Future Internet-based Collaboration in Factory Planning

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Abstract: As the design, development and execution of manufacturing processes continue to spread out across the world, globally distributed enterprises demand new paradigms. Distance collaboration tools are becoming increasingly important in order to maintain synergies between spatially distributed entities enabling effective cooperation over large distances. Virtual Reality (VR) technologies offer unique possibilities for the exchange of planning stages as well as for the identification and collective resolution of problems. This paper discusses the requirements of manufacturing engineers for distance collaboration tools and the challenges associated with the creation of such systems through a working prototype implemented in the VirCA NET framework. This pilot solution is a novel application in the field of VR-enhanced spatially distributed collaboration via shared virtual spaces using immersive visualization. Typical scenarios are provided to highlight the capabilities offered by VirCA NET. The paper identifies and classifies the challenges of distance collaboration from a cognitive infocommunications (CogInfoCom) perspective. The challenges are presented with respect to the theoretical background of CogInfoCom engines and channels emphasising the link between virtual collaboration and the aim of CogInfoCom.

Keywords: Future Internet; 3D Internet; Virtual reality; Remote collaboration; Factory design; Digital factory

1 Introduction

Globalized companies have to adapt continuously to variations in product life cycles, emerging product complexities, agile worldwide markets and supply networks [1]. The inclusion of multiple stakeholders to adaptation processes is crucial in maintaining sustainable factory life-cycles. Several divisions and employees must be involved, so that the effects of non-optimal planning can be alleviated and special planning expertise and professional knowledge can be exploited from many sources at the same time [2]. As spatially distributed entities become involved in this process, the task of achieving such goals is rendered increasingly complex [3, 4]. Especially in the case of multinational corporations, it is necessary to ensure the operation of multi-site manufacturing systems, and the use of appropriate collaborative VR supporting tools should ideally be considered [5]. Information technology within mechanical engineering – mainly expressed as part of the Digital Manufacturing approach in the past decade – has led to the creation of a wider set of software tools and technologies. The main objective of digital manufacturing is to master crucial challenges such as shorten design cycles, increasing product variants and complexity, fast changing market needs, etc. (for details see, e.g. [6]). The spatial distribution of planning participants, which is evolving today, even requires additional support for long-distance collaboration [7].

Although this field has been investigated from different points of view in the past decade, a comprehensive approach to tackling spatially distributed factory planning by means of immersive, collaborative Virtual Reality (VR) is still not available [3].

Cognitive infocommunications (CogInfoCom) is an emerging research paradigm which focuses on the merging process occurring between natural and artificial cognitive systems in modern ICT theories and applications alike [8, 9]. Inspired by CogInfoCom, results of the cognitive sciences – which investigate biological cognitive capabilities – are expected to converge towards ICT through modern applications [10].

In this paper, – extending and summarizing the previous works of the authors [11, 12] – the relevance of CogInfoCom for augmented/virtual collaboration is considered in terms of emerging demands coming from worldwide distributed manufacturing companies. The discussions are based on the Virtual Collaboration Arena (VirCA) framework and a recent extension to the system. The extension (referred to as VirCA NET from here on) allows users to view and collaborate through a shared virtual reality [13, 14]. Usually, CogInfoCom systems such as VirCA are based on technologies and components that are individually well-known to the wider community of engineers. However, the purpose of this paper is to show that the unique combination of these components gives rise to something that is more powerful than the sum of its parts: a system that strongly supports Future Internet research and encapsulates the philosophy behind CogInfoCom. At the same time, new perspectives are opened up and new design challenges are introduced, which will inevitably change the way we relate to our interactions with infocommunications devices.

The paper is organized as follows. Section 2 briefly introduces the VirCA NET platform. Section 3 gives a comprehensive overview of the collaborative processes in the field of Manufacturing Engineering, while focusing especially on factory planning and the supporting digital tools. Section 4 discusses the distance collaboration from the point of view of the end-user requirements, and provides example scenarios covering the main issues of the topic and identifying the key challenges. Following the general discussion, the pilot implementations of two scenarios are introduced and evaluated in terms of the previously identified requirements. A thorough discussion of the challenges from the CogInfoCom aspect is provided in Section 6. The final section concludes the paper.

