Preprints of the 21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

Digital Twin in 5G Digital Era developed through Cyber Physical Systems

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Abstract: The paper Cyber Physical Systems integrated in VIPRO- Platform through intelligent control interfaces and genetic algorithms to build "digital-twins" robots vectors tools for cyber-physical manufacturing presents. Intelligent control interfaces are useful for simulating robots vectors' capabilities in a safe and cost-effective way, but it is challenging to accurately emulate the behavior of the physical tools. When an unmanned autonomous vehicles breaks down or malfunctions, engineers can always go back to check the digital traces using the "digital-twins" VIPRO- Platform for diagnosis and prognosis. This paper presents an integration of Cyber Physical Systems using intelligent control interfaces and genetic algorithms into developing "digital-twins" VIPRO- Platform in 5G Digital Era to improve their accountability and capabilities for cyber-physical manufacturing. The intelligent control interfaces data are used to extract the machining characteristics profiles of a digital-twins machine tool, with which the tool can better reflect the actual status of its physical counterpart in its various applications. The modelling techniques and decision making in complex systems for controlling the position of a unmanned autonomous vehicles engaged in a mission are discussed, and analytical techniques of data and genetic algorithms are presented for modeling and developing "digital-twins "VIPRO- Platform. Copy-right © 2019 IFAC

Keywords: Integrated monitoring, control and security for critical infrastructure systems; distributed navigation and control of unmanned autonomous vehicles; modelling and decision making

1. INTRODUCTION

Cyber-Physical Systems developed by Advanced Intelligent Control integrate the dynamics of the physical processes with those of the software and networking, providing abstractions and modeling, design, and analysis techniques for the integrated whole. Cyber-Physical Systems are closely tied to concepts of robotics and sensor networks with intelligence mechanisms proper of computational intelligence leading the navigation, orientation, stability in the motion environment. A cyber-physical system (CPS) is a mechanism controlled or monitored by computer-based algorithms, strong integrated with the internet and its users [De Santis, 2008, Vladareanu L., 2015]. In cyber-physical systems, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a myriad of ways that change with context. Cyber-Physical Systems paradigm, exploring the modeling, design and implementation of complex systems involving software components that impact real environment and interact with human operators, has become a priority research area in the past few years.

By developing the VIPRO platform related to the digital twin concept, the intelligent interface of position control of a flight formation engaged in a mission is analysed using autonomous robotic system architecture (Vladareanu L., 2018).

The German strategy and initiative to change the concept of industrial production called Industry 4.0 (Rojko, A. 2017), is an initiative that wants to digitize and exploit new technologies in the production environment. This will allow factories to change their entire automated production line only by re-configuring the used robots, leading to much lower costs but also increasing the range of products offered by a single production unit.

Reported on the advanced intelligent control this is an inter-disciplinary field which combines and extends theories and methods from control theory, computer science, and operations research areas with the aim developing controllers which are highly adaptable to significant unanticipated changes [Mitroi D., 2017, Vladarenu L, 2013, 2017].

Integrated in advanced intelligent control, the intelligent control is based on the control method which imitates human intelligence in learning, decision-making, and problem solving [Chunyan, Y., 2005, Vladareanu, V, 2013]. The human characteristic consists of experience, learning, adapting, and changing their methods of approach and solving problems. Intelligent control techniques allow the development of an environment which leads to recreating the advantages of natural intelligence with artificial intelligence. Advances in sensors, actuators, computation technology and communication networks help provide the necessary tools for the implementation of intelligent control hardware.

The scope of the paper is to present and discuss new trends in the design, control and applications of real time control of Cyber-Physical Systems, including robots vectors and unmanned autonomous vehicles, applying advanced intelligent control methods and techniques for cyber-physical manufacturing.

Cyber Physical Systems integrated in VIPRO- Platform to build "digital-twins" robots vectors tools [3, 6, 9] by adaptive intelligent control interfaces for robot vectors communications presented in paper is intended for robot vectors with real-time control that involves, through the data volume of communications and quick response between system agents, the need for 5G network Densification Era communications.

