adaptive Least Squares Correlation (GOTCHA) algorithm.The first step consists of extracting the initial points using an implementation of the SIFT key points matching from OpenCV.The next step is to combine the subset of cloud points obtained from the LIDAR source with the RGB-D images generated by the Kinect camera.

The following graphs show the Precision-Recall curves obtained, in which only Kinect images, only LIDAR images were used, and for the experiments in which combined images obtained as a result of the fusion of data between Kinect and LIDAR were used. For the objects, three algorithms were used to detect:

- recognition of SIFT objects that involve 4 phases: detection of features; description of the local image; model indexing, matching and verification;
- BlitzNet which proposes a complex architecture for a real-time understanding of the scene with its implementation;
- Tensorflow Object Detection that creates precise machine learning models capable of locating and identifying multiple objects in a single image with its implementation;

The Precision-Recall curves are drawn in blue for the SIFT algorithm, green for BlitzNet and red for Tensorflow.

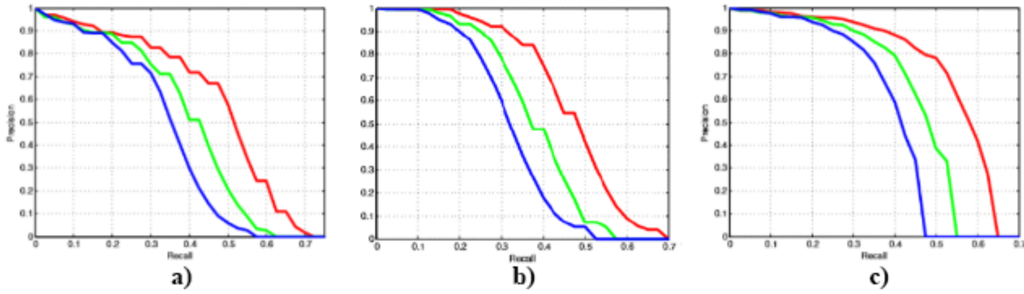


Figure 2.2.5 a) Precision-Recall graph for Kinect dataset; b) Precision-Recall graph for the LiDAR data set; c) Precision-Recall graph for the data set obtained from the data fusion process

Activity category: A2 - Industrial research, Expected results, Sensory system model and simulation results;
Activity 2.3. Simulation of trajectory control algorithms bypassing obstacles based on the information provided by the distributed sensory system. In this stage, the following trajectory control algorithms have been simulated bypassing the obstacles based on the information provided by the distributed sensory system: VFH +, an obstacle control algorithm using Fuzzy logic and a control algorithm based on artificial potential field method and Fuzzy logic. The VFH + method uses a four step data reduction process to calculate the new direction of motion. In the first three stages, the two-dimensional map grid is reduced to polar histograms that are built around the current location of the robot. In the fourth step, the algorithm selects the most appropriate direction based on the masked polar histogram and a cost function. The purpose of the control algorithm around obstacles using the proposed Fuzzy logic is to move the vehicle close to the border of the object, avoiding collisions.

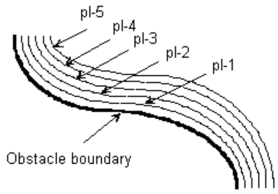


Figure 2.3.5 Obstacle boundaries and proximity levels

The artificial potential field method is considered a "local" method that is based on the following idea: the electric vehicle in its trajectory motion must be "attracted" by the target and rejected by the boundaries of obstacles and, possibly, the operating field.

The field of artificial attraction potential is a function of potentials whose minimum points are attractive elements for the controlled system.
The main idea that comes from the definition of the rejection potential is to create a potential barrier around obstacles so that it is not crossed by the trajectory of the mobile platform.

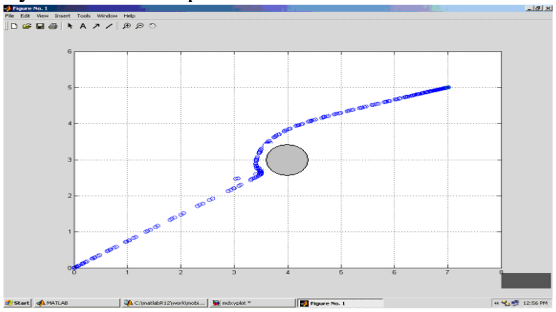


Figure 2.3.11 The trajectory of the autonomous mobile vehicle in the presence of an obstacle

Activity category: A2 - Industrial research, Expected results

- Trajectory control algorithms bypassing the obstacles based on the information provided by the sensory system defined in the previous stages;
- The results of the functional simulations based on the algorithms definitions;
- Participation in conferences, workshops, articles in ISI / BDI magazine;

CONCLUSIONS: The detailed scientific report highlights the scientific solutions that the project team of Project 1 offers for the requirements of Stage 2. In the detailed scientific report uploaded on the P1 project platform (http://cidsactech.ucv.ro/data/_uploaded/Documents/ REPORT% 20CIDSACTEH% 20P1% 202019% 20UCV.pdf), the solutions / results for research related to Stage 2 can be viewed. Project 1 "Intelligent and distributed management of 3 complex autonomous systems integrated in emerging technologies towards personal medical-social assistance and service precision flexible manufacturing lines ".

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

ISI- Proceedings Paper

1) Manta L.F., Cojocaru D., Vladu I.C., Dragomir A., Mariniuc A., 2019, Wheelchair Control by Head Motion Using a Non-contact Method in Relation to the Patient, 2019 20th International Carpathian Control Conference (ICCC), May 26 – 29, Kraków-Wieliczka, Poland, Electronic ISBN: 978-1-7281-0702-8, DOI: 10.1109/CarpathianCC.2019.8765982, WOS:000490570500097, ISBN:978-1-7281-0701-1

2) Viorel Stoian, Ionel Cristian Vladu, Cristina Pana, Daniela Pătrașcu, Ileana Vladu, Locomotion Solution for Stair Climbing Wheelchair with ER Fluid Based Control, 2019, Proceedings of the 20th International Carpathian Control Conference (ICCC'2019), Krakow-Wieliczka, Poland, May 26-29, 2019, ISBN: 978-1-7281-0701-1, IEEE Catalog Number: CFP1942L-USB, WOS:000490570500070

BDI – IEEE XPLORE

3) Dorian Cojocaru, Andrei Dragomir, Florin Manta, Alexandru Mariniuc, Cristian Ionel Vladu, Iulian Deaconu, Involving Students with Special Needs In Research Projects, 29th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE) 2019, 4-6 September, University of Ruse, Ruse, Bulgaria, (in curs de aparitie)

4) Cojocaru D., Manta L. F., Vladu I.C., Dragomir A., Mariniuc A., 2019, Using an Eye Gaze New Combined Approach to Control a Wheelchair Movement, 2019 23rd International Conference on System Theory, Control and Computing (ICSTCC), October 9-11, 2019, Sinaia, Romania, ISSN: 2372-1618, DOI: 10.1109/ICSTCC.2019.8886158.

5) Resceanu Ionut Cristian, Vladu Ionel Cristian, Ganea Eugen, Roibu Horatiu, Bazavan Lidia-Cristina, Decision Making using Data Fusion for Wheelchair Navigation, Proc. of 23rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, October 9-11, 2019, Page(s): 614 - 619, IEEE Catalog Number: CFP1936P-USB, ISBN: 978-1-7281-0698-4, DOI: 10.1109/ICSTCC.2019.8885823

6) I.C. Vladu, D Cojocaru, F. Manta, I Resceanu, Rheological Based Hibrid Hyper-Redundant Robot - Design, Proc. of 23rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, October 9-11, 2019, Page(s): 603 – 607, IEEE Catalog Number: CFP1936P-USB, ISBN: 978-1-7281-0698-4, DOI: 10.1109/ICSTCC.2019.8885467

Conference under the patronage of Ministry of Research and Innovation:

7) Pană Cristiana Floriana, Vladu Ionel Cristian, Pătrașcu Pană Daniela Maria, Manta Liviu Florin, Cojocaru Dorian, Tarniță Daniela, Bîzdoacă Nicu George, *Smart Fluid Based Variable Geometry Wheel*, Proceedings of the 11th European Exhibition of Creativity and Innovation EUROINVENT 2019, 17-19 mai, 2019, ISSN Print: 2601-4564

Presentations at national events organized in 2019:

1. Prezentare proiect - în cadrul conferinței **11th European Exhibition of Creativity and Innovation EUROINVENT 2019, 17-19 mai, 2019**, patronată de Ministerul Cercetării și Inovării

Premii: http://cidsactech.ucv.ro/index.php/Publicatii

- Diplomă și Medalie de aur pentru: *Smart Fluid Based Variable Geometry Wheel* - Cerere de Brevetare

A/00212/2019, Universitatea din Craiova, Pentru Proiectul Complex: CIDSATECH, autori: Pană Cristiana Floriana, Vladu Ionel Cristian, Pătrașcu Pană Daniela Maria, Manta Liviu Florin, Cojocaru Dorian, Tarniță Daniela, Bîzdoacă Nicu George, EUROINVENT 2019

- Diplomă și Medalie de aur pentru: *Smart Fluid Based Variable Geometry Wheel* - Cerere de Brevetare A/00212/2019, Universitatea din Craiova, Pentru Proiectul Complex: CIDSATECH, autori: Pană Cristiana Floriana, Vladu Ionel Cristian, Pătrașcu Pană Daniela Maria, Manta Liviu Florin, Cojocaru Dorian, Tarniță Daniela, Bîzdoacă Nicu George, EUROINVENT 2019

2. **Prezentarea proiectului CIDSACTEH** în cadrul evenimentului ***„Noaptea cercetătorilor”*** 27 Septembrie 2019 organizat la Universitatea din Craiova. http://cidsactech.ucv.ro/index.php/Noaptea-Cercetatorilor
3. Prezentare proiect - în cadrul conferinței: **29th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE) 2019**, 4-6 September, University of Ruse, Ruse, Bulgaria

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

RESEARCH AND TECHNOLOGICAL SERVICES

Name - Structural and architectural analysis of mobile platforms for people with disabilities
- Analysis and selection of integration and interface solutions of sensory systems in driving architectures for mobile platforms for people with disabilities
- Study on "Integration of Intelligent Sensors in Robot Management Structures"
- Assisted design services of mobile platforms for people with disabilities
- Integration and interface services of sensory systems in driving architectures for mobile platforms for people with disabilities

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

Project 2:Activity 2.4. Definition of basic models for distributed configurations of sensors and visual servoing systems associated with flexible manufacturing lines, *2.4.1. Implementation of the experimental model of MVD.*

2.4.1.1. Basic features:The development environment comprises two main components: the web application and the execution module. The connection between the two is done through an exchange of REST messages, represented in XML format. The web application has as main elements: The user interface; Graphic editor for creating link structures; Execution preparation module; Interface module with the execution server. A user can launch executable function structures in execution. From the execution point of view, this can be: 1) Local, on the web application server; 2) Inside the development environment, in real time, through interconnection via an industrial communication protocol; 3) Inside the development environment, offline, using log files with input data and output files to communicate execution results. The functionalities offered by the platform are presented in Annex 1 (extended RST).

2.4.1.2. Implementing REST interfaces

REST comes from Representational State Transfer and is a web-based architecture, using HTTP for data transfer. In REST architecture, a REST server grants a client access to resources. Each resource is uniquely identified by a Uniform Resource Indentifier (URI). REST uses the following representations to define a resource: XML, JSON or Text. XML representation is used in the CIDSACTEH project. Details are presented in Annex 2 (extended RST).

2.4.1.3. Description of the execution mechanism

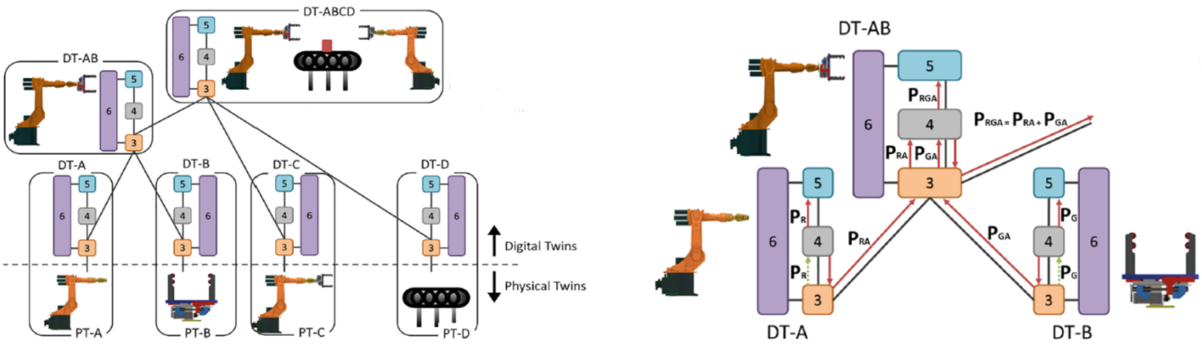
Local execution that allows the execution of a single-block model, running on the local machine, using an OPC server to obtain the input data and provide the user with the output data; Cloud execution that can be done in two ways: Execution based on a set of data stored in a log file and Real time execution respectively.

2.4.1.4. Simulation MVD testing

The testing was performed both after completing each module of the application, during its development, and finally, in the integrated form. This approach allowed the adjustment of the technical solution initially proposed according to the results obtained during the course, so that the level of performance is as high as possible. The test part included 5 steps: i) Testing the execution of the scripts on the server; ii) Testing the OPC server client in Java; iii) Testing of REST interfaces; iv) Testing the web interface; v) Testing the application as a whole.

2.4.2. Implementation in MVD of the design and testing framework in Digital Twin technology

Three emerging technologies currently dominate research in the field of digital process management: Big Data Analytics (BDA), Machine Learning (ML) and Digital Twin (DT). Of these, DT has established itself as essential in the field of robotic manufacturing systems. In the special framework created in MVD for simulation, DT is represented in three hypotheses: 1) Digital Twin Prototype (PDT): a PDT describes the information to create a virtual asset, for example, the 3D model of the asset; (2) Digital Twin Instance (IDT): IDT describes a single specific physical instance of an asset, for example the list of parts that were used to produce this asset or the exact stages of the process that were passed in the production of the given asset; IDT also contains the operational states captured by the sensors connected to the asset; 3) Digital Twin Aggregate (ADT): ADT is an association of multiple IDTs and allows querying information about an asset group. DT-based implementations fall into three categories: 1. Simple equipment models; they contain two main sets of information: the set of current values, measured by the sensors of the equipment and respectively the set of desired values that the control application spears to obtain. 2. Built-in digital avatars (EDT-Embedded Digital Twins); they are involved in all the activities that involve DT, e.g. resource control or production management. The connection between the physical model and the related virtual avatar is established in dual mode: by generating real-time data using sensors and by generating real-time control commands with the help of a decision-making entity. An EDT is the only point of interaction and the only source of information for its counterpart in its real world. 3. Network Digital Twins (NDT); the network offers each EDT the ability to interact with other EDTs in its environment, thus reflecting an extended physical reality. By extension, for the global manufacturing system there will be a single NDT that aggregates DTE for each resource, and for each instance of equipment. In the simulation platform, the DT emulation framework is placed at the highest level - level 6 in a 6-level architecture, defined as follows: Levels in the real physical world: Level 1 - Sensors and equipment (both measurement and measurement) and execution); Level 2 - Data sources processed - usually process management equipment (programmable controllers, process computers, digital controllers): Levels in the virtual physical world; Level 3 - Local data repositories (in the CIDSACTEH platform we used a UPC UA server compatible with SOA, implemented with GPL 2.0 license); Level 4 - IoT Gateway (in the validation the border interface device in Edge technology described in activity 2.6) was used; Level 5 - Data warehouses in the Cloud; Level 6 - Emulation and simulation (which appears as a tire of levels 3, 4 and 5). Fig. 2.4.12 describes a DT simulation application for a typical manufacturing line scenario consisting of several stations for a typical take-over and placement process. Specifically, we have 4 physical entities PT (Physical Twin): a robot without final effector (PT-A), a smart gripper (gripper) (PT-B), a robot with a gripper fully controlled by the robot controller (PT-C) and a conveyor (conveyor) of parts that reach from the source to the destination (PT-D). Each PT, which provides all the source data, has a corresponding digital avatar (DT-A, DT-B, DT-C and DT-D). DT-AB represents an aggregation between DT-A and DT-B. Globally DT-ABCD is an aggregation between DT-AB, DT-C and DT-D. As can be seen from FIG. 2.4.12 a, if a PT is connected to a data source (usually a controller), the OPC UA server at level 3 is able to obtain the homologous PT status. Therefore, even though PT-A and PT-B are part of an ensemble, each can have its own PT. DT-A and DT-B OPC UA servers can be configured so that DT-AB has access only to the information that is made available to DT-A and DT-B, thus maintaining data confidentiality, if PT -A and PT-B would come from different suppliers.



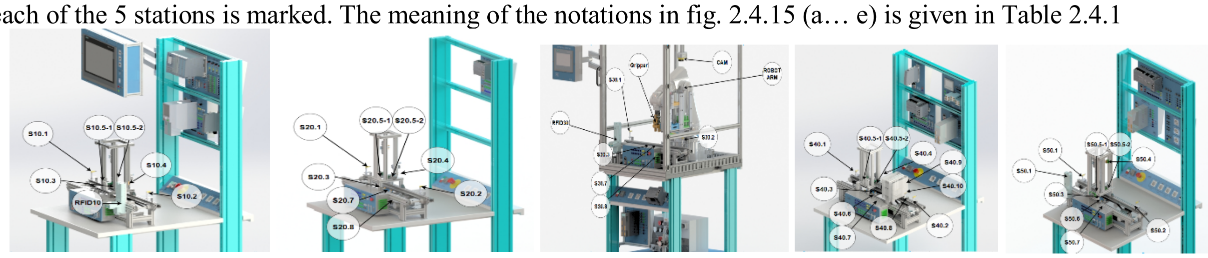
a *b*

Fig. 2.4.12. Using DT in a manufacturing line simulation scenario (a-location; b-connections)

The information flows can be viewed in Fig.2.4.12 b. In this simple example, the computing power requirement of each component is aggregated to a higher level DT. The data regarding the gross computing power consumption at the robot (PR) and the clamping device (PG) are obtained from the data sources (level 2) of the DT through level 3. The IoT gateways of the DT-A and DT-B obtain these data from level 3 and allow calculating the average power consumption of the robot (PRA) and the clamping device (PGA). The DT-AB aggregate can then calculate the average power consumption of the robot-gripper combination (PRGA) using the level 4 IoT gateway.