2 Introduction to VirCA NET

VirCA (Virtual Collaboration Arena) [1] is a software platform — developed and maintained by MTA SZTAKI [2] — that supports various types of collaboration involving shared 3D virtual environments. VirCA consists of a 3D Virtual Reality core engine responsible to maintain and display the virtual environment where the collaboration takes place, and a web-based editor where the content and the actual operation of the virtual environment can be constructed from building blocks representing 3D objects and/or functionalities. This modular behaviour relies on the RT-Middleware (RTM) standard [15] and its open source implementation OpenRTM-aist [16, 17]. RTM is originally developed for networked robotic systems, however it serves well for a much wider field of applications [18].

As a framework, VirCA enables the developers to build customized and flexibly reconfigurable 3D environments and implements the paradigm of augmented virtuality by the synchronization of real world objects and processes with the virtual reality. In this way a virtual augmentation of real environments can be created. VirCA facilitates the so-called "Knowledge plug and play" since different alreadz existing hardware components (e.g. input devices, sensors, etc.) and computational technologies (e.g. speech synthesis and recognition, machine vision, semantic reasoning, etc.) can be integrated into the VirCA-based applications thanks to the RTM-based component interoperation. Exploiting the virtual sensoring capabilities of VirCA, it is possible to "virtualize" the not yet existing or unreasonably expensive technologies and investigate whether its addition to a physical system would bring the anticipated advantages.

These capabilities make VirCA appropriate to be a pilot framework for CogInfoCom applications and/or a candidate collaboration tool of the Future Internet.

The recently introduced VirCA NET extension [3] provides further enhancement en-

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[3] Integrated into VirCA version 0.2 and higher

abling the connection between multiple VirCA instances (possibly located far from each other) to share and manipulate 3D virtual environments collaboratively. The collaborative session is managed by a VirCA Master instance that serves as a hub in the synchronization of the distributed virtual world.

Let us define some VirCA related concepts which are often used within the remaining part of the paper:

Collaborator
: In the VirCA NET context, a Collaborator is understood as a person or a group of people who are interacting with the shared virtual reality at the same location. For example a team of 4 persons working in the CAVE system at the University of Kaiserslautern are considered as a single Collaborator in the VirCA NET session.

Master VirCA
: The VirCA instance to which all other VirCA instances are connected. Master VirCA acts as a hub for the interconnected VirCAs.

Slave VirCA
: A VirCA instance that is connected to the Master VirCA. Multiple slaves can be connected to a single master. Slave VirCA instances provide the cloned versions of the virtual space maintained by the master VirCA.

VirCA NET connection
: The communication channel between the master VirCA and a slave VirCA. This channel is responsible for the synchronization of the virtual space and for the transmission of user actions in order to ensure that all collaborators receive the same information from the shared virtual reality.

RT-Component or RTC for short
: A reusable software component that complies with the Robot Technology Component (RTC) Specification [15]. Different types of capabilities (e.g. machine vision, speech technologies, etc.) and hardware interfaces (e.g. sensors, actuators, complex devices) can be implemented in the form of RTCs. In the VirCA context, RTC is a reusable building block that does not directly appear in the virtual space but operates as background knowledge or as an interface between virtual and real-world objects.

Cyber Device or CD for short
: Cyber Devices are special types of RTCs which appear as 3D objects in the shared virtual space. For example, machine tools, robots and other visually instantiated parts of a manufacturing system are implemented as Cyber Devices.

Input Device
: Input devices are software components interfacing different UI hardware to VirCA (e.g. pointing devices, MS Kinect, etc.).

System Editor

The VirCA System Editor is a web application for the management of collaboration sessions. Collaborators can build systems from Input Devices, RTCs and CDs as building blocks.

3 Manufacturing Engineering Review

3.1 Manufacturing planning as collaborative process

The overall system complexity faced by manufacturing companies is continuously rising. The ability to react to changes in globalized, uncertain markets within short periods of time requires sophisticated design, manufacturing and business processes. To handle this complexity with success, manufacturing companies not only have to design flexible technological solutions and products, but also have to focus increasingly on developing and managing complex socio-technical systems [19]. This means that modern products and manufacturing systems involve not only complex mechanical and electrical components, but also include software systems, control modules and advanced user-machine interfaces. To achieve real-time feedback, such systems are and will be connected to the World Wide Web and the Internet of Things, which further increases complexity [20].