The work applies the Cyber Physical Systems integrated in VIPRO- Platform through intelligent control interfaces and genetic algorithms to build "digital-twins" robots vectors tools for cyber-physical manufacturing.

2. VIPRO CONCEPT FOR ROBOT DDIGITAL TWIN

VIPRO Platform develops in an environment of the virtual reality the versatile, intelligent and portable control interfaces, validated in real time on a classical own mechatronic control system and/or a physical mechatronic system, with the aim of improving system performances for motion, navigation and orientation, having as main applications control systems for nano - micro - macro - manipulators, mechatronic systems and humanoid (Vladareanu L., 2017, Mitroi D., 2017).

The architecture of the VIPRO platform for modeling and simulation of mobile robots is based on the virtual projection method (Vladareanu L., 2017, Vladareanu V., 2018), through which mechatronic systems of mobile robots are developed in a virtual environment. The virtual projection method tests the performance of dynamic position-force control by integrating dynamic control loops using a Bayesian interface for the sensor network and neutrosophic interface for decision making (Vladareanu V., 2013, 2015, Vladareanu L., 2016-2018).

The open architecture system CPS (CPS&OAH with intelligent interfaces (OAH) of the VIPRO platform includes the intelligent control interfaces integrated in the CPS Engineering Station to simulate the control of the robot vector through the virtual projection method applying digital twin concept in interfaces development. Neutrosophic control interface (ICNs) using the Robot Neutrosophic Control (RNC) method have been developed using digital twin extended control interface (ICEx) uses extended control (Chunyan, Y., 2005, 2007) hybrid force -position (eHFPC), neural networks interfaces (INN) for hybrid dynamic control force-position DHFP and intelligent interface for optimizing robot vector performance (IVR).

After testing, they are integrated into the virtual reality robot control, through the Grahical Station, as follows: for multi-users through the components of the VIPRO platform consisting of eLear & REM User 1, eLear & REM User 2 or individually through the components of the VIPRO platform formed of Notebooks dedicated to the intelligent interfaces, respectively "Extenics Intelligent Interface Notebook" (Wen C.,1983, Vladareanu V.2013), "Neutrosophic Intelligent Interface Notebook" and "Neural Network Intelligent Interface Notebook".

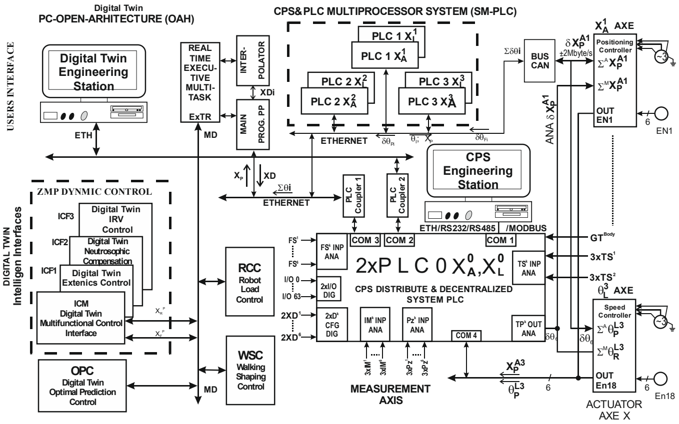

Fig.1. Open Architecture System and intelligent interfaces of the VIPRO Platform

The open architecture system (PC - OAH) integrated in the CPS Engineering Station (figure 1) using digital twin concept contains multifunctional control interface (ICM) which provides real-time control, priority control and information exchange monitoring between the 3 digital intelligent control twin interfaces (DT-ICNs, DT-ICEx, DT-INN and DT-IRV) connected to each other by a data magistrate (MD) with high speed of communication and the classic mechatronic control system of the robot formed from the PLC system, the PLC multiprocessor system and the PC system with open architecture PC-OPEN Architecture OAH.