2.4.3. Implementation and testing of the functional model of a visual control system located on a robotic system integrated in a flexible assembly / disassembly line: 2.4.3.1. Sensor placement on the flexible line

The flexible assembly line has 5 stations (coded: 10, 20, 30, 40 and 50). In fig.2.4.15 (a… e) the location of the sensors for each of the 5 stations is marked. The meaning of the notations in fig. 2.4.15 (a… e) is given in Table 2.4.1



a b c d e

Fig. 2. 4.15. Sensor placement on individual stations

Table 2.4.1

Sensor type	Station 10	Station 20	Station 30	Station 40	Station 50
Notification of pallet when entering the	S10.1	S20.1	S20.1	S40.1	S50.1

station					
Notification of pallet when leaving the station	S10.2	S20.2	S20.2	S40.2	S50.2
Notification of pallet in the assembly area	S10.3	S20.3	S20.3	S40.3	S50.3
Notification of the present piece in the depot	S10.4	S20.4	-	S40.4	S50.4
Notification cylinder 1 actuated	S10.5-1	S20.5-1	-	S40.5-1	S50.5-1
Notification cylinder 2 actuated	S10.5-2	S20.5-2	-	S40.5-2	S50.5-2
RFID antenna	RFID10	-	RFID30	-	RFID50
Notification indexing cylinder raised	-	S20.7	S20.7	S40.6	S50.6
Notification Indexing cylinder down	-	S20.8	S20.8	S40.7	S50.7
Vision system	-	-	CAM	-	S50.1
Manipulator (Robot arm + Gripper)	-	-		-	
Notification pallet to the press	-	-	-	S40.8	-
Notification press cylinder raised	-	-	-	S40.9	-
Notification press cylinder down	-	-	-	S40.10	-

2.4.3.2.The block diagram of the visual control system

The visual control system can be represented in the reaction loop according to the diagram illustrated in fig.2.4.16. In this system, the reference comes from the system at station 10, the characteristics of the part being introduced from the HMI terminal. The configuration is performed by the operator on the HMI screen where the number of final products for a system operating cycle is specified and the number and positions of the small parts assembled by the robot for each product.

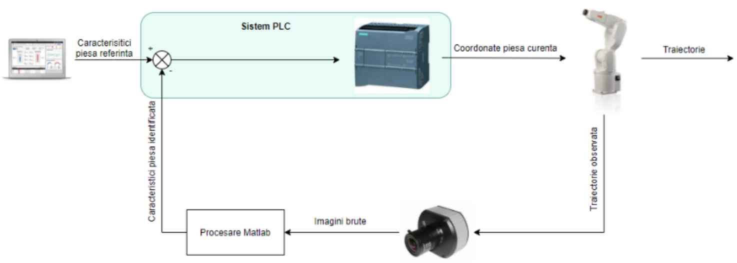


Fig. 2.4.16. Visual control system - feedback loop

The characteristics of the parts are transferred to the PLC system of station 30. The PLC system analyzes the results obtained from the image processing system by direct communication MODBUS TCP and selects the necessary information from the register table, according to the received references, to transfer the coordinates of the parts of interest to the manipulator. Fig. 2.4.18 shows the functional scheme for the camera communication with the Matlab® IBVSViewer application, together with the main routines in the Modbus server.

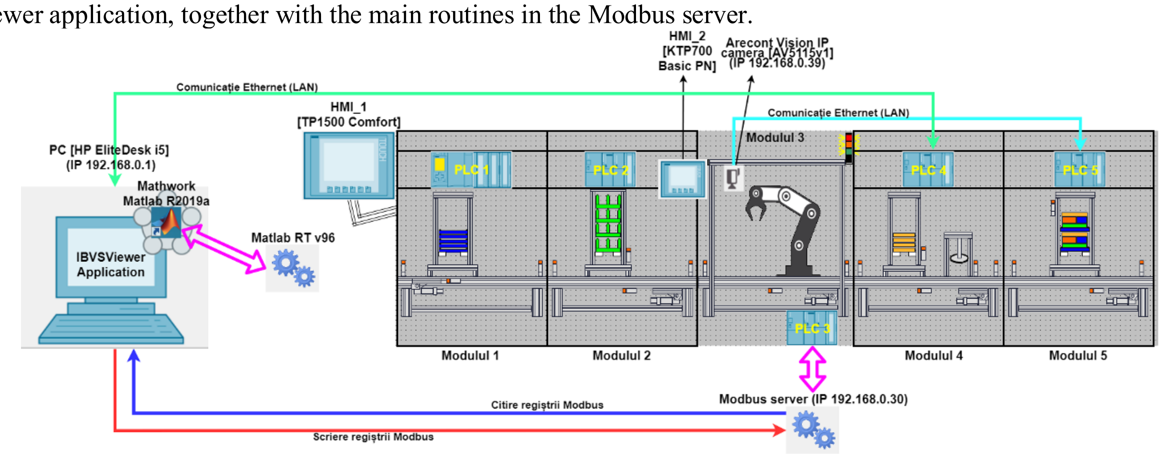


Fig.2.4.18. Functional diagram for integrating the sensor in the assembly line

Activity 2.5. Integration of sensor network technologies into models of flexible manufacturing systems

2.5.1. Functional model of a predictive control structure of a visual image-based servoing system

2.5.1.1. Basic characteristics of the predictive control

In order to reach the assumed objectives regarding the design, monitoring and control of the manufacturing lines in this activity, the aim was to confirm two new technologies: 1) Digital Twin (DT) technology for representation in the 3D simulation environment, technology that allows a dynamic virtual representation of an object or physical system throughout its life cycle, using real-time data; 2) Preventive Assets Management technology to enable the optimization of maintenance depending on the industrial installations.

2.5.1.2. Methodology for activating modeling based on Digital Twin technology in predictive maintenance

To reduce modeling efforts to provide a common framework for modeling different resources that allow Digital Twins, we proposed a generic three-phase modeling methodology. In turn, each phase can be divided into actions and sub-actions: Phase 1. Modeling of the technological installation; The actions in phase 1 are: 1. Defining the components of the plant that is modeled. 2. Define the level of modeling of the component of each installation. 3. Construction of the complete digital model of the installation; Phase 2. Modeling of virtual sensors. The actions in phase 2 are: 1. Definition of the data to be monitored with virtual sensors. 2. Selecting virtual sensors and creating their models. 3. Integration of the virtual sensors in the model of the installation; Phase 3. Definition of updatable (adjustable) modeling parameters. The actions of phase 3 are as follows: 1. Selecting the Digital Twin components to be adjusted, 2. Defining the available data that will be used for adjustments related to the source of these data. 3. Selecting the updatable modeling parameters.

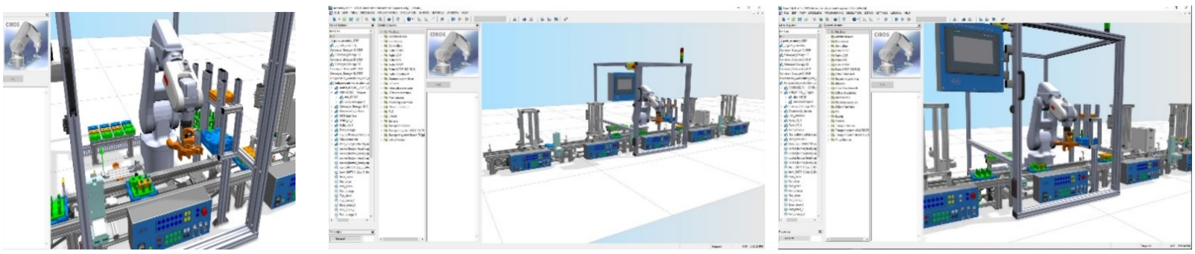
2.5.1.3. Functional model for an adaptive image-based control system for adjusting the operating parameters of a manipulator.

In this section we present the functional model of a robust adaptive control system that allows highlighting the way in which unknown parameters can be taken into account - in the case of hysteresis type nonlinearities that appear when operating a manipulator arm through video-based video control (IBVSC - Image-based visual servoing control). The research carried out resulted in two notable results: 1. The possibility of investigating the hysteresis of the actuator with the help of IBVSC; 2. Elaboration of a new adaptive law, which aims to estimate the unknown hysteresis parameters.

2*.5.2. Testing the functional models SAC-ARP and SAC-VAM integrated in hybrid technologies on flexible assembly / disassembly lines*

The tests performed in this stage aimed only at validating the solutions of virtual environment representation of the components of the autonomous systems of type SAC-ARP and SAC -VAM, as well as the possibility of aggregating the functional models of these components into complex models.

2.5.2.1. Testing the SAC-ARP functional models: In order to realize the functional model of the visual control system located on the robotic system integrated in a flexible manufacturing line, the platforms for developing and evaluating the assembly performance of the manufacturing cells were studied, of which it was selected the development and simulation environment CIROS produced by the German company FESTO. The reason for this choice is the fact that the 3D model library offered by CIROS Studio includes the ABB IRB120 manipulator, a model that is part of the flexible manufacturing line that is being worked on within the CIDSACTECH project. Figure 2.5.6 (a, b, c) illustrates some catches with the experimental model used for evaluation in the CIROS simulation environment.



a b c

Fig. 2.5.6. Captures from the simulation model of the flexible assembly line
(a - robot arm station; b - full line view; c - assembly cell)

2.5.2.2. Testing the functional models SAC-VAM

In order to test the functional model of a mobile robot (it will be procured in stage 3 of the project) it was decided to build an experimental model of small scale autonomous vehicle (1:10) with 4 motor wheels, with the help of which were tested several image-based driving algorithms. From the navigation point of view, several scenarios were considered. The first use case is that of navigation based on QR codes placed on the desired path. The second scenario is that of a vehicle that is guided by a factory-drawn line, which must pass from a marked position on the line to another marked position. A third use case is that of driving the machine between two boundary lines, which form a band.

Activity 2.6. Design and implementation of the sensor-cloud interface (ISC) for virtual data retrieval of data from physical sensors

2.6.1. Infrastructure for cloud data acquisition from physical sensors

2.6.1.1. ISC software architecture - implementation details.

The ISC software architecture has 7 components: 1) Client: The users can access the ISC user interface through web browsers; 2) Portal: The portal provides the ISC user interface. 3) Allocation: Start-up / automatic allocation of virtual sensors. 4) Resource management: ISC uses IT resources for virtual sensors. 5) Monitoring: ISC provides dedicated monitoring and monitoring mechanisms. 6) Grouping of Virtual Sensors: ISC allows grouping of sensors to end users; 7) Sensors: Physical (real) sensors used in ISC

2.6.1.2. Analysis of the interface possibilities.

Two interfacing techniques were analyzed: M2M (machine-to-machine) interface for cloud integration; Interface with OPC unified architectures.

2.6.2. Border interface device in EDGE technology for efficient data transfer between IIOT and Cloud

2.6.2.1. Basic features of Edge technology. Edge Computing architecture transfers processing tasks closer to users and devices that need it. Advantage has become essential for industrial and manufacturing processes that use vast amounts of data, which require rapid reaction time and which require rigorous security. In principle, the computing power in EDGE devices is provided by microchips or micro-controllers built into the device. Although their processing capacity is limited, there are advantages in reducing the energy consumption for transferring to the cloud a smaller volume of information. Computing resources of the border devices can be located on two sides: on the operator and on the user side respectively. Operator resources are called edge infrastructure, while user resources are called edge devices. Calculation facilities are available on both sides, working in coordination with the calculations made in the Cloud.

2.6.2.2. Border interface device design. The device designed is an original product, for which a patent application has been submitted to OSIM. He was registered with the acronym MEG (Mid Edge Gateway), because he is able to interact both as an intermediary between the IIoT network (the physical level) and the higher levels in the Cloud, as well as with some external autonomous entities with the same profile. The purpose of this device is to improve the decision-making process, as well as the response time and communications in different applications based on IIoT. The position of MEG in the hierarchical computer network is shown in figure 2.6.5. As can be seen, MEG acts as an intelligent gateway which, depending on the nature of the application, can be placed as a MIST device (as an intermediary between IIoT and a FOG level) or as a FOG device (as an intermediary between IIoT and Cloud)

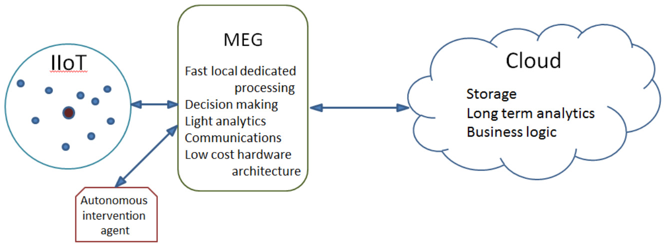


Fig.2.6.5 MEG functions as an intermediary device (gateway) in the multi-level computer network

In the specific case of the CIDSACTEH project, MEG is used as a front-end device incorporated in the Sensor-Cloud Infrastructure.

CONCLUSIONS: This scientific report highlights solutions that the project team of Project 2 offers for the requirements of Stage 2. Details and full experimental results are presented in the extended version of the report uploaded on the P2 project platform (http://cidsacteh.upb.ro)

RESULTS : The following results were obtained: 1. Experimental model of the Virtual Development Environment (MVD); 2. Functional model of a visual control system located on a robotic system integrated in a flexible assembly / disassembly line; 3. Functional model of a predictive control structure of an image-based visual servoing system; 4. Dedicated frontier interface for heterogeneous environments (ISC - Sensor Interface - Cloud).

PERFORMANCE INDICATORS REACHED: Activity 2.4: A new research job supported by the program; Design and testing framework in the experimental MVD model of Digital Twin technology for flexible assembly / disassembly lines (New software); Functional model of a visual control system located on a robotic system integrated in a flexible assembly / disassembly line. Activity 2.5: Functional model of a predictive control structure of an image-based visual servoing system; Testing the SAC-ARP and SAC-VAM functional models integrated in hybrid technologies on flexible assembly / disassembly lines. Activity 1.6: Border interface device in EDGE technology for efficient data transfer between IIOT and Cloud (Sensitively improved technology, supported by patent application).

DISEMINATION: ***Papers published in the volumes of international scientific events:***

1. Viorel Mihai, Razvan Adrian Luchian, Cristian Dragana, Dan Popescu - Levereging industrial communication in technical training systems, 22nd International Conference on Control Systems and Computer Science (CSCS22), 2019, pp. 536-540, DOI: 10.1109/CSCS.2019.00098, Electronic ISBN: 978-1-7281-2331-8, Electronic ISSN: 2379-0482, Publisher: IEEE

2. Romeo Cojocaru, Loretta Ichim, Dan Popescu - Image Based Fault Detection Algorithm for Flexible Industrial Assembly Line, 22nd International Conference on Control Systems and Computer Science (CSCS22), 2019, pp.541-546, DOI: 10.1109/CSCS.2019.00099, Electronic ISBN: 978-1-7281-2331-8, Electronic ISSN: 2379-0482, Publisher: IEEE

3. Alexandru Mihai Vulcan, Maximilian Nicolae - Distributed Concurrent Actor Models with Akka.NET and CAF, 22nd International Conference on Control Systems and Computer Science (CSCS22), 2019, pp. 563-568, DOI: 10.1109/CSCS.2019.00103, Electronic ISBN: 978-1-7281-2331-8, Electronic ISSN: 2379-0482, Publisher: IEEE

4. Mihai Craciunescu, Diana Baicu, Maria Circiumaru, Stefan Mocanu, Radu Dobrescu - Towards the development of autonomous wheelchair, 22nd International Conference on Control Systems and Computer Science (CSCS22), 2019, pp. 552-557, DOI: 10.1109/CSCS.2019.00101, Electronic ISBN: 978-1-7281-2331-8, Electronic ISSN: 2379-0482, Publisher: IEEE

5. Dan Popescu, Radu Dobrescu, Loretta Ichim - Romanian Complex Project - CIDSACTEH as an Education - Research - Industry Triad – Proceedings of the 13th International Technology, Education and Development Conference (INTED), 2019, p. 6173-6181, DOI: 10.21125/inted.2019.1506, ISBN: 978-84-09-08619-1, ISSN: 2340-1079

6. Viorel Mihai, Dan Popescu, Loretta Ichim, Cristian Dragana - Fog Computing Monitoring System for a Flexible Assembly Line, 9th Workshop on Service Oriented, Holonic and Multi-agent Manufacturing Systems for Industry of the Future, SOHOMA 2019, pp. 197-209, https://doi.org/10.1007/978-3-030-27477-1_15, ISBN 978-3-030-27477-1
7. Crăciunescu M., Chenaru O., Dobrescu R., Florea G., Mocanu S. - IIoT Gateway for Edge Computing Applications. In: Borangiu T., Trentesaux D., Leitão P., Giret Boggino A., Botti V. (eds) Service Oriented, Holonic and Multi-agent Manufacturing Systems for Industry of the Future. SOHOMA 2019. Studies in Computational Intelligence, vol 853, pp.220-231, Springer DOI: 10.1007/978-3-030-27477-1_17, Print ISBN 978-3-030-27476-4, ISBN 978-3-030-27477-1
Note: The underlined authors are part of the UPB team for the CIDSACTEH project.