Complex systems, such as a manufacturing system, are characterized by multi-dimensional interrelations between a large number of affected participants, elements and agents, which interact with each other as well as their environment [21]. When such systems are re-configured and evolved to new processes, it is necessary to consider the entire life-cycle of the system as a whole. Hence, a manufacturing system must be understood as a comprehensive product that needs to be designed, manufactured and assembled with a holistic view in mind [22]. Typical for such wide and complex problem definitions is the requested interaction between various divisions such as those dealing with engineering, operations management, logistics and IT [23]. The inclusion of a number of different planning fields and specialists is one of the most crucial points of current factory planning projects. Interdependencies must be respected; therefore the participation of employees from several divisions is recommended [2, 24].

To detail out the collaborative aspect of such team-oriented problem solving environments, [25] introduced a formal definition of collaborative engineering as a "socio-technical engineering discipline, which facilitates the communal establishment of technical agreements among a team of interdisciplinary stakeholders, who work jointly towards a common goal with limited resources or conflicting interests". Manufacturing planning in this sense is a task that requires a high level of collaboration. Only comprehensive and efficient communication can result in short planning cycles, improved planning quality and reduced effort during factory planning projects [26]. Sharing experience and knowledge between several co-designers is therefore a key requirement for a successful factory planning process [27].

3.2 Digital tools supporting collaborative manufacturing planning

In the range of manufacturing planning, industrial companies are using a wide set of software tools to achieve improvements of planning quality and reduction of planning time [28]. Nevertheless, the exchange of planning states and results in industrial projects is often realized with only little support of digital collaborative tools. Even if digital data is provided for each separate planning aspect, approval of comprehensive solutions and decision-making is still paper-based. This is grounded in the fact that visual analytic tools are typically insufficient for collaborative work. They are designed for single user operation on standard desktop systems [29]. Support of whole planning teams, involving several experts with differing technical skills out of different domains is not guaranteed [30]. Even the so called “collaborative solutions” which are available at the market do not fully cover the challenges of collaborative engineering. One open point that is crucial, but not yet covered is that stakeholders perceive problems differently, due to their expertise and personal objectives [25].

To overcome such problems VR is proposed as a beneficial tool to consider different viewpoints and personal objectives of several involved planning specialists and their relationships [31]. The fact that every planning participant has a subjective perception of the common model, which is shaped by his or her own experience and professional know-how adds additional value to VR supported manufacturing planning. This makes VR an ideal platform to foster the cooperation between different technical specialists, reducing interface problems and increasing planning quality [32].

Besides these considerations, the upcoming worldwide spatially distribution of planning participants requires also for collaborative support over long-distance [7]. Tailoring of factories and organizational structures to fulfil the needs of worldwide markets requires the consideration of specific local constraints, cultural diversities and existing factory conditions. To merge distributed expertise for optimised planning results, the support of factory planning by distance collaboration tools is proposed [3, 4].

In general three main challenges could be identified, which must be addressed by distance collaboration tools [25].

- The problems to be solved must be defined in a clear way. The problem definition must be fully shared between all planning participants [25].
- All planning participants need access to the whole set of information behind the problem. There must be a shared understanding of the problem, highlighting all aspects with an equal priority [33].
- The rules for decision-making must be clear for all the stakeholders [34].

VirCA NET will therefore be a contribution and help bringing planning participants together to one shared virtual environment and one shared problem understanding.

4 Distance Collaboration supporting Manufacturing Engineering

In this section, we outline the requirements against the effective collaboration from the viewpoint of the manufacturing engineering and sketch two related collaborative scenarios of different complexity. The first scenario is currently implemented using VirCA NET, while the second scenario is more futuristic and has yet to be implemented.

