MIDDLEWARE FOR PRODUCTION ROBOTIC SYSTEM MODELING, INTEGRATION AND CONTROL

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The paper presents the developed middleware dedicated to the industrial robotic system modeling, integration and control. Due to several vendors of industrial robots and industrial equipment which deliver different simulation tools with different communication software, there is a need to integrate several technologies to build unified distributed robotic system. The proposed middleware combined by CORBA (Common Object Request Broker Architecture) communication layer and NVIDIA PhysX rigid body simulation, solve the integration issues by providing the methodology for distributed control system development and validation in hybrid environment (virtual and real). CORBA is independent from operating system and programming language, it is used as integration tool. It should be noted that CORBA can be combined with another communication techniques. We show the example application with the DeviceNET communication link between industrial robot and high level control PC combined with proposed middleware for Human Machine Interface purpose. It is important to emphasize that the proposed approach can be adapted to the design the manufacturing system combined by industrial robots, mobile robots and intelligent sensors such as cameras. Therefore it can be starting point for multi agent robotic system design and development.

In paper the process of development industrial robot system based on proposed middleware is shown. The advantages of the robotic system modeling, integration and control are investigated.

Keywords
production robotic system, middleware, rigid body simulation, supervision.

Introduction

Robot technology has been widely used in industrial production and daily life. Due to the uncertainty of the environment and large diversity of functions, the complexity of the robot software is growing dramatically [1, 2]. Several approaches such as a middleware based control architecture for modular robot systems and distributed component middleware for robot technology are described in [3, 5]. The middleware based on CORBA communication layer [6] is common in robotics society [7, 8] because of its flexibility and independence from the platform and operating system. It is important to emphasize that the modularity of the middleware [4] is crucial in case of modern approaches. In this paper we introduce the idea of combining CORBA based on distributed control architecture with DeviceNet communication between robot and control PC and NVIDIA PhysX rigid body simulation, to achieve a better performance of industrial robot integration issue. The combination of NVIDIA PhysX and COLLADA format of industrial robot physic model is used for simulation purpose. COLLADA is a COLLAborative Design Activity for establishing an interchange file format for interactive 3D applications. The main contribution in this paper is the developed simulation/integration software “PhysX Arena” that combines advantages of PhysX simulation and COLLADA portability for industrial robotics applications.
The paper consists of architecture, where the general architecture of web connected industrial robotic system is shown, *NVIDIA PhysX rigid body simulation*, where our “PhysxArena” software for integration and testing processes is described, *industrial robot system application*, where proposed middleware was used for industrial application development, *development and integration*, where general idea of proposed approach is described, *conclusion and references* which finalize the paper.

**Architecture**

Figure 1 shows the general scheme of the proposed web connected industrial robotic system. It is multi agent system. The main components of the system are listed as follows:

- HMI – Human Machine Interface,
- Agent 1,
- Agent 2,
- Agent N.

For the purpose of this study the industrial robotic system has been implemented using the CORBA distributed architecture, because of its independence from the programming language and operating system, which consequently provides the possibility of integration with existing tangible modules from different manufacturers e.g. Beckhoff (Interface DeviceNet I/O) or Prosilica (high resolution Video Camera). All system modules are compatible with CORBA, therefore the software implementation is independent from the hardware. The distributed implementation of the control – supervision system [9] is shown in Fig. 2. The HMI – Human machine interface from Fig. 1 is supervised by program called Cognitive Supervisor of Industrial Robotic System (CSIRS), all agents are supervised by programs Cognitive Supervisor of Agent N (N – agent id).

The main system components are developed and implemented as distributed cognitive model of the human supervisor of the Industrial Robotic System. It is combining the elements of a centralized system and multi agent system in the same time. The Fig. 3 illustrates the idea of the approach.
Multi agent architecture [9] of the developed cognitive supervisor consists of three layers. The first layer is reserved for the most important in the hierarchy of the agent—the cognitive supervisor of the industrial robotic system. In the case of the absence of the communication problems in the system between layer I and II the scheme operates as a centralized system. In this case programs from layer II are fully dependent from programs from layer I. From the perspective of software engineering in this case we are dealing with a distributed implementation of a centralized system of cognitive supervisor. Otherwise, if there are communication problems between layer I and layer II or between programs only from layer II, the agents from layer II are fully autonomous and operate in the pattern of multi agent system. It should be noted that the assumed fault-free communication between the agents of layer II and layer III resulting from the use wired Ethernet communications. Cognitive architecture is strongly conditioned by programs—supervisors using the multi agent system where CSIRS is installed at the main PC of the system, CSA1, CSA2, CSAn are installed on a industrial PCs interfaced to industrial robotic system components, and will coordinate the work of sub-CS1, CS2, CSn, which are supervising running programs. Presented scheme of the distributed multi agent cognitive supervisor is the core of the concept of the proposed middleware for robotics applications.