WORK PLACES SUPPORTED BY PROGRAM, INCLUDING NEW HUMAN RESOURCES: The project team that contributed to the researches in Stage 2.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** - Transfer procedure in the virtual environment data collected in real time from the assembly / disassembly processes. The implementation of the service is based on two new products: the design and testing framework (DTF) based on Digital Twin technology (see http://cidsacteh.upb.ro/index.php/ro/demonstratii) and a border interface device based on Edge Computing technology for efficient data transfer between IIOT and Cloud (patent application, see http://cidsacteh.upb.ro/index.php/ro/anunturi/19-rapoarte):**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 :Stage abstract

The technical-scientific report presents the results of the research that had two objectives:

1. The design and implementation of the navigation structure for the two complex systems SAC-ARP and SAC-VAM

The results obtained from the achievement of this first objective correspond to the achievement of the two activities:
Activity 2.7 - The design and implementation of the navigation structure based on ultrasonic and laser sensors for the complex system SAC-ARP;
Activity 2.8 - The design and implementation of the navigation structure based on ultrasonic and laser sensors for the complex system SAC-VAM.
To solve the navigation problem for autonomous robotic systems, the ability to avoid obstacles is a fundamental requirement. For SAC-ARP, a navigation structure has been proposed using laser - for passing through doors and other narrow spaces - and sonar for navigation with keeping distance from a wall. This navigation structure has been simulated and implemented for the Pioneer 3DX robot. The problem of navigation with the detection of obstacles for SAC-VAM has been solved for a fixed obstacle and for a fixed obstacle and a mobile one, using for the detection, the laser sensor.

2. The design and implementation of the control structure for precise positioning of the manipulators equipping SAC-ARP and SAC-VAM

The results obtained in pursuit of this second objective are appropriate to the activity:
Activity 2.9 - Design and implementation of the control structure for the precise positioning of the manipulators that equip SAC-ARP and SAC-VAM, based on mobile visual servoing systems.
To close the loop for adjusting the position of the robotic manipulator, the feature extraction of the objects from the served manufacturing system was used. Depending on the position of the camera, which provides the information for closing the adjustment loop, the servoing system can be fixed or mobile. In this paper, a driving structure based on mobile visual servoing (eye in hand) used for extracting a defective part from the quality control station is presented, depositing it on a robot that performs the transfer to the processing station and then depositing the piece (for reprocessing) in the station related to the respective operation.
Objective 1: This report presents the results of the researches to reach the first objective, considering two directions:
1.a - The design and implementation of the navigation structure based on ultrasonic and laser sensors for the complex system SAC-ARP;**1.b** The design and implementation of the navigation structure based on ultrasonic and laser sensors for the complex system SAC-VAM.In an industrial environment, the autonomous vehicle serving a technological manufacturing line, it is necessary to be equipped with a navigation system to avoid fixed obstacles (poles, boxes, tables), or mobile (people, other autonomous systems).If mobile robots are used to solve different tasks, they need to be able to generate, without the intervention of the operator, a trajectory through which to avoid the encountered objects, therefore the algorithm must be as structured as possible to achieve independence the robot, thus managing to overcome different situations without the need for assistance.
The equipment that is considered for the proposed navigation structures is presented in the extended report, which can be found at http://cidsacteh.ugal.ro/index.php/proiecte-componente/proiect3.To solve the problem of navigation in an unknown environment, the first stage aims at detecting obstacles, based on the information coming from the sensor and

a positioning map is elaborated. Following the analysis, the nearest obstacle on the direction of travel of the autonomous system is determined. This information contributes to the speed adjustment and is used in the second stage, to generate the bypass trajectory. Tracking of the bypass trajectory must be done with the satisfaction of tracking performance (position, speed, acceleration). Finally, the third stage follows, in which the autonomous system must follow the initial trajectory with the required performances. The three stages are shown in Fig. 1

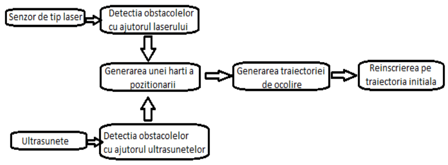


Figura 1. Steps taken to solve the navigation problem with obstacle detection

The sensors used in the navigation structures of this project are laser sections and ultrasound sensors and the information provided is merged. Considering the advantages and disadvantages of using the two types of sensors, in the proposed navigation structures are used together and the navigation system contains a component in which the fusion of the two sensors is made. The ultrasound sensors have the "blind" areas, for the elimination of which the laser is used, which does not have dead angle areas. This advantage of using laser type sensors is shown in Fig. 3. In MobileSim, the laser detection area is blue.

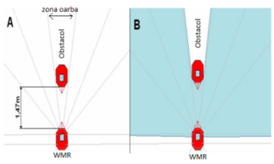


Figura 3. Comparison between ultrasound sensor and laser sensor

1.a- Design and implementation of the navigation structure of SAC-ARP, with advanced techniques, based on ultrasound and laser (*Activity 2.7*). SAC-ARP system navigation for the assistance of persons with disabilities has specific characteristics, namely the tracking of a defined trajectory between a starting point and a destination point. The path of this trajectory, by the Personal Robotic Assistant system, must be done safely for the patient. The determined path must be traveled without collisions with fixed or moving obstacles and sometimes through narrow spaces and avoiding collision with walls or other obstacles. SAC-ARP displacement is done, without the prior knowledge of the environment in which it is moving, and therefore we considered moving with tracking the walls (keeping a constant distance from the walls) and supplemented with the algorithm of moving through narrow spaces (for example a door). The displacement algorithm maintaining a constant distance from the walls is based on the distance evaluation on the ultrasonic sensor (sonar).

The algorithm of detection and passage through narrow spaces

The narrow space detection algorithm is based on an adaptive grouping algorithm. It uses the information obtained from the laser sensor and is designed to detect an optimal trajectory of crossing a narrow space taking into account the SAC-ARP dimensions.The logic scheme for operating the mobile platform is described in Fig.1a.1.

Figura.1a.1. SAC-ARP mobile platform navigation system diagram

In Fig.1a.2 is represented the situation where the border points are on a path that is not navigable for the mobile robot. In this case, the distance that the laser can scan is taken into account, and using the algorithm an average of the points encountered is established, establishing the intermediate points that make up the route to be traveled by the mobile robot.

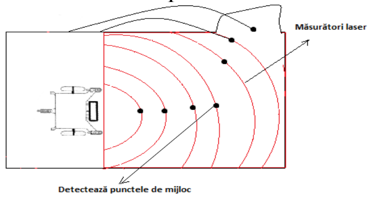


Figura 1a.2. Median points detected on an unknown route

The pseudocode algorithm that was implemented is given below

```
for dim.arc=0.5:0.2:4
  for nr.fereastra=1:6
    for puncte_fereastra=1:85
      dacă dim.arc<citire_laser
          atunci fereastră=goală
        altfel fereastră=obstacol
      END
    END
  END
  Salvare date în matricea A
END
for dim.arc=0.5:0.2:4
  for nr.fereastră=1:6
      dacă fereastră=goală
          atunci calculează "medie" pt. toate ferestrele succesive
        altfel medie=0
  END
END
Salvare valori medii/arc
```

The results obtained in the simulation and after the implementation in real time, can be found in the full report, at the address http://cidsacteh.ugal.ro/index.php/proiecte-componente/proiect3: **AC-ARP navigation at a constant distance from the walls**:The robot used to solve the problem of navigation at a constant distance from the walls of the enclosure is Pioneer 3DX, which has a weight of 9kg and can work with a maximum of 17kg. The maximum displacement speed is 1.2m / s and the rotational speed is 300 ° / s. Although the robot can have up to a maximum of 16 sonars, for this algorithm only 8 were used, each sonar having a radius of 20 degrees, starting from the left side with sonar 0 and ending with sonar 7 from the right, which is I see in Fig.1a. 3.

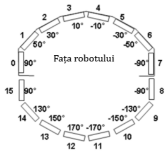
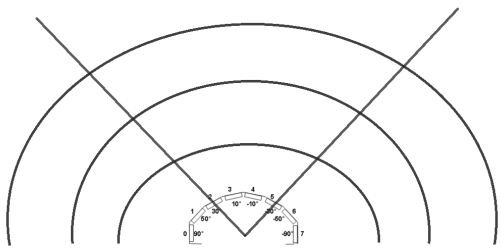


Figura 1a.3 The robot ultrasonic sensors

The algorithm proposed for use is that the robot follows the wall with the help of sonars. The sonar sends a sound to detect the wall, then it waits for the echo to return. The sonar sends a voltage signal to the microcontroller, which calculates the distance to the wall. In this algorithm, the sonar 2 and the sonar 5 of the robot were used.

The calculated distance is divided into three levels. For the left side we will have L1, L2, L3 and for the right one R1, R2, R3, as can be seen in Fig.1.a.4 For the three levels we will take the following values L1 = R1 = 1 meter, L2 = R2 =



2 meters and L3 = R3 = 3 meters.

Figura 1a.4. The robot sonars

To plan the actions of the mobile robot, we use the table presented in Table 1a.1. If no sonar detects an obstacle then the robot will move at full speed. When one (or both) sonar detects one (or more) obstacles, level L3 and / or R3, the robot will move at medium speed. When one (or both) sonar detects one (or more) obstacles, at L2 and / or R2 level, then the robot will move at low speed. If a sensor (or both) detects one (or more) obstacles, at level L1 and / or R1, then the robot will move left or right, depending on the position of the obstacles.

L_3	L_2	L_1	R_3	R_2	R_1	
0	0	0	0	0	0	Mişcare foarte rapidă
0	1	0	0	0	0	Mişcare rapida
0	1	0	1	0	0	Mişcare inceata
0	1	0	1	0	1	Întoarcere 25 ° la stânga
1	0	0	0	0	0	Mişcare rapidă
1	0	1	0	0	0	Mişcare inceată
1	0	1	0	1	0	Întoarcere 45 ° la stânga
1	1	0	0	0	0	Mişcare rapida
1	1	1	0	0	0	Mişcare înceată
1	1	1	0	1	0	Întoarcere 45 ° la stânga
1	1	0	1	0	0	Mişcare inceata
1	1	0	1	0	1	Întoarcere 25 ° la stânga
1	1	1	1	0	0	Mişcare înceată

1	1	1	1	0	1	Întoarcere 25 ° la stânga
1	1	1	1	1	0	Întoarcere 25 ° la stânga
1	1	1	1	1	1	Întoarcere 25 ° la stânga

Tabel 1a.1. Robot behavior, depending on the obstacles and the position of the wall

The simulation of this algorithm was done using Aria, in Mobile Sim, using two different maps. The first map was used to verify the correctness of the wall tracking, and the result is presented in Fig. 1a.7.

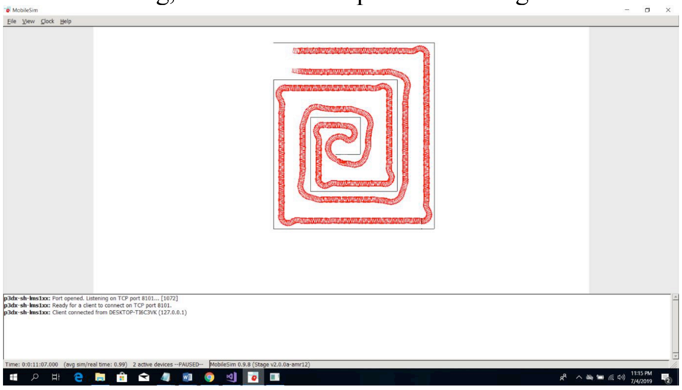


Figura1a.7. Verifying the correctness of the route tracking

The second stage of validation of the algorithm had the objective of moving away with keeping distance and avoiding obstacles. In this stage, the robot was moved to the 4th floor of the building of the Automatic, Computer, Electrical and Electronic Engineering building, and the result is shown in Fig. 1a.8, of the complete report, which can be found at http://cidsacteh.ugal.ro/index.php/proiecte-componente/proiect3. **1.b - Design and implementation of the SAC-VAM navigation structure, with advanced techniques, ultrasound and laser based structure**

The "bubble rebound" reactive algorithm was used to avoid obstacles. The algorithm defines a sensitivity bubble around the robot that is adjusted according to its speed of movement. Once the bubble is defined, it is checked if an obstacle has penetrated inside. If an obstacle is detected inside the bubble, a bypass path is generated, given the minimum obstacle density, until the obstacle has been avoided or a new obstacle is detected.

The algorithm includes the 3 driving phases (all based on driving using Sliding Mode Control controllers) SMC in the following trajectories: imposed for the final destination; to bypass the obstacle;
re-enrollment on the required path. The block diagram of the obstacle avoidance algorithm is shown in Fig.1.b.1.

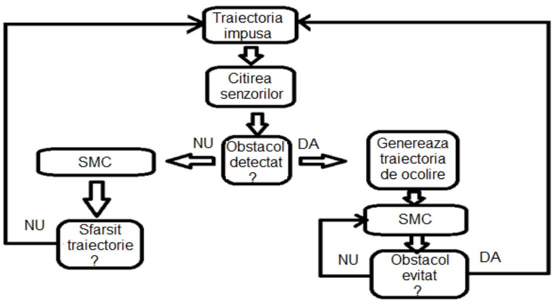


Fig.1b.1. Schema bloc a algoritmului pentru evitarea de obstacole

Two experiments were performed in which the imposed trajectory is linear. This trajectory is in the first case blocked by a single obstacle, Fig.1.b.6, and in the second case, the trajectory is blocked by two obstacles, Fig.1.b.7. The WMR must avoid obstacles that are the same size as the robot and re-enter the required path.

The data from the closed loop simulation obtained in MobilSim were entered in Matlab for graphical representation, Fig.1.b.8, in which the imposed path is red and the path of the mobile robot obtained in the simulation is blue.

In Fig.1.b.9 is presented a map of the environment in which there are two obstacles, one on the left and one on the right, created with the help of Maper3Basic and uploaded to MobileSim.

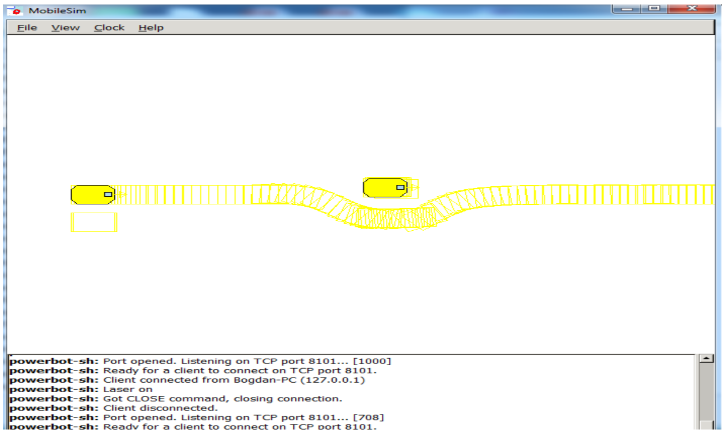


Figura 1.b.6. Evitarea unui singur obstacol în MobileSim

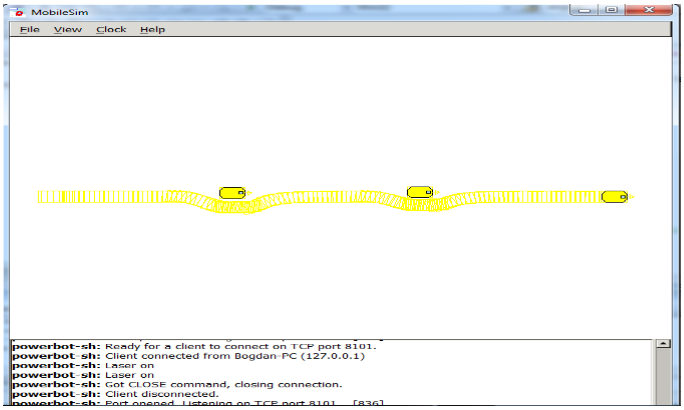


Figura 1.b.7 Evitarea a două obstacole în MobileSim

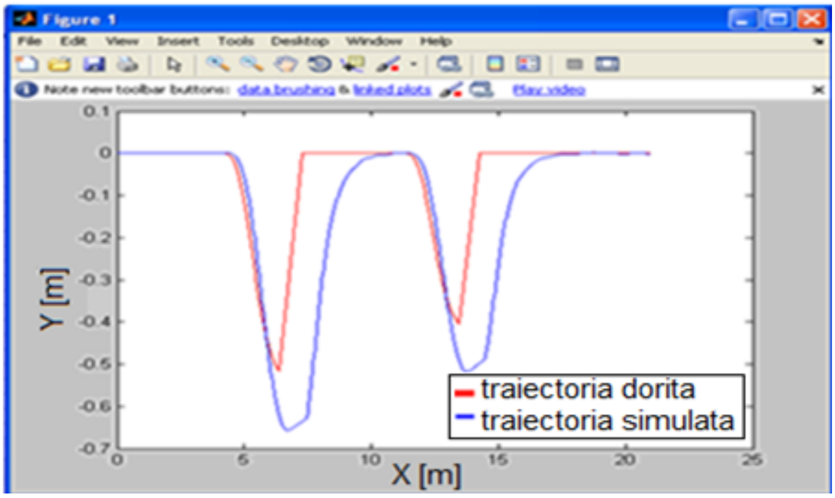


Figura 1.b.8. Comanda calculată și traiectoria robotului mobil în simulare

In the real-time experiment with WMR PowerBot, it is desired to avoid an obstacle located at a distance of 2.5 meters. The dimensions of the obstacle are: 40 cm wide and 50 cm long. Obstacle avoidance is done on the left side, as shown in Fig.1.b.10 The results of the experiment were introduced in Matlab for graphical representation and are presented in Fig.1.b.11.