3. VERSATILE INTELLIGENT PORTABLE (VIPRO) PLATFORM ARCHITECTURE

The innovative platform VIPRo (fig.2), developed as open architecture system and adaptive networks integrates. Future Internet Systems vision enabling: cyber-physical systems by adaptive networks, intelligent network control systems, human in the loop principles, data mining, big data, intelligent control interfaces, shared resources and distributed server network - remote control and e-learning users by interconnected global clouds. Based on all the above, the challenges and, therefore, expected progress of VIPRo are its ability to be interactive, integrated and competitive with advanced scientific research concepts.

The need to manage all behaviors and interactions is solved by developing a new interface for intelligent control based on advanced control strategies, such as extended control (Extenics), neutrosophic control, human adaptive mechatronics, implemented by high speed processing IT&C techniques in real time communication for a high amount of data processing, including a remote control & e-learning component and an adaptive networked control.

This will allow the development of new methodologies, evaluation metrics, test platforms, reproducibility of experiments, novel approaches to academia-industry co-operation for enabling disruptive product and process innovation and last but not least an manufacturing engineering network for research and modeling complex of the data for digital twin of the GCS robot vector tools on manufacturing quick actions.

VIPRO Platform enables developing the IT Industry 4.0 concept through the design, testing and experimentation of new intelligent control interfaces on a classical mechatronic control system (SCMC) in the presence of the physical mechatronic system (SMF), with own control system and mechanics structure, or in the absence thereof, without the need to modify its hardware structure, and, from optimal decisions and information fusion between the intelligent control interfaces, resulting in a high degree of versatility and portability to a global communications network.

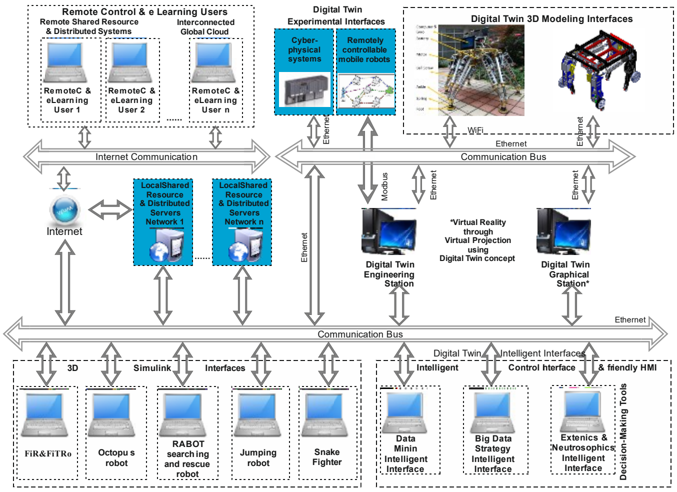

Figure 2. Versatile intelligent portable (VIPRO) platform architecture

Robotic control is essential in developing digital twin and perception algorithms for robotics applications. A 3D simulator for mobile robots must correctly control the dynamics of the robots vector and of the objects in the environment. Moreover, real-time control is important in order to correctly model interactions among the robots and between the robots and the environment, so it is often necessarily an approximation to obtain real-time performance.

Development of 3D dynamic perception and visualization, and human-robot interaction software systems are formidably challenging and accordingly the activities to support software developments and project management processes are of vital importance to this piece of research. Attribute selected techniques can be categorised on the basis of a number of criteria. Dynamic data come from environmental and wearable sensors, mobile robots and radio communications.

New computational software tools and virtual reality engines are being developed to support both risk and the decisions. Also, was develop adequate metrics and testing tools to determine the effectiveness and validity.

4. INTELLIGENT INTERFACE FOR OPTIMIZING PERFORMANCE OF ROBOT VECTORS (IVR)

A virtual model of the control system has been developed for a complex robots vector that can monitor, analyze and improve the control functions performance of the GCS system. The robots vector consisting of 2 aerial robots type quadcopter / drone and a flying wing. The model was created using computer-aided engineering and is integrated with the Internet of Things, machine learning and Big Data analytics.

The system has several digital twin tools of the GCS system, for position control of a flight formation involved in carrying out a mission, developed on an optimization interface and mission control, automatically loaded into the aerial robots vector flight plan.