**NVIDIA PhysX rigid body simulation**

We developed program called “PhysXArena” for rigid body dynamics simulation and collision detection using NVIDIA PhysX. The rigid body dynamics PhysX component enables to simulate objects with a high degree of realism. It makes use of physics concepts such as reference frames, position, velocity, acceleration, momentum, forces, rotational motion, energy, friction, impulse, collisions, constraints, and so on in order to give a construction development kit to build many types of mechanical devices. Figure 4 shows the main rendering window of PhysXArena program.

![Fig. 4. Rendering window of PhysXArena program.](image)

![Fig. 5. Free DWG Viewer.](image)
In the scene of “PhysX Arena” it is possible to add several models of industrial robots, objects, and surfaces with CAD data. It is important to emphasize that PhysX Arena allows to manipulate all degrees of freedom of virtual industrial robots, therefore this tool can be used for the robot proper mounting position evaluation. The purpose of PhysX Arena development is determined by the idea of usage PhysX simulation during Industrial Robotic System design and interface to CORBA distributed system. Many of available software tools provide functionality of industrial robot simulation and visualization, such as Free DWG Viewer shown in Fig. 5.

Unfortunately they do not provide any interface, therefore the development of distributed control system is limited. For this reason we assumed that, the PhysX Arena software can improve the integration process by adding simulation component with proper interface during industrial robotic system development. It is also important to mention, that PhysX Arena software can import models in COLLADA format, therefore it is compatible (in case of model exchange) with another software tools such as SolidWorks.

## Industrial robot system application

The presented middleware has been used for the development the industrial robotic system applied for concrete bricks production check quality control. Figure 6 shows the pallets with such bricks.

Due to potential defects of concrete bricks during production process it is assumed to add check quality control based on video camera and industrial robot equipped with vacuum device. The vacuum device is able to eliminate defected bricks from pallet. The following scheme shows the check quality control system.

## Development and integration

The industrial robot KUKA KR 16 was chosen as a host of vacuum device. Figure 8 shows the robot and its properties.

The DeviceNet communication was chosen to interface industrial robot with control PC (Fig. 7). Following figure shows the configuration of DeviceNet and system architecture during simulation/integration processes.

![Fig. 6. Pallets of concrete bricks with potential defects.](image)

![Fig. 7. Concrete bricks check quality control system.](image)
Payload 16 kg
Supplementary load 10 kg
Max. reach 1610 mm
Number of axes 6
Repeatability < ±0.1 mm
Weight 235 kg
Mounting positions Floor, ceiling, wall

Fig. 8. Robot KUKA KR 16 and its properties.

Fig. 9. Configuration of DeviceNET and system architecture during simulation/integration process.

Fig. 10. Testing virtual robot movement in PhysXArena software.
It is important to emphasize that PhysX Arena software can emulate some functionalities of industrial robot and communicate via DeviceNet. Therefore the integration process is improved. It is important to emphasize that from communication point of view it is easy to replace PhysX Arena PC by real robot and start performing the real experiments. Therefore the effort of system developers is decreased.

Once the communication between all components of the system is established, it is important to evaluate the proper mounting position of the robot in the virtual environment. PhysX Arena software allows to monitor collisions between robot and virtual object (static and movable – Fig. 10) during simulation process. Figures 10 and 11 show the main view of PhysX Arena program during simulation process.

Figure 12 shows the final implementation of distributed industrial robotic system.

**Conclusion**

In the paper, the middleware combined by CORBA (Common Object Request Broker Architecture) communication layer and NVIDIA PhysX rigid body simulation is demonstrated. It is important to emphasize that COLLADA can be used as portable format for 3D rigid body simulation model. The main functionalities of new PhysX Arena software are shown. It is important to mention that proposed architecture that combines Cognitive Supervisor of Industrial Robotic System and multi agent system with PhysX Arena simulation software are the core of proposed middleware dedicated for production robotic system modeling, integration and control. We are focused on the integration issue, therefore our approach delivers several software tools that can decrease the effort needed to integration and testing purposes. Due to the PhysX Arena software is based on NVIDIA PhysX for rigid body dynamics simulation and collision detection, it is obvious that it can be adapted also for mobile robotics applications. We believe that proposed approach can be starting point for multi agent robotic system design and development.

**References**