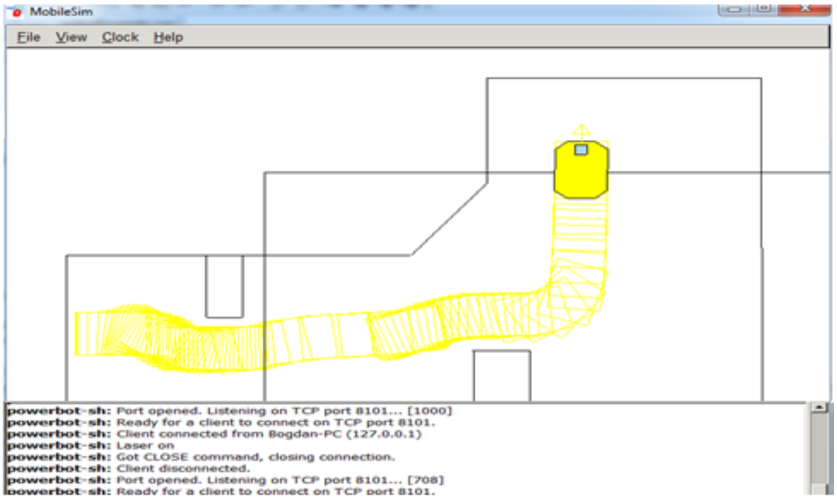


Figura 1.b.9 Evitare pe partea stângă și partea dreaptă în MobileSim

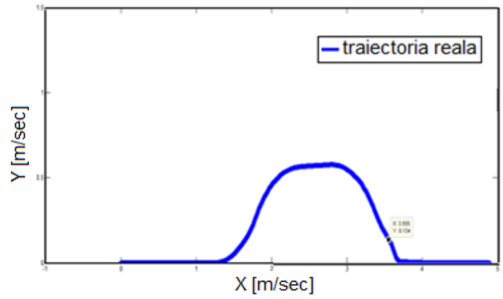


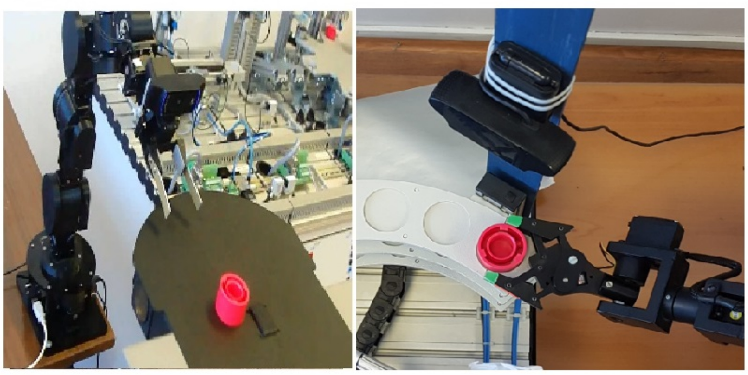
Figure 1.b.11. The real-time trajectory of the WMR PowerBot when it encounters an obstacle

Deliverable: The proposed, ultrasonic and laser based navigation structure has been simulated and implemented in real time

Objective2: **Activity 2.9 - Design and implementation of the management structure for precise positioning of the manipulators that equip SAC-ARP and SAC-VAM, based on mobile visual servoing systems**

The control structure for precise positioning of the manipulators, based on mobile visual servoing systems is designed for a flexible machining line Festo MPS-200 that also contains a quality check of the parts so that the parts that do not have irremediable defects can be reprocessed . For reprocessing, the parts are brought to the first processing station, by a Pioneer P3-DX robot equipped with a Cyton Gamma 1500 robotic manipulator. The defective part is taken over by a Visual Servoing (SV) system that works with the Cyton Gamma robotic manipulator. 1500. The sensor for the Servoing Visual system is a camcorder used to position the manipulator so that it can grip the part accurately.

Depending on the mounting location of the camcorder, two working architectures are distinguished for SV systems. The visual sensor mounted in a fixed position in the workspace defines the eye-to-hand architecture (Fig. 2.1 a), and the camera assembly on the last joint of the robotic manipulator defines the eye-in-hand configuration (Fig. 2.1 b). Each of these two types of architectures has advantages and disadvantages, and depending on them and the desired application, the configuration can be chosen.



a) b)

Figura 2.1. - Tipuri de arhitecturi: a) Configurația eye-in-hand b) Configurația eye-to-hand

Design and implementation of the management structure for precise positioning of the manipulators that equip SAC-ARP and SAC-VAM, based on mobile visual servoing systems: Preliminary image processing

A camcorder provides a video signal that is received by the process computer in the form of a two-dimensional array that will provide information about each pixel that is part of the image. This information relates to luminance and color.
Using representation in the form of two-dimensional matrix, the video signal is converted into two-dimensional (2D) numerical signal, in which the luminance will be represented as a function of two spatial coordinates. If the image is color, the resulting video signal will be a combination of 3 two-dimensional signals. The color signals can be represented either by the RGB variant, which refers to the use of the intensity value of the 3 basic component colors (red, green and blue) or by the YUV variant which refers to the use of the luminance value and two color differences (the same as in PAL standard). Filtration for the elimination of impulse noise will be performed in the preliminary phase, as it is required for any of the subsequent processing.

Modeling of the SV system. Un sistem SV are la bază următoarele componente: un ansamblu robot manipulator, un senzor vizual și un regulator. Modelarea unui sistem de SV se va reduce la minimizarea erorii apărute între trăsăturile reale ale sistemului, extrase de senzorul vizual și trăsăturile dorite ale cadrului de lucru. Fig. 2.6 ilustrează structura unui sistem SV.

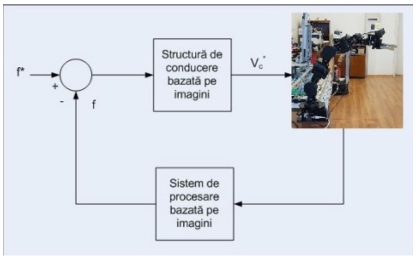


Figura 2.6. – Structura de conducere a unui sistem robotic utilizând un sistem SV

Open-loop modeling of the system leads to the need for separate analysis of both the robotic structure and the visual sensor. The signal v_c^* associated with the output of the controller represents the control for the robotic assembly and represents the reference speed of the camera having the structure $v_c^* = (v^*, \omega^*)^T$, where: $v^* = [v_x^*, v_y^*, v_z^*]^T$ and $\omega^* = [\omega_x^*, \omega_y^*, \omega_z^*]^T$ define the linear and angular components of the speed.

Real-time control of the processing line using a mobile SV system. To increase the productivity of the Assembly / Disassembly line, by reducing the transport time and making more efficient use of available resources. For this purpose, within the P / RML system defined above, a PeopleBot robot was also integrated, for the transport of the reprocessed parts and a robotic manipulator Cyton Gamma 1500 for the retrieval and reintroduction of the parts in line, for reprocessing. In this case, the real-time control of the described system is also based on the process driving through the Siemens S7-300 programmable control loop with 313C-2 DP processors, the driving of the mobile robot and of the robotic and additional manipulator, the driving loops for the PeopleBot robot and the Cyton manipulator. The latter will be controlled by a mobile SV system, having mounted on the effector's structure a high resolution video camera.
As in the case of the structure described above, a process PC will interface all the management loops, resulting in the principle diagram of figure 5.10. Thus, by using the same programming environments, Microsoft Visual Studio and Matlab, real-time system management is achieved. For the part recovery stage, the same Pioneer P3-DX robot, connected to the PC through wireless communication, will be used. The transport stage will be served by the PeopleBot robot, newly integrated in the process and having the same type of communication, based on the TCP / IP protocol and also being managed with the help of the SM. For the process of handing over the piece for reprocessing, the Cyton manipulator, controlled via USB 2.0 communication, will be used. This time, the second chamber, used for teaching the piece on the processing line, will be located on the manipulator effector.

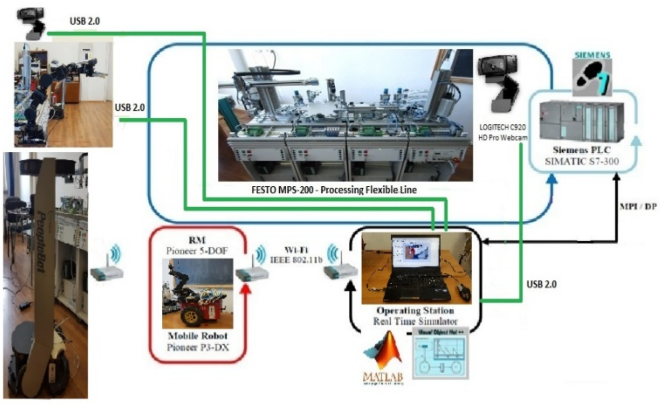


Figura 2.7. - The management and communication structure of the processing line served by 3 autonomous systems and fixed and mobile SV systems

In order to serve the Festo P / RML line according to the structure presented in figure 2.7, in order to use and a mobile SV system, the structure and development presented in the first stage, that of recovering the reprocessed part, were kept.

This will be done with the same Pioneer P3-DX robot equipped with manipulator and using the fixed SV system available at the end of the processing line. Also, all the conventions declared initially, related to the color and the place of storage of the reprocessed parts will be kept. The new features of this new structure are the use of the PeopleBot robot to perform the transport of the parts and the use of the Cyton Gamma 1500 manipulator to re-enter the reprocessed parts processing line. The advantages of this new structure, whose graphical interface is given in Fig. 2.10, refer to the improvement of the delivery times of the reprocessed parts, the removal of the Pioneer robot from the transport task and the possibility of transporting several pieces at the same time. The peopleBot transport robot is operated using a sliding-mode loop..

Figura 2.8. - The PeopleBot robot taking over the reprocessing piece

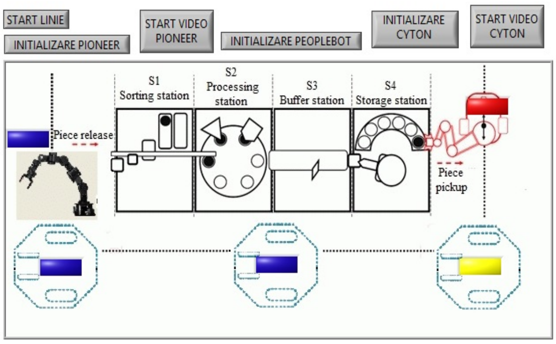


Figura 2.10. - The graphical interface to view and control of the processing line served by 2 robots and fixed manipulator

The results of the real-time implementation, for this visual servoing structure for the precise positioning of the manipulators that equip SAC-ARP and SAC-VAM integrated in technologies of medical-social assistance and service of flexible precision manufacturing lines, of laboratory (mechatronics lines are explained extensively on the project website, at http://cidsacteh.ugal.ro/index.php/rezultatep3, where are also some videos, from which you can see the results of the real-time implementation of this structure.
Activity: Act 2.9 - Design and implementation of the management structure for precise positioning of the manipulators that equip SAC-ARP and SAC-VAM, based on mobile visual servoing systems;
Deliverables: Visual servoing structure for the precise positioning of the manipulators that equip SAC-ARP and SAC-VAM integrated in technologies of medico-social assistance and servicing of flexible precision manufacturing lines, laboratory (mechatronics lines), structure based on visual servoing systems mobile**;**
100% DEGREE OF FULFILLMENT

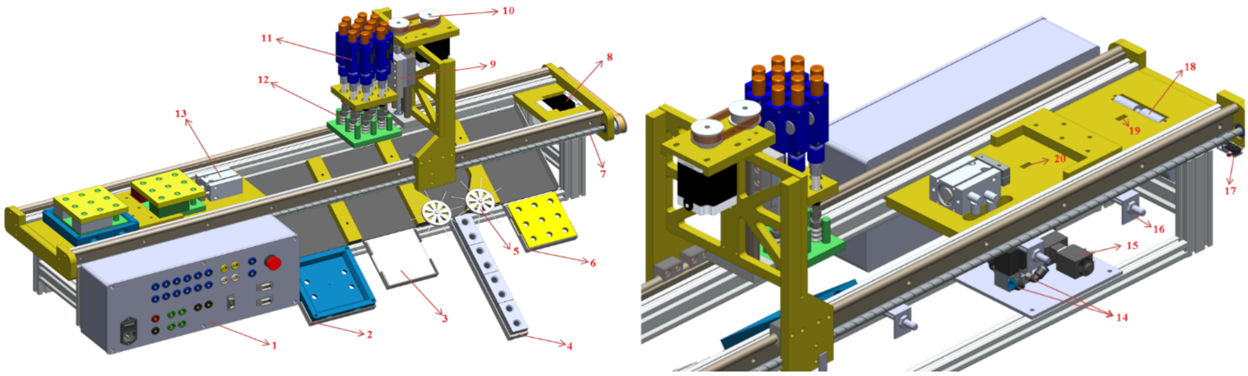
Results of Stage 2 (2019) PROJECT 3
Activity Act 2.7 - -Design and implementation of the navigation structure of SAC-ARP, with advanced techniques, based on ultrasound and laser http://cidsacteh.ugal.ro/index.php/rezultatep3
Deliverables: Navigation structure of SAC-ARP integrated in personal-medical assistance technology, ultrasound and laser based structure; **100% DEGREE OF FULFILLMENT**
Activity 2.8 - Design and implementation of the navigation structure of SAC-VAM, with advanced techniques, ultrasonic and laser based structure.
Dissemination of results
Deliverables: The proposed, ultrasonic and laser based navigation structure has been simulated and implemented in real time. The results obtained, justify **the achievement of the objective in a proportion of 100%**.http://cidsacteh.ugal.ro/index.php/rezultatep3
Dissemination of results:

- F. Dragomir, E. Minca, O. Dragomir, A. Filipescu, “Modelling and Control of Mechatronics Lines Served by Collaborative Complex Autonomous Systems”, *Sensors* Journal, **2019**, vol.*19, Issue* 15, 3266; https://doi.org/10.3390/s19153266, IF 3.302 (Q1)

- Filipescu, E. Minca, A. Filipescu jr, „Mechatronics Manufacturing Line with Integrated Autonomous Robots and Visual Servoing Systems”, 9th IEEE International Conference on Cybernetics and Intelligent Systems, and Robotics, Automation and Mechatronics (CIS-RAM 2019), November 18-20, 2019, Bangkok, Thailand
- Adrian Filipescu, Adriana Filipescu and Eugenia Minca, “Assisted Technology of a Mechatronics Line with Integrated Robotic and Visual ServoingS ystems”, The 7th INTERNATIONAL SYMPOSIUM ON ELECTRICAL AND ELECTRONICS ENGINEERING, Galati, Romania from 18th to 20th October 2019
- Adrian Filipescu, Adriana Filipescu, Silviu Filipescu, Eugenia Minca - Technology on a Mechatronics Line Assisted by Autonomous Robots and Visual Servoing Systems, The 7th INTERNATIONAL SYMPOSIUM ON ELECTRICAL AND ELECTRONICS ENGINEERING, Galati, Romania from 18th to 20th October 2019
- Justin Aurelian Braharu, Razvan Solea - Trajectory-Tracking First Order Sliding-Mode Control of a WMR, ISEE The 6th International Symposium on Electrical and Electronics Engineering
- Dan Ionescu. Trajectory - Tracking Cascade Control of a Nonholonomic WMR based on Kinematic and Dynamic Model, The 7th INTERNATIONAL SYMPOSIUM ON ELECTRICAL AND ELECTRONICS ENGINEERING, Galati, Romania from 18th to 20th October 2019

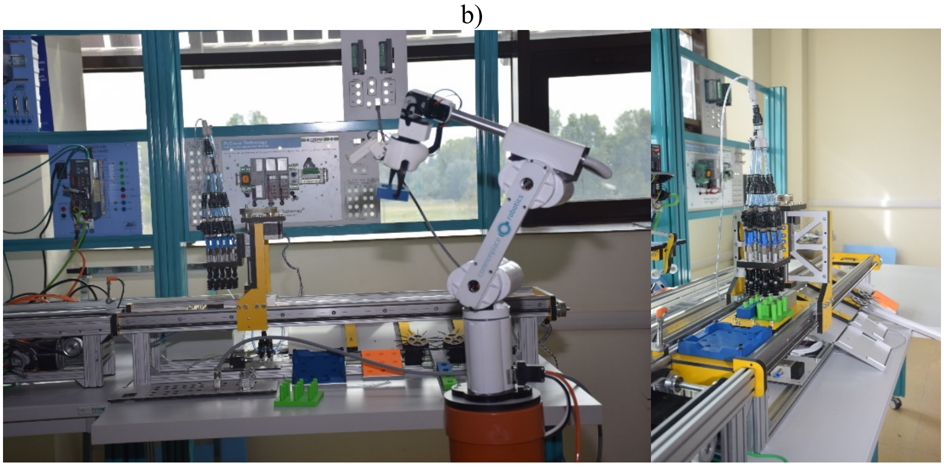
100% DEGREE OF FULFILLMENT:Activity: Act 2.9 - Design and implementation of the management structure for precise positioning of the manipulators that equip SAC-ARP and SAC-VAM, based on mobile visual servoing systems; Deliverables: Visual servoing structure for the precise positioning of the manipulators that equip SAC-ARP and SAC-VAM integrated in technologies of medico-social assistance and servicing of flexible precision manufacturing lines, laboratory (mechatronics lines), structure based on visual servoing systems mobile;
100% DEGREE OF FULFILLMENT
ERRIS Services https://erris.gov.ro/Process-Control-Systems :
2.2. Research service on the SAC-ARP platform for personal and medical assistance in the hospital and at home.
2.3. Research service on the SAC-VAM platform for personal in / out Hospital assistance and rescue in rugged terrain
ERRIS Tehnologies https://erris.gov.ro/Process-Control-Systems
Tech. 1. Hybrid flexible, precision manufacturing technology, on laboratory and industrial lines, with the Integrated Autonomous System - Integrated Multidirectional Vehicle (SAC-VAM);
Tech. 2. Hybrid technology for the manufacture, precision, on laboratory and industrial lines, with Autonomous Complex System - Integrated Robotic Personal Assistant (SAC-ARP);
Jobs supported by the P3 project: the research team of the P3 project and, in addition, two young hired researchers: ing. Răzvan BUHOSU and ing.Iustin Aurelian BRAHARU/ing.George SIMION