4.1 Requirements from Manufacturing Engineering perspective

The human factory plays a key role for reconfiguring and optimizing manufacturing systems [35]. To support multi-national corporations, operating multi-site manufacturing systems distance collaboration VR systems should be taken into account for configuring and reconfiguring manufacturing systems. These processes require features for supporting multi stakeholder decision-making and joint discussion on planning results [5, 36]. The extension of communication and cooperation beyond organizational and divisional boundaries will speed up planning processes and reduce the complexity during work. This can be realized by interconnected but spatially distributed VR systems [7]. Because VR systems are identified as suitable tools allowing an intutitive and fast identification with the planned factory, even for participants which are normally uncommon with specialised digital planning tools [37].

The idea of collaborative engineering is to support engineering tasks which are intrinsically human-centers by socio-technical means, to pursue their initial character [25]. One core objective is to support knowledge transfer between remote partners in a social oriented way. In detail, knowledge related to personal skills, that cannot be formulized easily because of its tacit nature must be considred. This knowledge can hardly transfered without direct personal interaction [38]. Even if some projects have been initialized, a comprehensive approach to support spatially distributed manufacturing planning by means of immersive, collaborative VR is still not available [3]. To develop a distance collaboration system in a target driven way, requirements coming from manufacturing planning must be identified. Following SMPAROUNIS' approach, the key features are identified as [39]:

- quick and easy data storage and sharing
- synchronous and asynchronous communication

- cooperation in designing and manipulating of geometrical models
- multi-user visualization and interaction
- decision support

Not to cope with all aspects of manufacturing planning at once, the scope of this article will be focused on factory planning in detail. Factory planning as one key activity during manufacturing planning is identified as one potential domain to be supported by collaborative VR tools in a beneficial way [40]. The key tasks during factory planning, which need to be enhanced by distance collaboration tools are summarized as follows: designing of the factory, validation of planning stages and overview of optimization in the planned and/or existing manufacturing system [40].

4.2 Typical collaborative way of working

Out of the preliminary considerations three main requirements have been derived, that need to be integrated into a VR distance collaboration tool supporting factory planning as:

- shared model visualization
- model interaction
- user interaction, knowledge exchange

Based on a digital factory model the future shop floor gets designed, analysed and later on discussed within a collaborative session. The 3D model which is used for this purpose usually consists of the factory layout (geometric descriptions of the shop floor), its direct environment and additional manufacturing related objects. Information regarding the operation of the manufacturing system, such as process descriptions for example, enrich the factory model [41]. Sharing the digital factory model among all involved planning participants and allowing a comprehensive view for all users is a key requirement of a distance collaboration tool [3]. By implementing a joint virtual environment, VirCA NET provides such an common workspcae which is identical at all remote sites.

As well as the shared visualization, interactive means have to be implemented into VirCA NET. Comprehensing of manufacturing processes and analyzis of simulation results is facilitated by bidirectional interaction between the virtual model and the user. Collaborative features for interaction between users and virtual agents have to be developed as well as interconnection means between several virtual agents.

Since the major target of distance collaborative sessions in factory planning is not to design a new layout or new product, the analyzis of proposed layouts and problem solving afterwards in a cooperatively way is central. Hence, features supporting the cognitive tasks of engineers and other stakeholders must be provided by distance collaboration tool; social interaction beyond the data visualization must be enabled [42, 43]. In detail tacit knowledge which is hardly transferable without direct personal interaction, must be considered [38]. Therefore the capability to achieve and support user-user interaction must be integrated into the VirCA NET.

The core idea while supporting factory planning is to adopt an established (everyday) working situation, in detail in-place, domain-overlapping factory planning into a distributed, virtual environment [44]. Worldwide distributed employees should work together as if they were in-place and use their well-known problem solving strategies. The shared digital model should allow a simultaneous analyzis, while users are free in navigation and can investigate the model on their own purpose. Due to the interconnected VR systems users will have the appearance as if they were co-located, because the VR systems will react as one distributed unit. By the extension of the VR setup with social user-user interaction means the perception of direct and "real" collaboration will be fully covered.

Because known working situations can be correlated in a direct way to this new way of cooperation, the results which are based on the discussions among the digital model, should be close to the optimizations developed in co-located sessions. The approach is beneficially integrated in existing VR-enhanced work-flows of factory planners. Users are enabled to use established processes and known problem solving strategies, even extended by the distance collaborative aspect.