Ground control center GCS (Figure x3), has aims to ensure a stable behavior of the robot vectors, with maximum performance. It supports the ability to fly after predefined trajectory with high accuracy in the presence of large amplitude external disturbances.

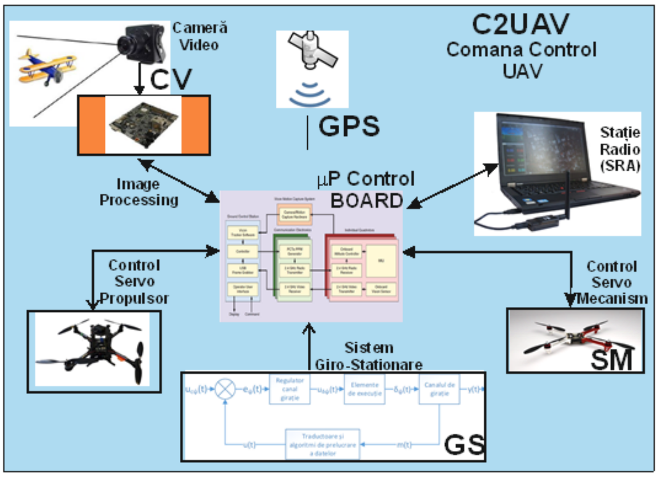

Fig. 3. Ground control center GCS

This is done by estimating UAV states, which include at least one set of information about position, flight speed, angular velocity and attitude. After processing the data obtained from the sensors and based on the automatic adjustment architecture, decisions are made to correct the errors that occurred as a result of the deviation from the flight path.

Multi-agent collaborative system with intelligent multi-agent optimization and decision interfaces implemented on GCS, intended for the applications digital twin is presented in Figure 4. It is made up of 3D robot vectors (tri-dimensional) – aerial, terrestrial, aquatic who have the role of intelligent agents, a command and control center CTC2, a mission management center CMM and a radio communications system SRA, SRB, SRC. GCS has implemented artificial intelligence algorithms for optimization and decision making. Multi-agent collaboration consists of sharing the messages transmitted in real time, extracting from the group's objectives into individual objectives, establishing the zones of influence and the types of interactions, adapting the strategy to the dynamics of events - areas followed, information transmitted, types of measurements, flight regime, etc

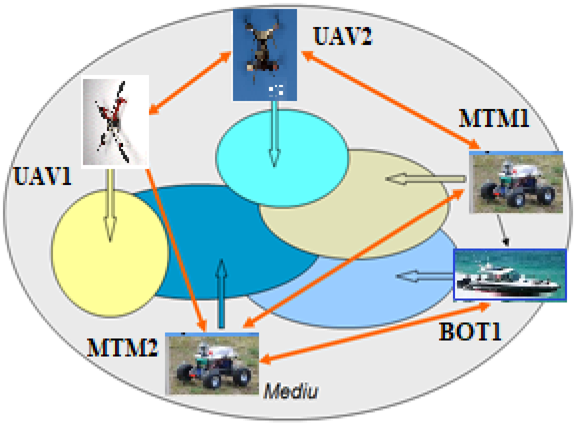

Fig. 4. Multi-agent collaborative system with intelligent multi-agent optimization and decision interfaces

Of vital importance to the mission's chances of success is the use of equipment that requires a wide transmission band, such as a live stream coming from the video-camera, which cannot usually be carried on the radio control devices network. The solution to this problem is to equip the two quadcopters with wifi access points, thus extending the possible communication area between the wing and the mission base, considered fixed.

5. GENETIC ALGORITHMS TO BUILD "DIGITAL-TWINS" ROBOTS VECTORS TOOLS

The optimization problem that arises of the GCS system digital twin control functions is the positioning of quadropters to maximize wing-base connectivity. The wing path will be previously generated by an algorithm that takes into account the region-specific topology and can be considered known. Based on this and the physical limitations of the various components of the proposed search system, the optimal quadropteras routes must be found. Also, the exposed problem would be trivial in the absence of any obstacles in the search space. Adding them to correctly model the situations encountered in real search contexts, however, leads to a complex problem (Rapai, M., 2008).