Project 4: **Summary:**The researches of Phase 2 respond to the research objectives related to activities 2.10, 2.11, 2.12, from the plan for the realization of the complex project, and finally led to the real-time control of the manufacturing line assisted by autonomous complex systems, SAC-ARP and SAC- VAM integrated in hybrid technology of flexible manufacturing, A / D, laboratory. In this stage, the disassembly station was equipped with a fully automated control structure. The flexible manufacturing takes place in the A / DML line stations, served by a dedicated transport / handling system. Both workstations, as well as the automated control structures assigned to the disassembly and flexible manufacturing processes, were designed / implemented within the activities of this phase of the project.The mechatronic assembly line becomes a fully automated mechatronic system, dedicated to flexible inline manufacturing, and to the assembly / disassembly and recovery of reusable components. The feedback of the flow of operations on the mechatronic line: in-line manufacturing / flexible manufacturing / disassembly / recycling of reusable parts, was achieved by equipping the entire mechatronic system with SAC-ARP, mobile robot (2DW / 1FW) equipped with 6DOF manipulator. We have developed a synchronization software for the manufacturing lines precision control, with the visual servoing control structures of complex robotic systems , SAC-ARP.At the end of this phase, real-time LA / D precision control structures are delivered, integrated in hybrid manufacturing technologies, assisted in the reversible SAC disassembly process by SAC-ARP technologies, 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
Task 2.10, 2.10.1 Hardware compatibility between the flexible manufacturing line LA / D and the movement / transport / handling of SAC-ARP and SAC-VAM.*Design and implementation of the disassembly control structure in a dedicated workstation:*In order to recover the components, on the manufacturing line, disassembly begins after the assembly is completed, only if the final product does not meet the quality requirements. The mobile robots equipped with manipulators, SAC-ARP and SAC-VAM, will take the components from the locations where the disassembles are operating and will transport them to the storage stations, to be reused in the assembly process. Thus, components can be reused. The disassembly station was design in SolidWorks (Figure 1), and the components are described in detail in http://cidsacteh.valahia.ro/p4/files/Raport Etapa2_extins.pdf. When the assembly is completed and after the quality test, the defective part arrives at the location for Start disassembly. A Cartesian manipulator, based on a pneumatic control system, sequentially grasps components, through matrices with suction cups and deposits them in the corresponding collecting trays.



a)

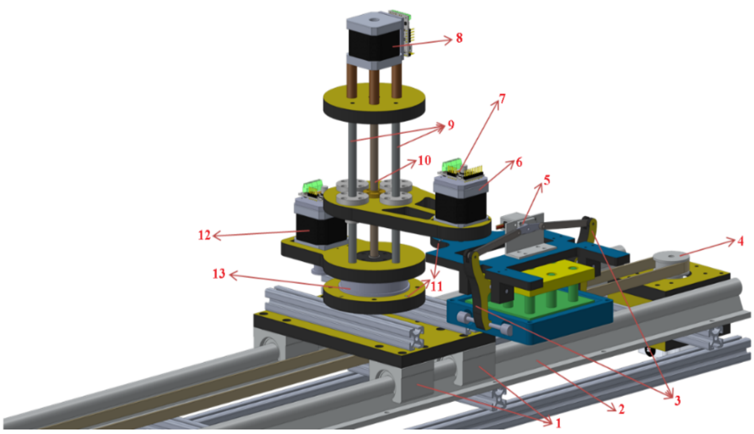
b)

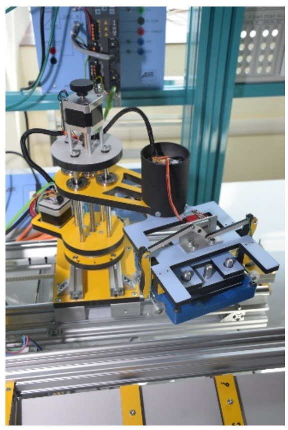


c)

Figure 1. Design of disassembly station a,b) SolidWorks project; c) implementation

Design and implementation of the flexible manufacturing automated control structure on a dedicated mechatronic line Flexible manufacturing is carried out in the positions of the mechatronic line of A / DML, served by a dedicated transport / handling system, designed and implemented in Phase 2 of the project. Design of the transport / handling system for flexible manufacturing components is made in SolidWorks (Figure 2)), and the components are described in detail in http://cidsacteh.valahia.ro/p4/files/Raport Etapa2_extins.pdf.





a) b)

Figure 2 Transport / handling system for flexible manufacturing. a) SolidWorks project; b) implementation

*Hardware compatibility between the flexible manufacturing line LA / D and the movement / transport / handling of SAC-ARP and SAC-VAM*The technical solution for the hardware compatibility between the manufacturing line and the mobile robots involves the compatibility of the physical interaction robot - mechatronic line and the compatibility at the physical level of communication. For the compatibility of the two entities on the physical level of communication, the visual communication was selected. By using visual servoing algorithms, the positioning system of the robot with respect to the manufacturing line and the transmission of signals was designed (Fig. 3).

To achieve the interaction on a physical level, the mobile robots equipped with 6DoF manipulators have the hardware structure modified to allow the robot's work area (pick-up and dropping actions) to be aligned with the manufacturing line stations.

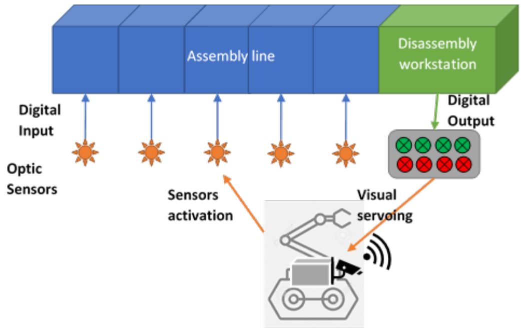


Figure 3. Flow of synchronization signals

For testing the interaction and transport compatibilities of the reusable components, back from the disassembly station to storage stations, the mechatronic line is assisted by a mobile robot (Pioneer 3DX) equipped with a robotic manipulator (Mover6) and a system with camcorder, mounted on the robotic arm. The camcorder will provide visual information about the presence of the disassembled components in the disassembly stations. An optical indicator with interchangeable modules, allows the robot to identify the needed operating sequence, to move component i to station i.

Figure 4. SAC-ARP

For testing the concept of manufacturing line hardware compatibility - mobile robot, Pioneer 3DX mobile robot equipped with a 6DoF manipulator. The SAC-ARP mobile robotic system was specially modified to assist the assembly / disassembly line (Fig.4). The robotic arm was mounted at an elevation that would allow the manipulation of reusable parts and their storage in the assembly stations. The elevation of the arm was computed taking into account the radius of action of the robotic arm and the mechanical constraints given by both the mobile platform, the robotic arm and the manufacturing line. The optimal solution for adapting the mobile robot was to create the hexagonal base that accommodates the control and communication elements. Cylindrical component that allows lifting the robotic arm without significantly changing the centre of gravity of the entire platform

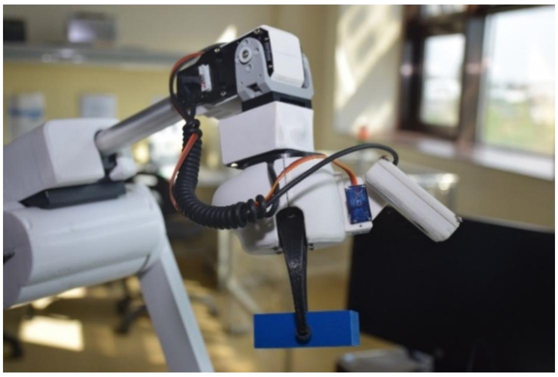


Figure 5. Visual servoing camcoder

The SAC-PA system was designed for assisting exclusively the SMART_ASTI laboratory mechatronics line. To test the compatibility of the hardware communication a video camera was added on the end-effector (Fig.5) of the robotic arm. The video servoing system identifies the optical indicators given by the disassembly station or assembly stations. These optical indicators can be represented by light indicators or simply by the presence of a part in a certain position of the workstation. The camcorder has a rotation mechanism that allows a reduced possibility of adjusting the viewing angle which allows easier identification of certain indicators or even the identification of defects in further developments. By using the combination of visual servoing and ultrasonic sensors, the robot becomes a system for the SAC-ARP manufacturing line assisting. SAC-ARP has implemented an automated control structure that allows sliding-mode control with obstacle avoiding, or commands for handling (pick-up and dropping) commands of components.

2.10.2. Integration into the control structure of flexible precision manufacturing lines, complex SAC-ARP and SAC-VAM management structures and distributed configurations of sensors and visual servoing systems defined in Projects 2 and 3.

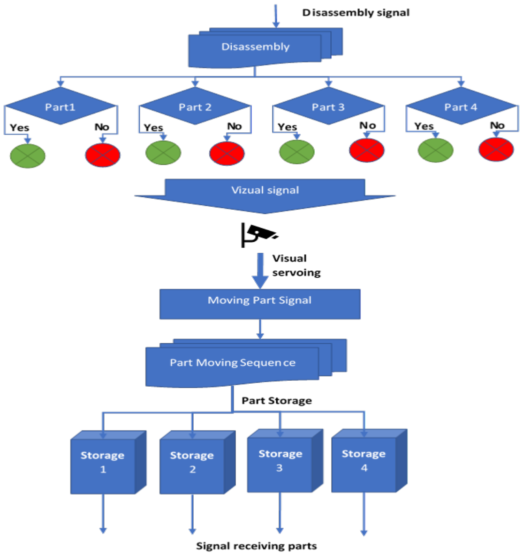
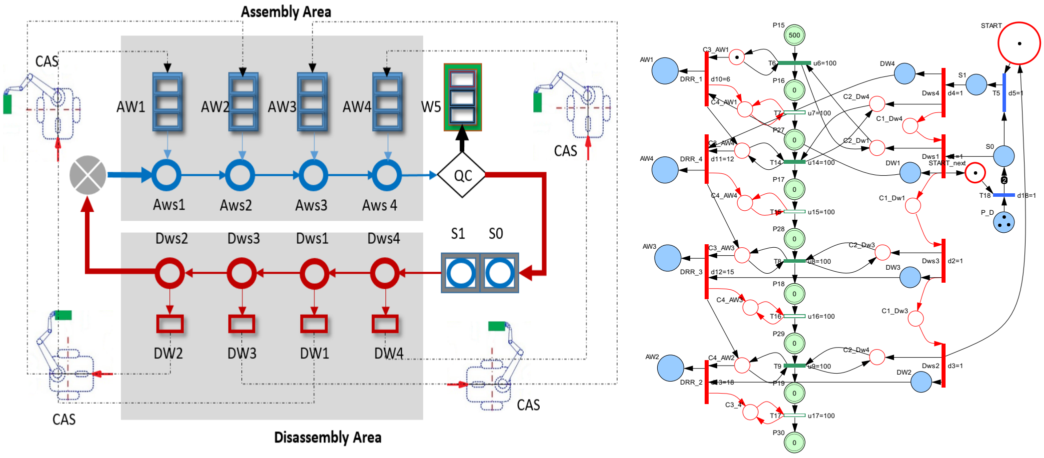


Figure 6. Control flow between manufacturing line control diagram and mobile robot

The control structure of the flexible manufacturing line assisted by mobile robotic systems and distributed systems by sensors is similar with a classic manufacturing system assisted by sensors and fixed robotic systems. The only difference consists in the transmission of information through different communication technologies: for the communication between the manufacturing line - mobile robot, the method of visual servoing was selected, being one-way communication method, able to ensure the efficient transmission of information, without additional equipment and procedures. The robot transmits information to the manufacturing line by interacting with different sensors, although this feedback is only redundant. The communication between robot and manufacturing line is made without perturbations for the production process. Fig. 6 shows the diagram of the integration of the visual servoing part, in the control structure of the manufacturing line assisted by the mobile robot. The complete control structure can operate in both open loop and closed loop, depending on the algorithms implemented. The control algorithms determine how the disassembly tasks are related, with the component delivery signals from the assembly stations. The mobile robot interaction - manufacturing line without process perturbations, is realized through the distributed system of sensors, integrated both in the manufacturing line and in the mobile robotic systems. Thus, continuous and accurate monitoring of the entire process is ensured. The laboratory mechatronic line was equipped with inductive sensors IEC201, magnetic sensors: D-A93, CST-232, SMT / SME-8, optical sensors: O8P202, positioned so as to ensure the precision of the monitoring of the manufacturing process. In addition, the manufacturing line integrates aa additional local RFID 6GT2821-4AC10 communication system that allows the monitoring of the production stage at each station, for the control of each stage of manufacturing.

Task 2.11: Development of software for synchronizing the control of flexible precision manufacturing lines, integrated in hybrid manufacturing technologies, with the visual servoing control structures of the SAC-ARP and SAC-VAM complex systems, as specified in projects 2 and 3, under the LabView / Matlab platform / Visual C ++

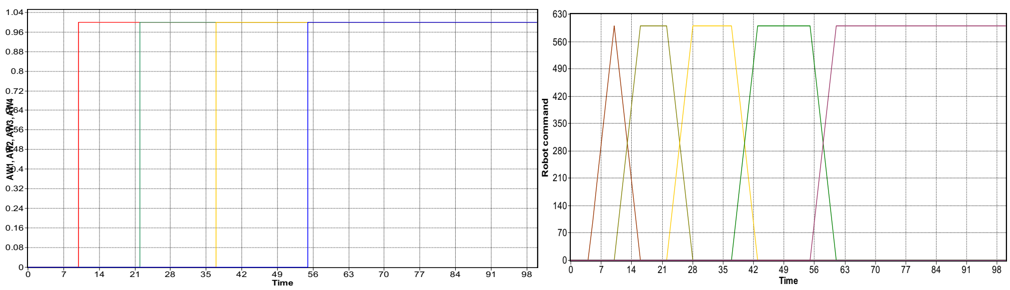


a) b)

Figure 7. a) Block scheme of A/DML served by SAC; b) HPN for A/DML served by CAS model

The design of the synchronization algorithm of the two entities, A / DML line and SAC-ARP (Fig.7a), is based on the HPN model built for the A / DML process assisted by mobile robots (fig.7b, Fig.8). Since the direct communication of the manufacturing line - mobile robot is performed at the level of each disassembly station, the synchronization of the manufacturing line with SAC-ARP was achieved by integrating the synchronization procedures in the PLC program of the disassembly station. For the synchronization of the manufacturing line with the rest of the modules, ProfiNet communication was used, with software changes in each station.

Finally, a distributed synchronization software system was obtained, which proved to be advantageous compared to a centralized one. Thus the synchronization between the control modules is made taking into account the interaction between them and the production stages. The control algorithm implemented, considers the level of local communication, in which each current module communicates with the previous and the next module, but also with the centralized control module.



a) b)

Figure 8. States evolution : a) dynamics of storage station supply ; b) robot control for disassembly

The main advantage in distributed synchronization software selection is the resistance to propagating the local synchronization at the whole process level. In the case of a local synchronization fault, this fault is limited to the local module, the rest of the modules continuing to communicate with each other, and even to continue manufacturing. This decentralized mode also allows synchronized monitoring of some sensor subsystems, according to the designed supervision algorithms. By comparison, a centralized synchronization system would operate according to the number of communication and interaction nodes, its continuous scaling being necessary, in order to operate all the necessary synchronizations. Such a system, in beyond the additional costs, can cause sequences of total production shutdown, due to part synchronization errors.

Task 2.12: Real-time control of flexible precision manufacturing lines, LA / D served in the reversible process of disassembly of SACs integrated into assistive technologies, SAC-ARP, mobile robots (2DW / 1FW) equipped with 6-DOF Manipulator and SAC-VAM , mobile robots (2DW / 2SW) equipped with 6-DOF Manipulator.

Flexible manufacturing involves manufacturing actions (assembly in the case of the laboratory line) in the A / DML line stations, but served by a dedicated system of handling / transporting parts from one station to another, in a different order from the flow manufacturing. The transport / handling system, for the flexible manufacturing (FF), represents an extension of the mechatronic line of the laboratory and allows the flexible manufacturing to be carried out - different ranges of products that are obtained through production operations specific to the workstations, but in the order dictated by the final product execution. The A / DML line finally becomes a complex mechatronic system, capable of supporting the production sequences: assembly / disassembly / manufacturing flexible / recovering reusable components. The integration of the transport / handling system for flexible manufacturing (T / MFF) respects the data communication flow of Fig. 9. Digital I / O signal communications, provided by the sensors, with the LattePanda control module are used.

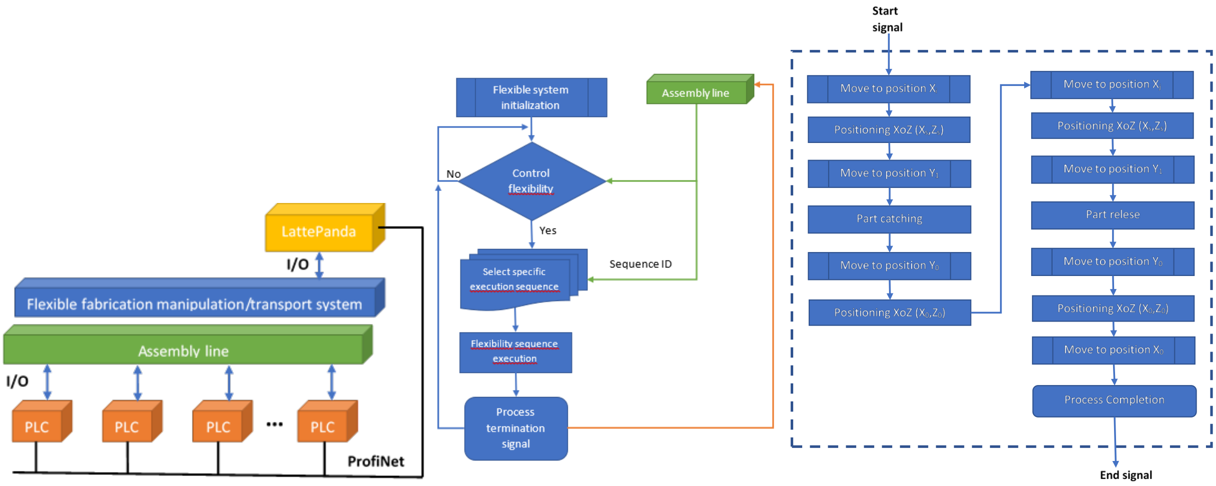


Figure 9. a) Communication between module block scheme ; b) Flexible manufacturing control algorithm; c) Algorithm for positioning / manipulating the Cartesian robot within an FF sequence

The synchronization of the A / DML line control with the T / MFF is made with the ProfiNet network, which ensures fast communication between the control modules. ProfiNet communication provides centralized monitoring support for the entire manufacturing process. The T / MFF control is performed by programming the HMI interface, which allows the selection of the control sequences required by the final product execution technology, in accordance with the designed control algorithms.