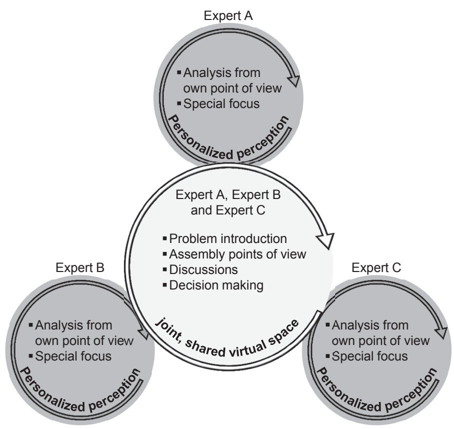

Figure 1
Workflow during collaborative VR sessions

Figure 1 is illustrating the general concept of the proposed collaborative VR sessions operated by VirCA NET. A joint, shared virtual environment is provided to which all planning participants access in the same way. There, several experts can introduce problems out of their own profession to the other involved participants. The discussion within the planning team is the main task in this shared space. In the collaborative discussion solutions will be developed and decisions, based on the entire expertise of all stakeholders will be made. In addition to this shared space, the personal analysis for each participants is provided by VirCA NET as well. Due to the differing professional expertise and experience of the stakeholders their perception of the factory layout problem will differ. Due to the free navigation and interaction capabilities of VirCA NET they are allowed to investigate the factory regarding their professional interest and figure out exactly the details they need for their personal analysis. Due to this dualism of personal analysis and joint problem solving a comprehensive solution for the factory layout problem should be achieved in a beneficial way, even if planning participants are spread all over the world. To prove this concept idea two scenarios dealing with factory planning have been developed and executed. The following sections will introduce the performed test in detail.

4.3 Collaborative design of automatic workpiece feeding

The objective of this basic scenario is to design an automatic workpiece feeding process for a lathe in cooperation with an industrial robot, which are both not yet physically available in the shop floor. Therefore, the position of the lathe and the robot need to be defined in an existing shop floor. Three remote connected sites are involved representing each a different planning participant. Kaiserslautern (Germany) is representing the factory where the shop floor to be adapted is located. Budapest (Hungary) is representing an division specialised in robot control and Kosice (Slovakia) represents the head office of the fictive company where the central industrial engineering department providing knowledge among the operation and implementation of the lathe is located. Each of the locations VR-systems are connected to VirCA NET, and thus are able to interact and collaborate using the hardware and software components running at different locations (figure 2).

In the collaborative scenario the industrial robot (physically located in Budapest) is connected to VirCA NET. The virtual representations of the robot can be controlled from all planning participants using VirCA NET (the indirect control of the physical robot is also provided through the manipluation of the digital model). The objective of the collaborative session is to optimize the position of the lathe and the robot in a way that the workpiece feeding process can be guaranteed. They have to respect constraints occurring out of the already existing shop floor layout and special basic conditions regarding the knowledge and know-how of the three departments concurrently. The collaborative VR system must therefore provide the capability to involve intrinsic know-how and personal skills of the planning participants to reach the complex objectives of the factory planning project. Every Participants are allowed to change the layout of the virtual shop floor (e.g. position of the robot, position of the lathe) and give commands to the robot (e.g. take workpiece, move workpiece to the machine tool). By doing this, one participant can propose a layout for the lathe and the robot that fits best to his personal targets (e.g., insert the machine tool and the robot without major variance to the existing layout). Afterwards each participant can

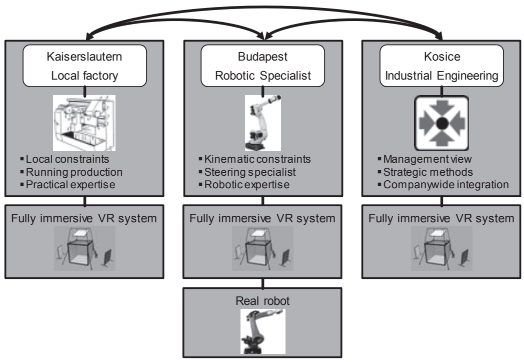

Figure 2
Schematic setup of the basic scenario

investigate the proposed solution according his own point of view and recommend changes (figure 3). This process ensures the achievement of the best solution for each point of view without neglecting requirements from other departments.