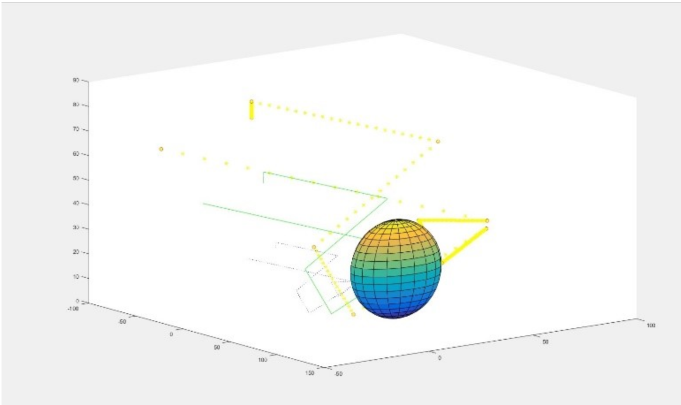

Fig. 5. Flight and search space

Figure 5 shows the example of a search space in which the obstacle, the path and the speeds of the wing are randomly generated, as well as the solution proposed by one of the intelligent algorithms running.

The optimization problem show as follows:

$$[max]\, F\big(tr(A), tr(B), tr(C)\big)$$

$$\begin{cases} v_B \leq v_{max}^{quad} \\ v_C \leq v_{max}^{quad} \\ Im\big(tr(B)\big) \cap Obst = \emptyset \\ Im\big(tr(C)\big) \cap Obst = \emptyset \end{cases}$$

where:

- *F is the measure of wing-base connectivity, depending on the path of the wing and the two quadropters. Although the parameterization of the application allows the use of any expression for F, however complex, for testing and debugging, a linear function has been chosen, the value of which decreases with distance.*
- *tr(A), tr(B) and tr(C) are notations for path aerian vectors: A is the base, and B and C are the quadropters, C being the closest to the base (O). In the application, these are three-dimensional value vectors that describe the mission of the air vector.*

The speeds of the two quadropters must be below the maximum limit that the equipment can reach.

No value of the path image (function) of either quadroptera can have points in common with the set of points modeled as obstacles.

The route points of the wing are constituted in a vector of three-dimensional values that contains the estimated position of the air vector at each time step. The number of points is modeled between two consecutive positions of an independent section of the operator (or algorithm generator) when a wing path is constituted, being one of the input variables of the optimization problem. In this mode, the travel time is modeled by default, each valoare appeared in the path vectors and is reached at the next time step. The time step is easy to calculate from the speed value (in application testing it is set to 1s by default).

This procedure is also valid for the constitution and modeling of the quadroptera route vectors. Each item contained in Im(tr(B)), for example, it is the position of the air vector at the next time step. Considering also that the Obst crowd is formed by modeling a sphere over the existing obstacle, so having a considerable margin of safety with regard to the points included, it is considered sufficient to check the points in the image of the route of each quadropter against the obstacle set, in order to avoid the collision.

The problem solving algorithm is written in the code Matlab / Octave (see figures 6 sequence code). The graphical interface implementation uses the GUIDE interface, owned by Matlab, to create the necessary functions for the graphic elements. The GCS system digital twin control functions flowchart was developed. The optimization algorithms used are described below:

fmincon – – Maltab's proprietary algorithm, which tries to find the minimum of a constraint function (hence the function name). The function automatically chooses between four possibilities of solution: interior point optimization, SQP algorithm, active crowd optimization and reliable region optimization. More details, as well as references for each of the algorithms used, (fmincon Matlab, 2019, Matlab Documentation, 2019).

```
quad_pos_script.m
%%
% main script for drone position optimization algorithm
% quad_pos determines the positions of qB and qC to maintain maximum connectivity to air wing
% -- inputs
% A = trace of A wing, provided by user Nx3 (flight granularity)
% O = origin of flight, provided or assumed 1x3
% mask = total space of obstacles, provided by user subspace
% -- outputs
% B = trace of qB Nx3
% C = trace of qC Nx3
% O --> qC --> qB --> A
% eventually re-write as function [B,C]=quad_pos1(A,O)
%% old
% call with
%load('msm_test.mat')
%[B,C]=quad_pos1(wAt2,[0 0 0])
%plot_trs(A,X,O)
%
% ConstraintFunction = @simple_constraint;
%[x,fval] = ga(ObjectiveFunction,nvars,[],[],[],[],LB,UB, ConstraintFunction);
```