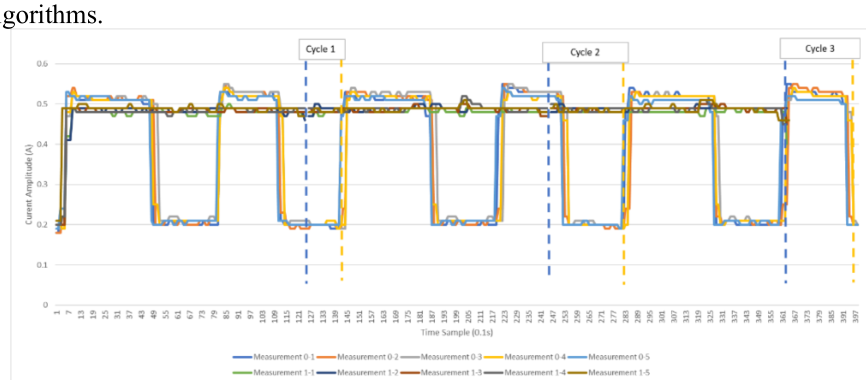


Figure 10. Optimization of the power consumed by the conveyor system on the conveyor. (article ICSTCC 2019)

Within an operating sequence of the FF, the programming of the positions and operations performed by the Cartesian robot of the T / MFF is performed. The positioning coordinate on the X axis (Xi, Xj Fig.9c) is the one that changes with each sequence, and is coordinated with the order of the elementary operations introduced by the operator through the HMI interface. r.

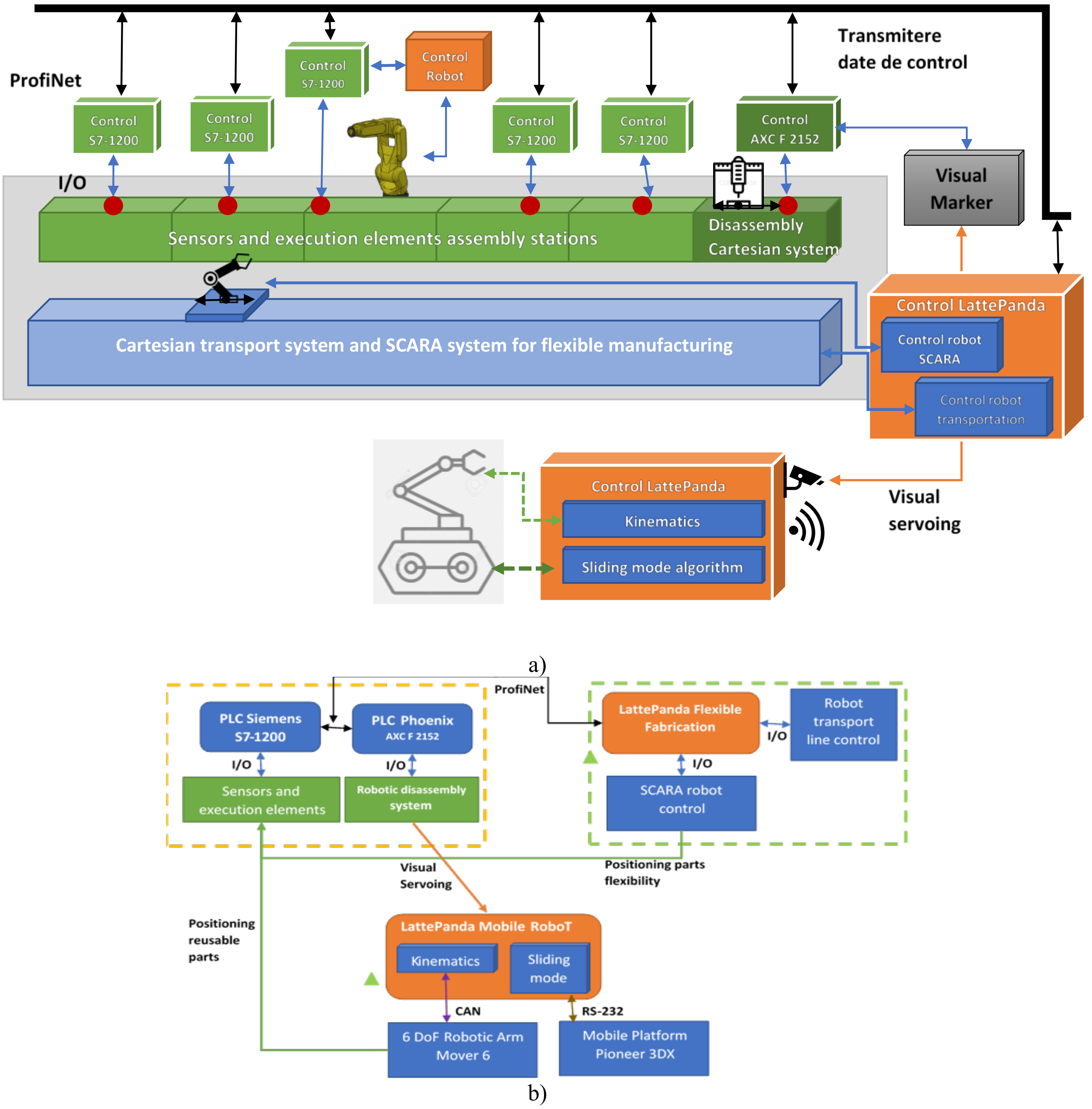


Figure 11. Structure of the assembly / disassembly / flexible manufacturing / component recovery line

Figure 12. Flexible precision manufacturing line, in laboratory, assisted in the reversible disassembly process of SAC-ARP (2DW / 1FW), mobile robot equipped with 6-DOF manipulator, with integrated management in assistive technologies

After scheduling each sequence of operations and assigning an ID, these will be used from the mechatronic line control modules, in accordance with the manufacturing schedule operated in HMI. Research is also reported on optimizing the control of the conveyor system of the SMART_ASTI laboratory line (Fig. 10), which is the subject of the article

"Optimal Control of the Complete Assembly / Disassembly Cycle for a Mechatronics Line Prototype", presented at the 23rd International Conference on System Theory, Control and Computing (ICSTCC), 2019.The control structure of the flexible precision manufacturing line, laboratory, assisted in the reversible disassembly process of SAC-ARP (2DW / 1FW), mobile robot equipped with 6-DOF Manipulator, with integrated control in assistive technologies, is represented in Fig. 11, Fig. 12. In Phase 2, control structures were designed and implemented for the disassembly station, for flexible manufacturing as well as robotic systems: mobile robot equipped with SAC-ARP manipulator, Cartesian manipulator serving the disassembly station, robotic manipulator serving flexible manufacturing (Fig.11b). The automated control of the assembly line has been reconfigured so as to synchronize with the specific tasks of disassembly, flexible manufacturing and retrieval in the wharestation of reusable components.

Conclusions : *The scientific report in extenso highlights the scientific solutions that the project team of Project 4 offers for the requirements of Phase 2. In scientific report in extenso (http://cidsacteh.valahia.ro/p4/files/Report Stage2_extins.pdf) can be analysed the solutions proposed for real-time control of flexible precision manufacturing lines, integrated in hybrid A / D manufacturing technologies, with SAC-ARP, autonomous robotic platform with two drive wheels, one or two free and manipulator wheels, and SAC-VAM , autonomous vehicle with 4 wheels multi-directional motors and manipulator.*

Phase 2 is completed by the implementation of the control structure of the flexible, precision manufacturing line of the laboratory, assisted in the reversible disassembly process of SAC-ARP (2DW / 1FW), mobile robot equipped with Manipulator 6-DOF (Fig.11), with integrated control in assistive technologies, tested on the mechatronic laboratory line from SMART_ASTI equipped with the additional modules, necessary for flexible manufacturing, automated disassembly and recovery of reusable components.

Expected outcomes

The following outcomes were obtained in Phase 2 of Project 4:

1. Synchronization software for manufacturing lines control with the visual servoing system under the LabView / Matlab / Visual C ++ platform
2. Synchronization software for manufacturing line control and navigation based on advanced control techniques for obstacles avoiding, detection and manipulating under the LabView / Matlab / Visual C ++ platform
3. Real-time control structure of precision LA / D, integrated in hybrid manufacturing technologies, served in the reversible process of disassembly of SACs 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 6-DOF Manipulator

Indicators

1. SAC-ARP and SAC-VAM integrated in hybrid technologies on flexible A / D manufacturing lines
2. Software for synchronizing the control of flexible precision manufacturing lines, integrated in hybrid manufacturing technologies, with the visual servoing and navigation control structures
3. Flexible, precision, A / D hybrid manufacturing technology on laboratory lines (mechatronics) with integrated SAC-ARP and SAC-VAM
4. 2 new research jobs supported by the program. At the UVT partner are employed 2 new early stage researchers in the field of Systems Engineering, in the position of Researcher in Automation, which are included in the UVT partner personnel list.**Dissemination**

Articles presented at national and international conferences in 2019

1. F. Dragomir, E. Minca, O. Dragomir, A. Filipescu, "Modelling and Control of Mechatronics Lines Served by Collaborative Complex Autonomous Systems", *Sensors* Journal, **2019**, vol.*19, Issue* 15, 3266*; https://doi.org/10.3390/s19153266,* IF 3.302 (Q2)
2. Octavian Gabriel DUCA, Ion Valentin Gurgu, Eugenia Minca, Adrian Filipescu, Florin Dragomir, Otilia Dragomir, "Optimal Control of the Complete Assembly/disassembly Cycle for a Mechatronics Line Prototype", 23rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania during October 9-11, 2019
3. A. Filipescu, E. Minca, A. Filipescu jr, „Mechatronics Manufacturing Line with Integrated Autonomous Robots and Visual Servoing Systems", 9th IEEE International Conference on Cybernetics and Intelligent Systems, and Robotics, Automation and Mechatronics (CIS-RAM 2019), November 18-20, 2019, Bangkok, Thailand
4. A. Filipescu, A. Filipescu Jr., S. Filipescu, E. Minca, Technology on a Mechatronics Line Assisted by Autonomous Robots and Visual Servoing Systems, The 6th International Symposium on Electrical, and Electronics Engineering, ISEEE 2019, 18-19, Oct, Galati, 2019, ISBN: 978-1-7281-2906-8/19/$31.00 ©2019 IEEE

Early stage researchers employed by the program at UVT partner of Project 4

The project team that contributed to the researches in Phase 2 Project 4, consists of 11 (eleven) researchers (included in the Project 4 personnel list). Two of them are early stage researchers hired at the UVT partner, in the position of Researcher in automation.

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

RESEARCH AND TECHNOLOGICAL SERVICES

Products / IT products / Technologies

Precise and reversible flexible manufacturing line, served by SAC-ARP (Complex autonomous system - Personal Robotic Assistant) and SAC-VAM (Complex autonomous system - Mobile Autonomous Vehicle)

Description - The real-time control structure of precision assembly / disassembly lines, integrated in hybrid manufacturing technologies, served in the reversible SAC disassembly process integrated in assistive technologies. Implementation on the mechatronic line of the laboratory. Precise and reversible flexible manufacturing line, served by SAC-ARP (Complex autonomous system - Personal Robotic Assistant) and SAC-VAM (Complex autonomous system - Mobile Autonomous Vehicle)
https://erris.gov.ro/Valahia-University-of-Targoviste

Services

Hybrid technology of flexible manufacturing, precision, assembly / disassembly on mechatronic laboratory lines with integrated SAC_ARP and SAC-VAM
https://erris.gov.ro/Valahia-University-of-Targoviste

Project 5: **Activity: Act 2.13** *Design of intelligent control structures (based on advanced techniques) and a navigation structure (based on performance sensors) for SAC-SI autonomous complex system - integrated into assistive technology for people with severe neuro-motor disabilities.*

Indicators of achievement:

- Intelligent control structure and navigation structure for SAC-SI, "Cirrus Power Wheelchair" integrated into assistive technology for people with severe neuro-motor disabilities;

- New software product

In this activity a wheelchair control method has been developed for people with severe disabilities who cannot manually operate the wheelchair with joystick. It started from the idea of improving an electric wheelchair, equipped with two motors and PC with video camera to perform face detection and to send the commands to the DC motors. The goal of application is to control de wheelchair and to be simple, safe and easy to learn for people with severe neuro-motor disabilities. Using the proposed method, the wheelchair can be controlled so that it can go forward, can rotate, and can move at variable speed depending on the user's needs. The general scheme proposed is shown in Figure 2.13.1.

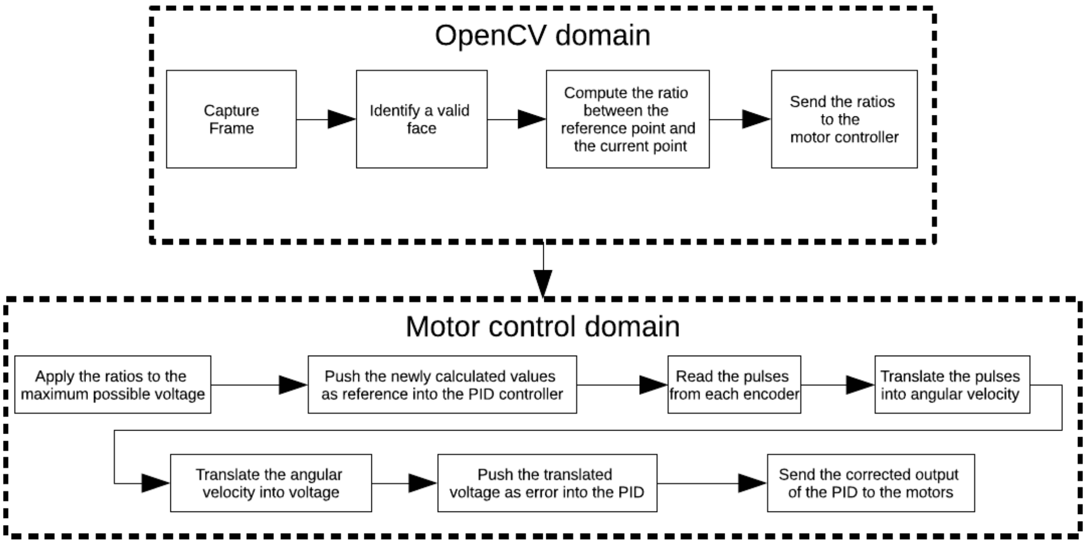


Fig. 2.13.1 Block diagram of the control procedure

In order to be able to perform face detection in real time, the OpenCV library was used (OpenCV is a software library, open-source that has a variety of uses in fields that require the recognition of object shapes). In this project we used a Microsoft LifeCam HD-3000 camera that has a resolution of 1280x720 pixels and provides 30 frames per second.

Each frame obtained by the camera must be processed to allow the OpenCV classifier to identify the user's face. The processing that takes place immediately after the acquisition of each frame is the conversion of the color frame into a black and white one. After the color image has been transformed into a black and white image, it is sent to a classifier that is responsible for the actual face detection.

In this case, the classifier is a software component that uses a set of rules to identify the user's face. The set of rules for the classifier is obtained by introducing images that represent positive (human face images) and negative (non-face images) examples in an application that uses all the introduced samples to determine what the user wants to be identified and what not. The classifier used in this paper is Haar Cascade. It receives the previously processed black and white image and begins to look in the image for features (shapes) that correspond to the previously obtained set of rules using a search window. The search window plays a very important role in the accuracy of face detection. The smaller the search window, the more accurate the results will be, but the real-time feature will no longer be possible because this process requires a lot of hardware resources and high computing time. That is why a size of the search window (rectangle) must be found to allow a good face detection and at the same time not to consume all the hardware resources, because there are other processes in the system that need computing time. In order to generate commands, the user has to move his head, for example the slight lifting of the head represents the "forward" command, and lowering the head stops the wheelchair. The solution was to use the second rectangle. One quadrilateral/rectangle, the initial one, is used as a starting point, and the second one is used to determine the current position of the face (see Figure 2.13.2).