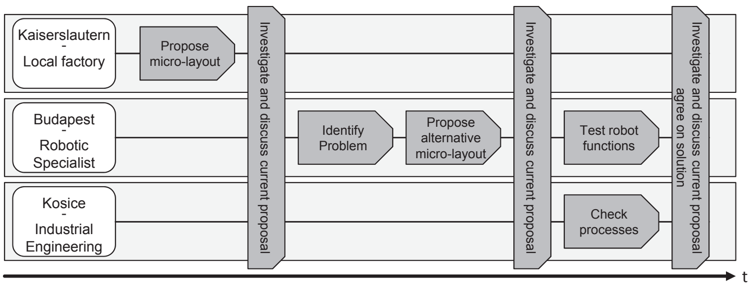

Figure 3
Example workflow for the collaborative design of automatic workpiece feeding scenario

4.4 Collaborative shop floor layout design

The target of this more complex scenario is to allow participants to design the complete layout of an industrial shop floor collaboratively. The scenario of the previous subsection is a step in this direction, but there are additional challenges when extending the example to a fully detailed industrial environment. Geometric information and ad-hoc impressions of the participants are often not enough for understanding complex manufacturing processes. Participants need to access additional information sources as for example simulation results, process plans and other metadata during a collaborative session to completely cover the impacts of changes to the shop floor layout. Also technical advancements are necessary in order to enable truly flexible collaboration. For designing a complete shop floor layout participants are allowed to change the position of all potentially movable machines and other infrastructural elements (e.g., shelves for storing tools and workpieces, pathways for mobile robots and workers, etc.). Further simulations of manufacturing processes and material flows should be accessible during the collaborative session, to estimate the impact of changes and investigate weak points. So the system must take into consideration a variety of constraints while the shop floor is being edited:

- the availability of supply sources for the industrial machines to be able to operate (e.g. power, water etc.)
- dependencies among machines and other infrastructure, dictating that they be placed in close proximity or far away from one another
- the workspace of various robots in order to ensure a safe working environment
- the manufacturing process itself and the material flow through the shop floor
- connections to neighboring workstations and subsequent working areas
- connections to the logistic system in general

Additionally to these hard facts which are extending the sheer geometric representation of the shop floor layout by overlaying information, also the support of soft skills and working methods need to be considered by the complex scenario. Therefore, features must be implemented and tested among their impact factor. To communicate not only the intermediate results to planning participants, the adaptation process itself need to be visualized and transferred to the remote partners. Voice communication and intelligent control protocols to avoid babylonian speech chaos need to be introduced. Highlighting objects and transmission of virtual pointers are only two potential feature which can underline the focus on the object or point of interest.

4.5 Challenges associated with the scenarios

The scenarios serve as typical examples for factory planning problems, they cover the key points and illustrate typical tasks which are executed during factory planning. These crucial challenges mus be considered while designing VirCA NET for factory planning purposes and executing the scenarios. Thereby the detailed characteristics of the key challenges are slightly differing due to distinct factory planning projects, but their main characteristics can be identified in advance. *Shared model visualization*, *model interaction* and *means for user interaction* are identified as three main challenges.

When using full immersive VR systems, the shared model visualization is a key requirement for distance collaboration tools. Thus VirCa NET is allowing a consistent visualization of a joint digital model at all connected sites, independent which users is in possession of the model parts. In the range of factory planning this gets important to allow all users the simultaneous access to the current planning results in a equal way.

The user-machine interaction is a second major challenge. Since the reorganisation of factory elements is a basic operation when optimizing the shop floor layout, the interaction with the factory model must be enabled for each user. To express ideas and emphasize layout proposals, adaptation of the layout must be allowed for all users. The interaction with intelligent agents such as virtual robots is another example for user-machine interaction. Predefined model behaviour, like material flow simulation is facilitating the understanding of the manufacturing processes.

