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Design, programming and orchestration of heterogeneous manufacturing systems through VR-powered remote collaboration

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ABSTRACT

Modern manufacturing systems are often composed of a variety of highly customized units and specifically designed manufacturing cells. Optimization of assembly and training of staff requires a series of demo installations and excessive use of costly operational resources. In some cases, components are located at different sites, making the orchestration of the whole system even more difficult.

Virtual Reality (VR) collaboration environments offer a solution by enabling high fidelity testing and training of complex manufacturing systems. On the other hand, such platforms are difficult to implement in an engineering perspective, as they are required to provide reliable, standard interfaces towards both robotic components and human operators.

The VirCA (Virtual Collaboration Arena) platform is a software framework that supports various means of collaboration through the use of 3D augmented/virtual reality as a communication medium. VirCA offers functions for the high-level interoperability of heterogeneous components in a wide range of domains, spanning from research & development, through remote education to orchestration and management of industrial processes in manufacturing applications. This paper provides an overview of the industrial requirements behind high-fidelity virtual collaboration and demonstrates how the VirCA platform meets these requirements. Use cases are provided to illustrate the usability of the platform.

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1. Introduction

Robotics has grown into a mainstream industrial application. Today, flexible cells perform complex assembly tasks in a routinely fashion. New trends, such as cloud manufacturing, intelligent flexible production, and organic human–machine co-existence in factories, have led to a new wave of automation science and research. Industrial automation needs to establish new ways to exploit and integrate emerging technologies and further improve efficiency in a cost-effective manner.

The rapid evolution of overlapping technologies is introducing revolutionary paradigms in application level engineering. This effect is mainly supported by a growing Internet bandwidth and an increasing number of connected devices, resulting in the rise of Cloud Computing and Internet of Things (IoT) [1–3]. A similar rise in powerful and flexible Human–Machine Interfaces (HMI) can be observed, supported by the appearance of a wide range of display technologies (e.g., UHD TVs, Google glass, and Oculus Rift) as well as smart personal devices. As an indication of the synergies created by these convergent technologies, the resulting new research directions are often categorized as fundamentally belonging to the Future Internet research paradigm [4].

Future Internet means that new theoretical concepts are emerging not only in home and service applications [3,5,6], but also in industry-oriented Information and Communication Technologies (ICT) [2]. Development in the past few years has spiraled back to industrial practices, where analysis, decision making and intervention procedures rely on logically and/or spatially distributed services. As a result, problems in industrial engineering are no longer strictly confined to industrial locations, and a substantially more advanced infrastructural background is required to ensure the continued effectiveness of industrial production.

Only a decade ago, the field of industrial robotics was characterized by closed, proprietary software and controller systems, based on proprietary control algorithms and peripheral interfaces.

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All of these components were maintained by single manufacturers, as this approach was claimed to guarantee the security of their products [7]. Today, however, the infrastructural background of such systems is gradually becoming untenable—a fact that is demonstrated well by the appearance of cross-platform organizations, such as the *Open Source Robotics Foundation* and the *ROS-Industrial Consortium* [8,9]. ROS-Industrial aims to apply ROS (*Robot Operating System*[1]) in the traditional industry, allowing for the exploitation of the previously mentioned new paradigms. In Japan, AIST (the National Institute of Advanced Industrial Science and Technology[2]) has similar goals based on the Robotic Technology Component standard [10] and its OpenRTM-aist implementation [11].

As a continuation of these trends, we are currently witnessing another paradigm shift, where cutting-edge middleware technologies are gaining strong support from immersive 3D Virtual Reality (VR) platforms. Recent middleware systems include e.g., DDS [12–15], ROS [16–18] and RT-Middleware [11,19]. This growth of industrial virtualization is generating new directions in numerous research domains, such as

- Remote laboratories [20–22].
- Mixing virtual and physical realities [23–25].
- System of systems [26,27].
- Cyber-physical systems [28,29].
- Collaborative virtual commissioning of automation systems [25,30–32].
- Exploiting cloud computing in industrial/service robotics scenarios [33–37].
- Education in collaborative virtual environments (e-learning) [24,38].

The VirCA (Virtual Collaboration Arena)[3] framework is aimed at realizing the union of requirements within these research domains. VirCA implements a complex vision by adopting the shareable and fully customizable 3D virtual workspace as a central idea. This concept enables people who are not necessarily in the same location to collaboratively create ideas, and then design and implement them together in a shared virtual space. VirCA can be considered as a pilot solution that highlights several key tenets of the trend of *Future Internet* [39], and provides an effective means of collaboration in virtual spaces.