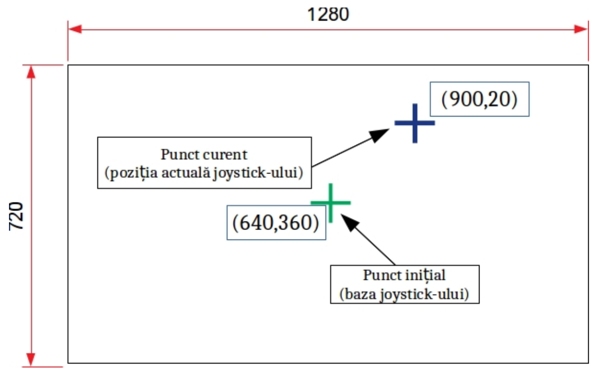


Fig. 2.13.2. Centers coordinates of the quadrilaterals (initial and current quadrilaterals)

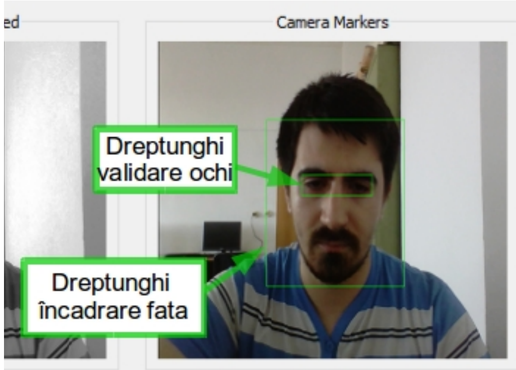


Fig. 2.13.3. Example of valid quadrilateral - which fits both the user's face and his eyes

In this case, a valid rectangle that can be used to generate orders is a rectangle that frames both the user's face and his eyes (see Figure 2.13.3). Two classifiers are used for this. One classifier is for the face and the other is for the eyes. If the eye square is entered in the face square then the face square is considered valid and thus the following command can be generated. Otherwise it is ignored and the previous command is repeated. If no valid quadrilateral/rectangle is detected within 2 seconds then the wheelchair will be stopped for safety reasons and the user will have to place the face at the initial point after which the wheelchair can continue to be used.Only the centers of the two rectangles (the reference and the current one) are used to generate the order, the rest of the attributes are no longer needed. A Kalman filter was used to eliminate the disturbance. The reason why the Kalman filter was chosen, to the detriment of other methods of eliminating the disturbance, is the reduced consumption of resources for filtering and the simplicity of implementation. At the same time, the Kalman filter offers good filtering to obtain the most stable signal values. At first glance, the OpenCV-based module does not appear to be a closed-loop system but this is not true, the element responsible for closing the control loop being the user. He plays the role of regulator and comparator, being responsible for the "calculation" of the error (where he wants to move and where the wheelchair goes) and for "generating" a corrective order.

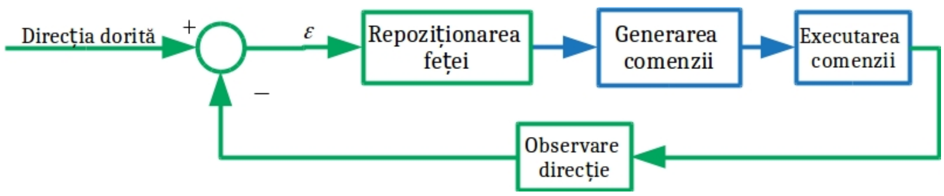


Fig. 2.13.4. Closed loop to obtain the commands

Fig. 2.13.4 illustrates how the command are generated by the user. In Fig. 2.13.5 is show a scheme developed for the proposed command generation algorithm.

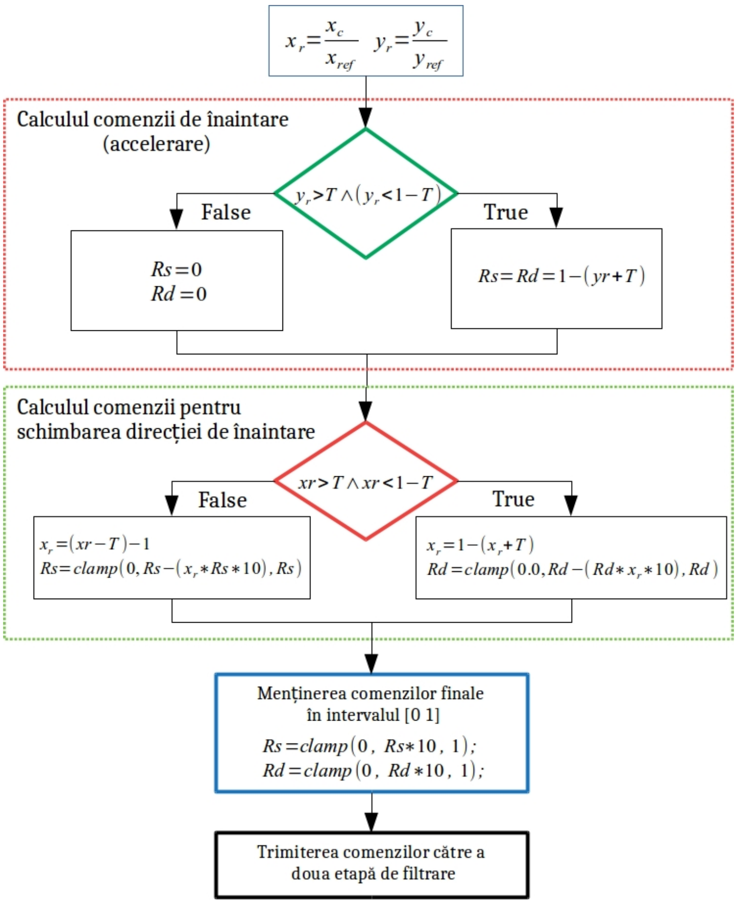


Fig.2.13.5. Block diagram of the proposed algorithm

The graphical interface implemented in OpenCV is exemplified in Figure 2.13.6.

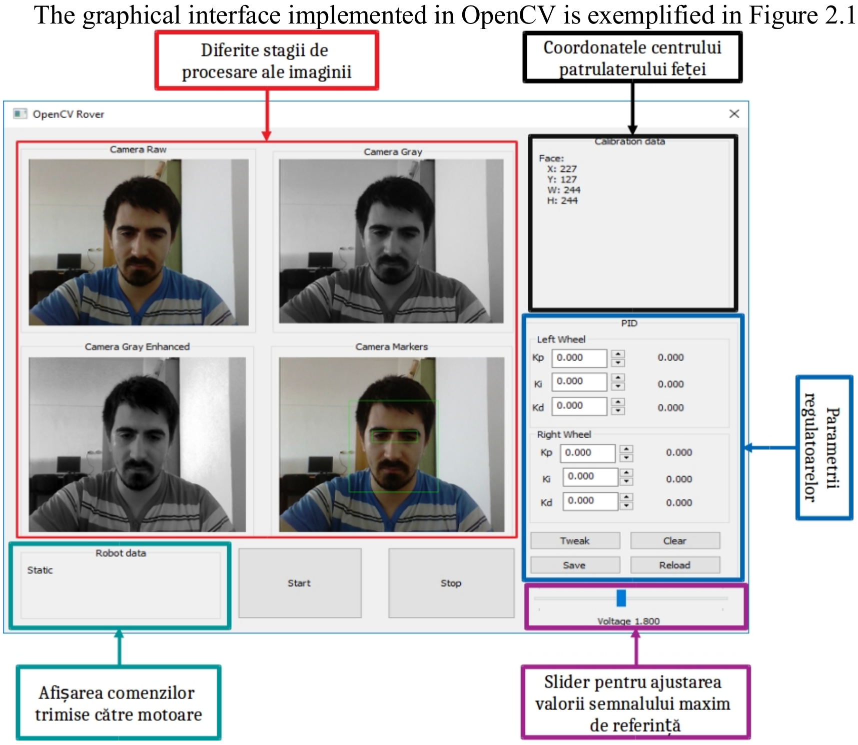


Fig. 2.13.6. Head movement control interface

The application was designed and implemented to be easily expanded in the future. This application can also be used on other types of mobile platforms used by people with disabilities. Based on the proposed solution, a BDI indexed article was published (with a proposal to index ISI Proceedings).

Activity: Act 2.14 - - Design of the obstacle avoidance structure (based on laser and video sensors) for the complex SAC-SI system integrated in the technology of assisting people with severe neuro-motor disabilities

Indicators of achievement:

- *Obstacle avoidance structure (based on laser and video sensors) serving the "Cirrus Power Wheelchair" (SAC-SI) wheelchair integrated in assistive technology for people with severe neuro-motor disabilities;*
- *New software product;*

In this step, an algorithm for the automatic determination of a trajectory (allowing the avoidance of fixed obstacles) for a wheelchair with two drive wheels using PSO (Particle Swarm Optimization) was developed in MATLAB.
Each particle updates its position and velocity using the following equations:

$$\begin{cases} V_i^{k+1} = WV_i^k + c_1 r_1 (P_i - S_i^k) + c_2 r_2 (P_g - S_i^k) \\ S_i^{k+1} = S_i^k + V_i^k \end{cases} \qquad (2.14.1)$$

The general form of the fitness function is:

$$\text{Fitness} = K_{goal} \cdot D_{goal} + K_{\theta_{goal}} \cdot |\theta_{goal}| + K_{obs} \cdot \sum_{m=1}^{\text{no.of obs.}} e^{-K_{D_{obs}} \cdot D_{obs}(m)} \cdot |\theta_{obs}(m)|^{-K_{\theta_{obs}}} \qquad (2.14.2)$$

In global methods of finding a route, the environment is assumed to be completely known and the route (path) is optimized taking into account all the information that appears on the map. The reference path can take the robot to its destination in a refined way. Moreover, the optimal route is only found if the obstacles in the path are fixed and there are no exit areas. The algorithm used for the global method is described in the table below:

Table I:

1:	Initialization Parameters: iterations, swarm size, initial swarm position, initial velocity.
2:	**FOR** iter = 1 to iterations **DO**
3:	**FOR** i = 1 to swarm size **DO**
4:	update particles S_i (see eq. 2.14.1)
5:	calculate the Fitness (see eq. 2.14.2)
6:	**IF** new position is better **THEN** update best S_i update the best value
7:	**End IF**
8:	**End FOR**
9:	update global best positioning
10:	**FOR** i = 1 to swarm size **DO**
11:	updating velocity vectors Vi (see eq. 2.14.1)
12:	**End FOR**
13:	**End FOR**

In Fig. 2.14.1 is presented a case of study with three fixed obstacles on the mobile robot path. It is easy to see from this figure that the path to the destination is found after 21 iterations of the algorithm. Also in Figure 1 is shown in detail the situation in which the robot must cross between two fixed obstacles. It can be observed that only 13 of the 25 particles (the size of the stream used for this case study) are taken into account. The other particles overlap with obstacles (11 particles overlap over obstacle no. 1 and one particle overlaps over obstacle no. 3).

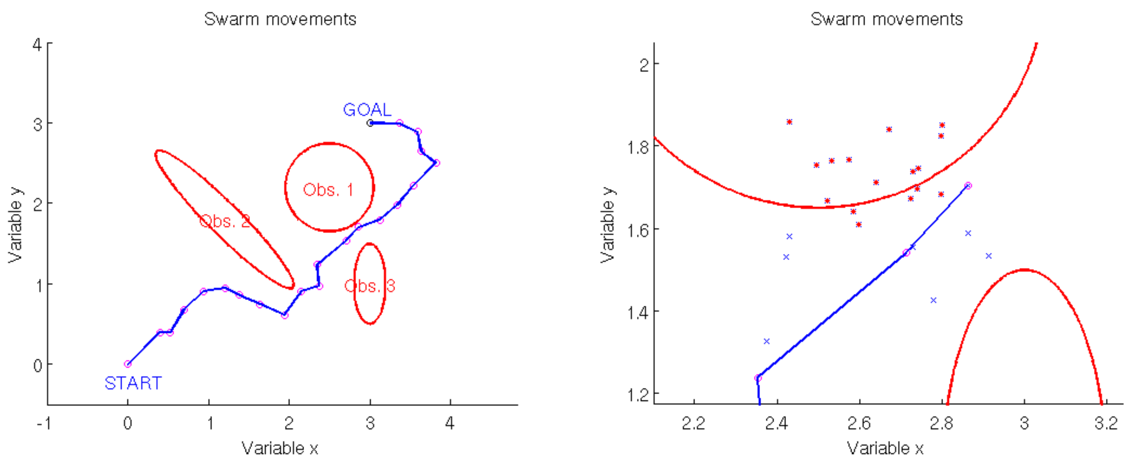


Fig. 2.14.1. The result of the algorithm for finding the optimal route between the START point and the FINAL point using PSO (global method); detail of the area between obstacles 1 and 3.

The final result for this algorithm is given by the set of intermediate points of the path (x_i, y_i). The set of intermediate points represents the input for the tracking controller of the mobile robot path. The task of the controller is to move the mobile robot autonomously on the path found using the PSO algorithm. Also at this stage was implemented in MATLAB an algorithm for the automatic realization of a trajectory that takes into accounts the time and comfort restrictions for a wheelchair. In this stage were generated the speed vectors (linear and angular) necessary for the real-time management of the mobile platform (autonomous system). Equations of 5 degree are used to determine the trajectory of a mobile robot.

$$Pos_{j,j+1}(u) = \begin{bmatrix} x_{j,j+1}(u) \\ y_{j,j+1}(u) \\ \theta_{j,j+1}(u) \end{bmatrix} = \begin{bmatrix} \alpha_{j,0} + \alpha_{j,1}u + \alpha_{j,2}u^2 + \alpha_{j,3}u^3 + \alpha_{j,4}u^4 + \alpha_{j,5}u^5 \\ \beta_{j,0} + \beta_{j,1}u + \beta_{j,2}u^2 + \beta_{j,3}u^3 + \beta_{j,4}u^4 + \beta_{j,5}u^5 \\ \theta_j(u) \end{bmatrix} \quad (2.14.\ 3)$$

The equation of curvature for each segment of the trajectory is:

$$K_{j,j+1}(u) = \frac{\dot{x}_{j,j+1}(u)\cdot\ddot{y}_{j,j+1}(u) - \ddot{x}_{j,j+1}(u)\cdot\dot{y}_{j,j+1}(u)}{\left(\dot{x}^2_{j,j+1}(u) + \dot{y}^2_{j,j+1}(u)\right)^{2/3}} \quad (2.14.4)$$

The length of the curvature is given by the equation:

$$L_{j,j+1}(u) = \int_{u=0}^{u=1} \sqrt{\dot{x}^2_{j,j+1}(u) + \dot{y}^2_{j,j+1}(u)} \cdot du \quad (2.14.5)$$

The speed profile that corresponds to each segment is divided into 5 parts, m = 1, 2, ..., 5:

$$v_{(j,j+1),m}(t) = \gamma_{1m} + 2\cdot\gamma_{2m}\cdot t + 3\cdot\gamma_{3m}\cdot t^2 \quad (2.14.6)$$

Similarly, the length and longitudinal acceleration for each segment are calculated as follows:

$$S_{(j,j+1),m}(t) = \gamma_{1m}\cdot t + \gamma_{2m}\cdot t^2 + \gamma_{3m}\cdot t^3 \quad (2.14.7)$$

$$a_{T(j,j+1),m}(t) = 2\cdot\gamma_{2m} + 6\cdot\gamma_{3m}\cdot t \quad (2.14.8)$$

The angular speed can be calculated using Frenet's formula:

$$\omega_{j,j+1}(t) = v_{j,j+1}\cdot K_{j,j+1} \quad (2.14.9)$$

and the lateral acceleration with the relation:

$$a_{Lj,j+1}(t) = v^2_{j,j+1}\cdot K_{j,j+1} \quad (2.14.10)$$

Human comfort is calculated according to the equation below (according to ISO 2631-1 and ISO 2631-5)

$$a_w = \sqrt{\tau_x^2\cdot a_{wx} + \tau_y^2\cdot a_{wy} + \tau_z^2\cdot a_{wz}} \quad (2.14.11)$$

where a_{wx}, a_{wy}, a^{wz} are the mean quadratic accelerations calculated on each segment of the trajectory, and iar τ_x, τ_y, τ_z multiplication factors: $\tau_x = 1.4$, $\tau_y = 1.4$, $\tau_z = 0$.

The proposed algorithm for calculating linear and angular speeds that takes into account the time constraints for a two-wheeled mobile robot is described in Table II.

Table II: Trajectory Planning Algoritm

1:	Calculate $x_{j,j+1}(u)$ and $y_{j,j+1}(u)$ for each curve (eq. 2.14.3) calculate the curvature $K_{j,j+1}(u)$ for each curve (eq. 2.14.4) and calculate the curve length $L_{j,j+1}(u)$ for each curve (eq. 2.14.5)
2:	Determine a time $t_{j,j+1}$ for each seg. $Pos_{j,j+1}$ of the path The time is calculate function of the comfort of human body constraint: $t_{j,j+1} = ((2\cdot L_{j,j+1})/a_w)^{1/2}$
3:	**FOR** j = 1 to goal (final position) **DO**
4:	Calculate an average velocity $\bar{v}_{j,j+1} = a_w \cdot t_{j,j+1}$
5:	Calculate an initial velocity profile $v_{j,j+1}(t)$ with $t \in [0, t_{j,j+1}]$ (see eq. 2.14.6) and longitudinal accel. profile $a_{Tj,j+1}(t)$ using eq. 2.14.8
6:	Calculate angular velocity profile $\omega_{j,j+1}(t)$ (see eq. 2.14.9) and lateral accel. profile $a_{Lj,j+1}(t)$ using eq. 2.14.10
7:	Calculate the overall r.m.s. acc. $a_{wj,j+1}$ for segment (eq. 2.14.11)
8:	**IF** $a_{wj,j+1} > 0.4$ m/s^2 **THEN** increase the time $t_{j,j+1}$ for this segm. and go to step 4
10:	**End FOR**

The following figures show the results obtained from the simulation of the proposed algorithm (table II):

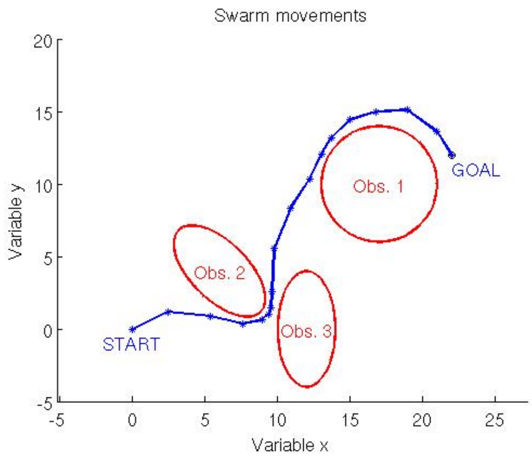


Fig. 2.14.3 Example of trajectory using 5th degree equations.