Fig. 6. The sequence cod for the GCS system digital twin control functions algorithm

AG – genetic algorithms are based on the iterative improvement of a population of possible solutions using the operators found in nature, in the natural selection process of evolution. The algorithm used in the application is part of the Matlab software package and details on implementation (fmincon Matlab, 2019, Matlab Documentation, 2019).

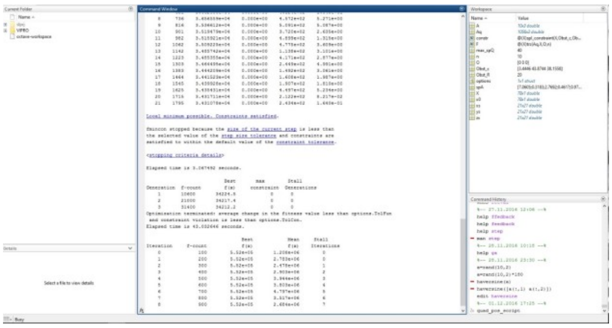

Fig. 7 – The running sequence of iterative optimization processes

PSO – – optimization algorithm using Particle Swarm Optimization. As AG, is an evolutionary algorithm, improving a population of possible solutions imitating the movement of insect groups in search of a suitable ecosystem. In the case of the application, two versions are implemented, there is a description of the Matlab software package (fmincon Matlab, 2019, Matlab Documentation, 2019) and the other is available (Rapai, M., 2008).

Code sequences for the digital twin control functions algorithm of the GCS system are shown in figure 6, respectively the running sequence of iterative optimization processes is shown in figure 7.

The genetic intelligent control interface uses a new artificial intelligence component to improve the instantaneous performance for positioning quadropters and for to maximize wing-base connectivity. Using digital twin concept and techniques an innovative application for the VIPRO platform results, with which to model and implement new actuator control methods.

Genetic control is unique in a number of aspects. It is a change in the control structure paradigm, being a way to implement a generalized theory, the purpose of which is to accurately formalize the innovation process.

6. CONCLUSIONS

The Cyber Physical Systems integrated in VIPRO- Platform through intelligent control interfaces and genetic algorithms in order to build digital-twins tools of the robot vectors for the cyber physical systems manufacturing was presented. Furthermore, was exemplified the design, testing and experimentation the intelligent interface for optimizing performance of robot vectors (IVR).

Together with the ability to function in a global communication network, the VIPRO Platform using digital twin concept and techniques is competitive with other well-known virtual platforms, such as DMC virtual application platforms, ICGC Data Portal, TCGA Data Portal, NCI Genomic Data Commons (GDC), or the powerful worldwide platforms for CAD applications (SolidWorks), medical imaging reconstruction (Simpleware, Mimics), multiphysics numerical modeling (Comsol), mathematical and biomedical modelling (Matlab+ Simulink, Mathematica), virtual instrumentation and measurements (Labview), or virtual reality environment (Coreograph, Webot, USARSIM, V-RAP). Furthermore, VIPRO platform develops the Industry 4.0 concept by e-learning, remote control and intelligent control interfaces, will be enter on the IT market as a new component among existing IT platforms.

Acknowledgment. This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, MULTIMOND2 project number PN-III-P1-1.2-PCCDI2017-0637/33PCCDI/01.03.2018, within PNCDI III, and by the European Commission Marie Skłodowska-Curie SMOOTH project, Smart Robots for Fire-Fighting, H2020-MSCA-RISE-2016-734875.

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