In this paper, we introduce a number of industry-related aspects of VirCA. Through our discussions, use case examples are presented to demonstrate the key concepts behind the system. The paper is structured as follows: Section 2 provides a general overview of VirCA. Section 3 gives an introduction to the industrial perspectives behind it. A more specific discussion is provided on high-level extensions that facilitate semantically informed task orchestration and communication in Section 4, as well as on the various industrial applications that have been supported by the VirCA system in the past, in Section 5.

2. The virtual collaboration arena

VirCA is a collaborative virtual reality platform that is developed and maintained by MTA SZTAKI (Institute for Computer Science and Control, Hungarian Academy of Sciences).[4] The authors of this paper affiliated with MTA SZTAKI are working directly on the core platform development, while other co-authors are involved in application design for the framework.

VirCA has a freeware license, and is available for download at its official website (http://www.virca3d.com). The platform runs on Windows PCs and supports various display systems ranging from a single LCD screen to immersive CAVEs or the Oculus Rift head-mounted display (Oculus VR Inc., Irvine, CA). Important specifics of VirCA are discussed in the following subsections.

2.1. Component-based architecture

VirCA is composed of a VR engine that provides the shared virtual environments, and a web-based interface, through which users can extend existing VR content and capabilities via customizable and interactive networked (i.e., external) applications. The networked extensibility of VirCA is provided through the Robotic Technology Component standard (often referred to as RT-Middleware or RTM for short [10]) through its open source implementation, OpenRTM-aist [11,19]. Although RTM was developed originally for the purpose of modular robot control software, it appropriately serves the goals of VirCA through underlying CORBA-based data-flow and Remote Procedure Call mechanisms [40].

The plug-in interfaces for VirCA are implemented as mutually provided and consumed RTM service ports on the core component (VirCA client). In VirCA terminology, the connected plugins are referred to as *Cyber Devices* or *CDs* for short. It is possible via the externally connected CDs to manipulate scenes (i.e., to add, delete, move and modify objects), acquire state information via getter functions, as well as receive notifications on various events—such as user actions and collisions— that can be handled in callback functions. Each CD may implement further RTM ports, or may act as a ROS gateway node that allows for the configuration of complex, heterogeneous component-based systems.

Fig. 1 shows the high-level structure of the framework and the relationships between system components. Through its architecture, VirCA supports the so-called "*knowledge plug-and-play*" paradigm, as various already existing hardware and software components (including those supporting and implementing robot systems, sensors, speech technology, machine vision, and semantic reasoning) can be integrated into VirCA-based applications. By exploiting the virtual sensor capabilities of the 3D engine, it also becomes possible to "virtualize" technologies that are either

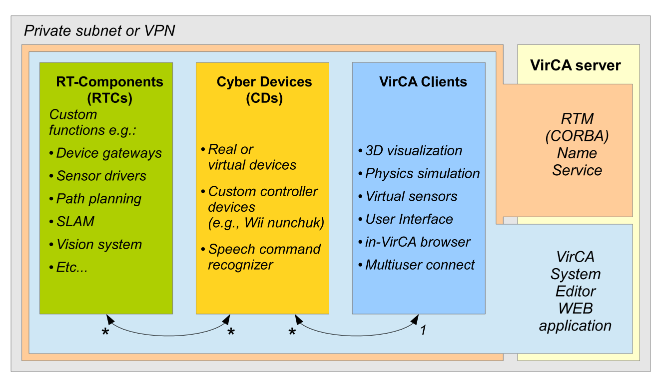

Fig. 1. Structure of the VirCA framework: the VirCA backend is composed of two server applications: the RTM name server and the VirCA system editor. Each component (VirCA clients, CDs and RTCs) appears as a set of CORBA objects in the naming service. The System Editor is responsible for handling data-flow (RTM Data Port) and Remote Procedure Call (RTM Service Port) connections according to the application scenario that is defined by the operators using the web front-end. In any given scenario, multiple VirCA clients can be used to realize the shared VR environment. Plug-in modules (CDs) are connected to one VirCA client, which will be the owner of the given CD. RTCs which do not implement a VirCA service port are responsible for specific functionalities and can be connected to each other and to multiple CDs depending on application-specific design considerations.

[1] www.ros.rog
[2] www.aist.go.jp
[3] http://www.virca3d.com
[4] http://www.sztaki.hu

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