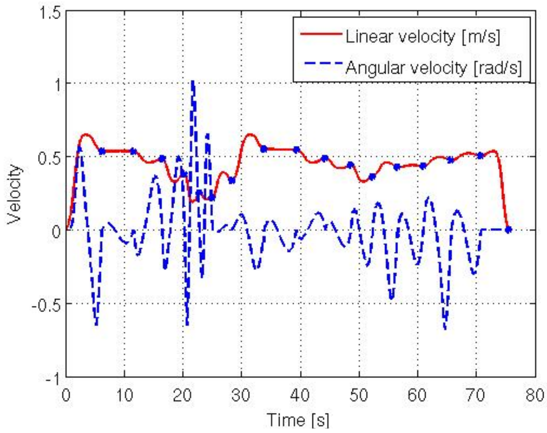


Fig.2.14.4 The linear and angular velocity calculated using the proposed algorithm.

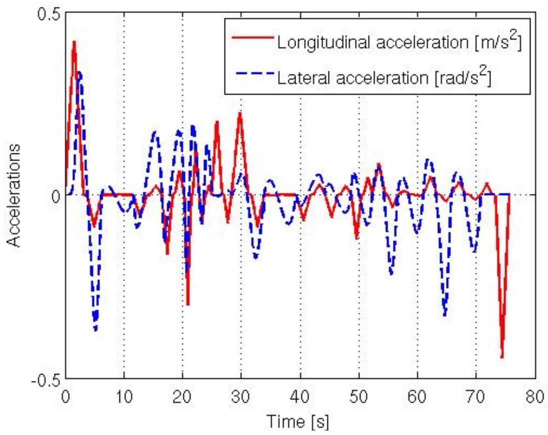


Fig. 2.14.5 The linear and latera accelerations for the example in figure 2.14.3.

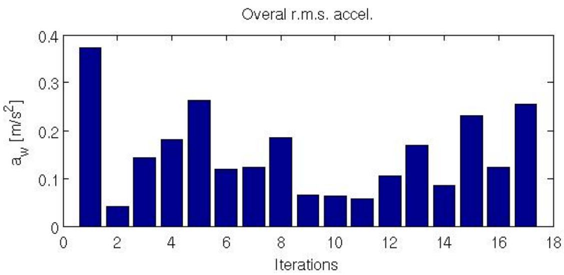


Fig. 2.14.6 The mean squared values of the accelerations for the example in figure 2.14.3.

Activity: Act 2.15 - -Design and realization of the advanced control structure based on visual servoing systems (for the 7DOF robotic manipulator) that serves the SAC-SI system integrated in the technology of assisting people with severe neuro-motor disabilities

Indicators of achievement:

- *Advanced control structure based on high performance sensors and visual servoing system mobile of the Cyton 1500 manipulator that equips the SAC-SI;*
- *New software product;*

In this activity, the objects were sorted on a work surface by their size, followed by their manipulation using a robotic arm (Cyton Gamma 1500).The proposed algorithm offers the possibility of selecting the smallest object on the work surface: selecting the largest object or arranging the objects in a stack in the order of their size, from the largest to the smallest. The algorithm is developed using MATLAB software, along with the image processing toolbox. Object detection is a technology that is part of the field of computer image processing. The structure of the hardware equipment is shown in figure 2.15.1.

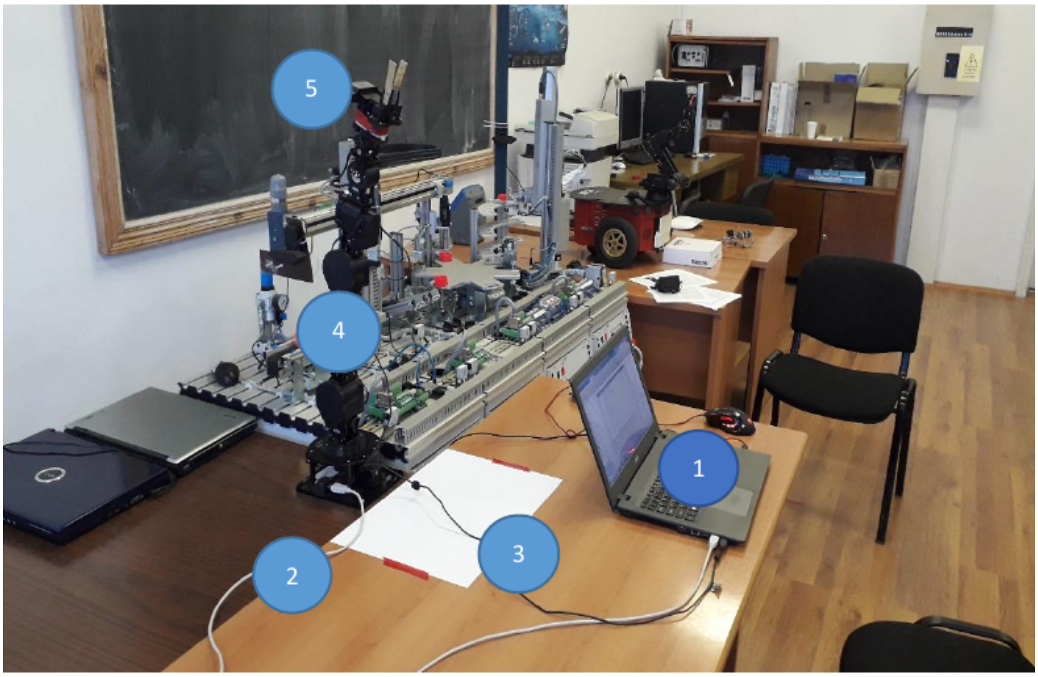


Fig. 2.15.1 Physical scheme of the assembly: 1-PC, 2-USB cable for PC-robotic arm connection, 3-USB cable for PC-webcam connection, 4-Cyton Gamma 1500 robotic arm, 5-Logitech HD Pro Webcam C920.

A first step is placing the end-effector of the robotic arm at a distance of 6 cm above the objects. After this step, the algorithm for image processing and calling the robotic arm control programs comes into operation. The MATLAB program is responsible for the following functions: calling the programs for controlling the robotic arm, capturing the image, identifying the objects in the image, sorting the areas of the descending objects and calculating the coordinates of the objects. After the robotic arm has reached the scan position, the image capture and processing according to the diagram shown in figure 2.15.2 are performed.

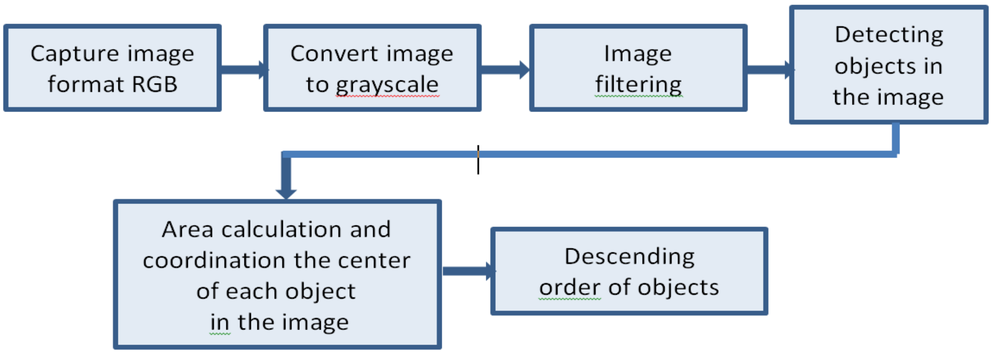


Fig. 2.15.2 Schematic of the algorithm for image processing

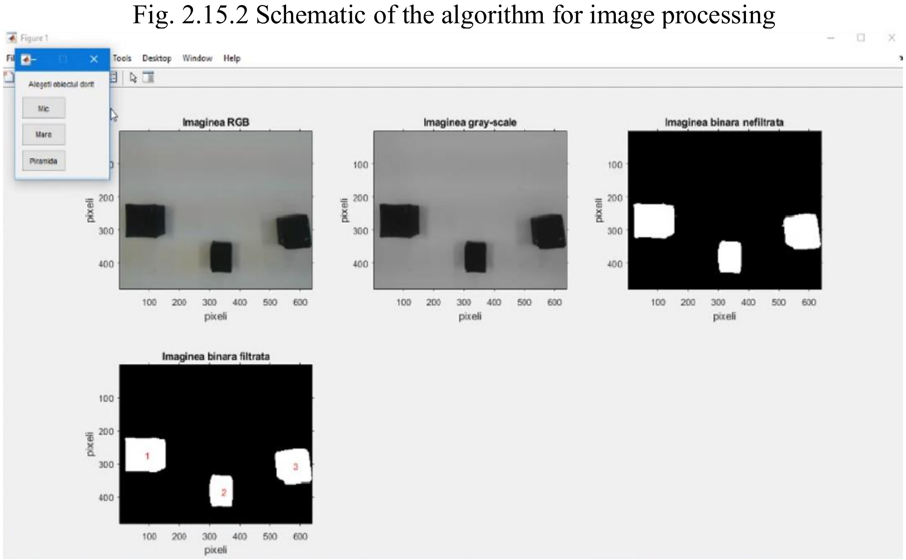


Fig. 2.15.3 Graphical interface made in Matlab

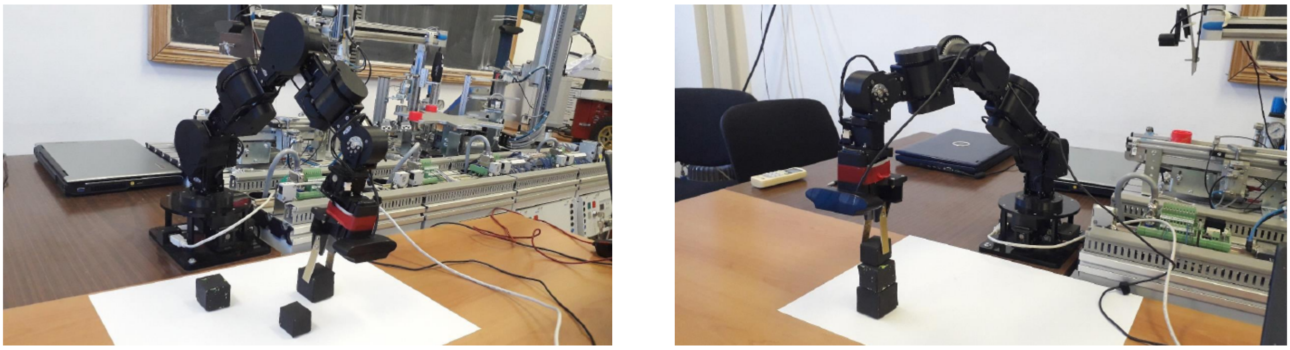


Fig. 2.15.4 The initial and final phase in the case of arranging the objects in a stack in order of their size, from the largest to the smallest.

A second algorithm developed allows the handling of drug boxes (which have various QR codes attached) by a robotic arm. The objectives of the algorithm were i) scan of drug boxes on which QR codes were attached with different means, ii) exact calculation of the position of the drug box, iii) send their position to the robotic manipulator and iv) manipulate the box chosen by the arm robotic. QR code (abbreviated from "quick response code") is a type of matrix barcode designed for the first time in 1994 for the Japanese auto industry. A QR code consists of black squares arranged in a square grid on a white background, which can be read by an image device, such as a camera, and processed using the Reed-Solomon error correction until the image can be interpreted suitable. The required data are then extracted from the models present in the horizontal and vertical components of the image. After detecting and decoding the QR code entered / requested by the user (see fig. 2.15.5) its position in the image (in pixels) is determined. This position is converted into centimeters (see fig. 2.15.6) and sent to the robotic arm for manipulation.

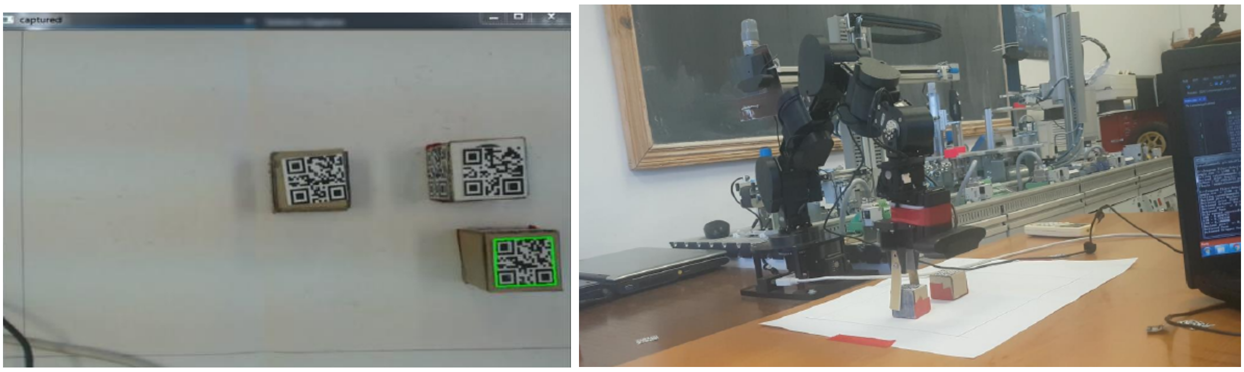


Fig. 2.15.5 Scan various QR codes and find / detect user-requested code.

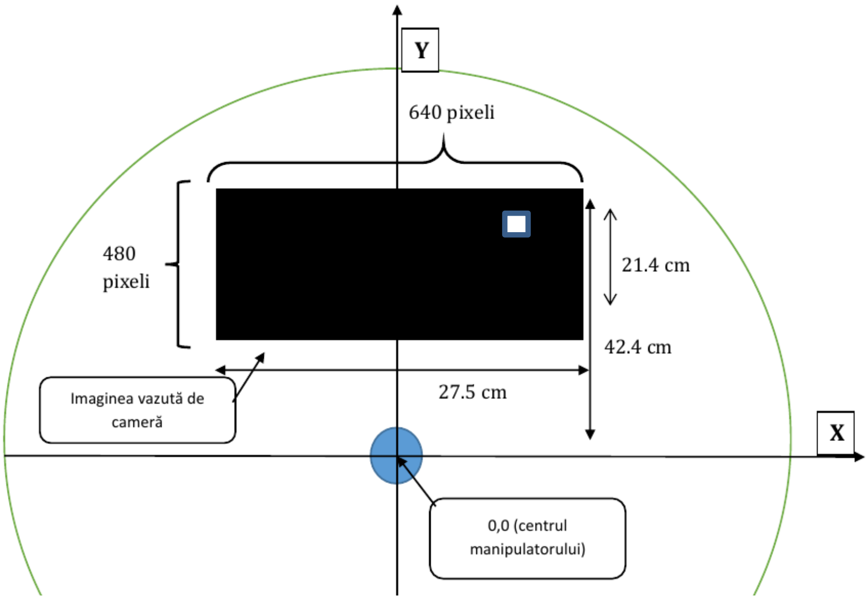


Fig. 2.15.6 Calculation scheme of the real coordinates (from pixels to cm)

The scheme of the proposed algorithm for manipulating drug boxes (which have a QR code attached) is described in figure 2.15.7.

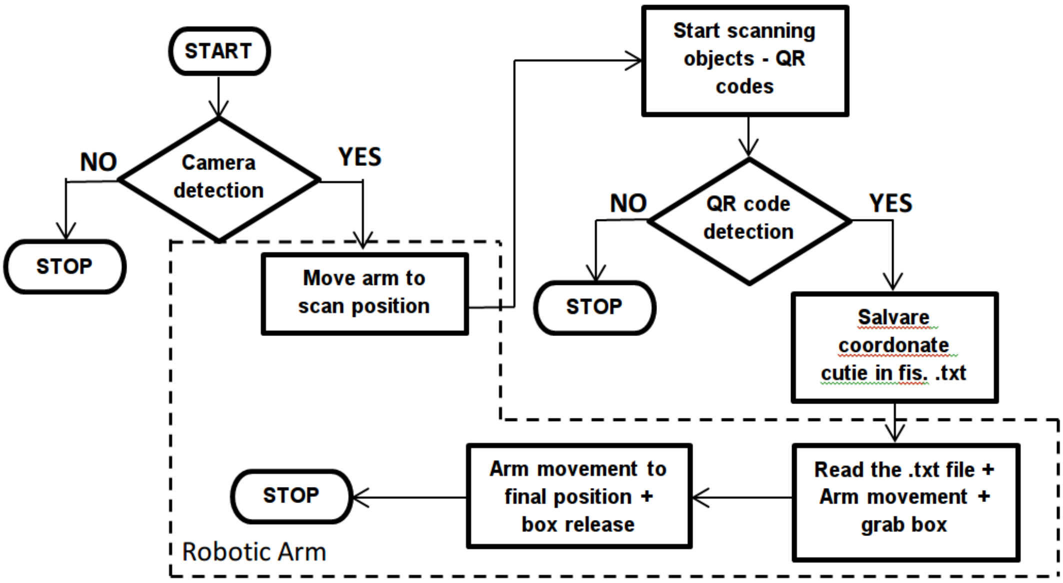


Fig. 2.15.7 Schematic algorithm manipulation box QR codes

CONCLUSIONS: The scientific report highlights the solutions that the Project 5 working team offers for the requirements of Stage 2. In the detailed scientific report uploaded on the P5 project platform (http://www.cidsacteh.ugal.ro/) the solutions and results can be viewed

RESULTS STEP 2: The following results were obtained:

- *Intelligent control structure and navigation structure for SAC-SI, "Cirrus Power Wheelchair" integrated into assistive technology for people with severe neuro-motor disabilities;*
- *Obstacle avoidance structure (based on laser and video sensors) serving the "Cirrus Power Wheelchair" (SAC-SI) wheelchair integrated in assistive technology for people with severe neuro-motor disabilities;*
- *Advanced control structure based on high performance sensors and visual servoing system mobile of the Cyton 1500 manipulator that equips the SAC-SI.*

DISSEMINATION: Articles (ISI Proceedings or BDI)

1. R. Solea, A. Margarit, D. Cernega, A. Serbencu, ”Head Movement Control of Powered Wheelchair”, IEEE - 23rd International Conference on System Theory, Control and Computing (ICSTCC), 9-11 Oct. 2019, Sinaia, Romania, DOI: 10.1109/ICSTCC.2019.8885844

Complex project manager
Adrian Filipescu, Prof., Ph. D., Eng.