As third key-challenge the user-user interaction is identified. A natural interaction on a social level must be provided.Even if ideas can be transferred via the reorganization of the layout related models, the verbal and non-verbal expression of ideas is a key element for introducing and solving problems.

5 Implementation details

This section gives a technical insight into the VirCA-based implementation of the previously discussed automatic workpiece feeding design scenario. Three VirCA instances are involved in the collaborative session according to the three locations (Figure 4). The procurer company (LOCATION 1) hosts the master VirCA and the cell controller Cyber Device, while the robot and machine tool responsible persons (LOCATION 2 and LOCATION 3) are running the slave VirCA instances and the components related to the devices to be tested.

Each collaborators have a special expertise and role in the design and testing procedure and accordingly, the different software components are managed by the stakeholder who is responsible for the given physical device. In the concrete example, the robot integrator operates a Robot Cyber Device and a Robot RTC while the machine tool specialist provides the machine tool Cyber Device and the corresponding RTCs. The role of the Cyber Devices is the visual representation of the real or pure virtual entities, while the RTCs establish interfaces between the virtual and real devices allowing access to the device's functions e.g. moving commands of the robot arm and the so-called M-code functions of the machine tools.

Figure 5 illustrates the shared scene from the viewpoint of a collaborator. This screen-shot displays the virtual shop floor where the robot application should be placed in accordance with the decision of the collaborators.

To support the effective interaction between the stakeholders, VirCA NET provides various visualization features for example, within the virtual scene, collaborators can see each other as a symbolic human head representing the gaze direction and can see the 3D pointer of each other. Voice and text based communication is also possible using appropriate software tools (e.g. Skype) parallel to the VirCA session.

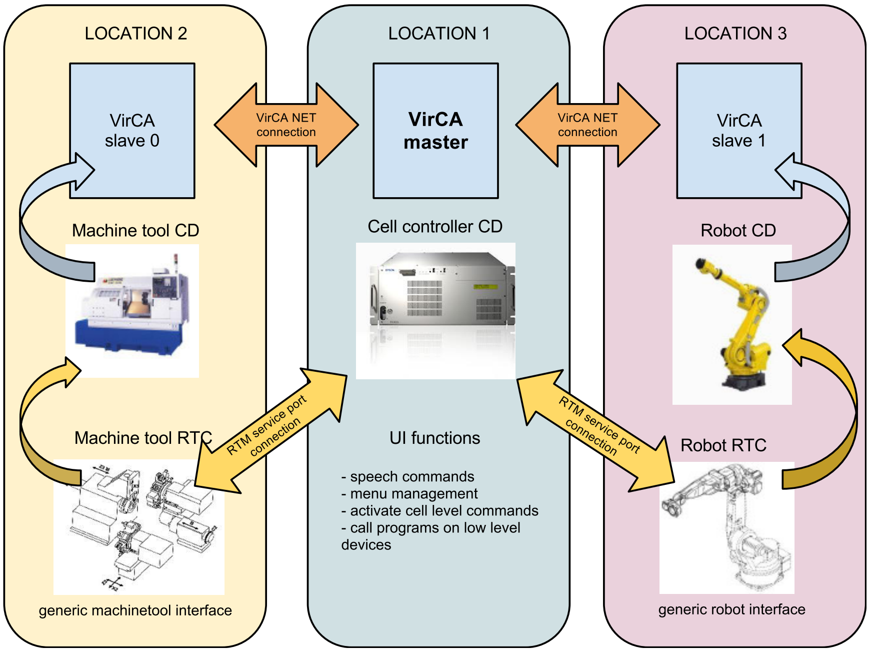

Figure 4
The VirCA NET structure of the proposed collaborative planning session

The integration of such features in VirCA will be the target of further development.

An other crucial point is the way of manipulation of virtual objects. Since users should not be burdened with having to wear complicated haptic devices, CogInfo-Com methods takes place that could provide unencumbered yet situation aware user experience [45].

Because of its extensible modular structure, the proposed scenario serves as good basis for the experimental investigation of different interaction methods. The working prototype of this scenario has been successfully demonstrated in pubic events and conferences [46].

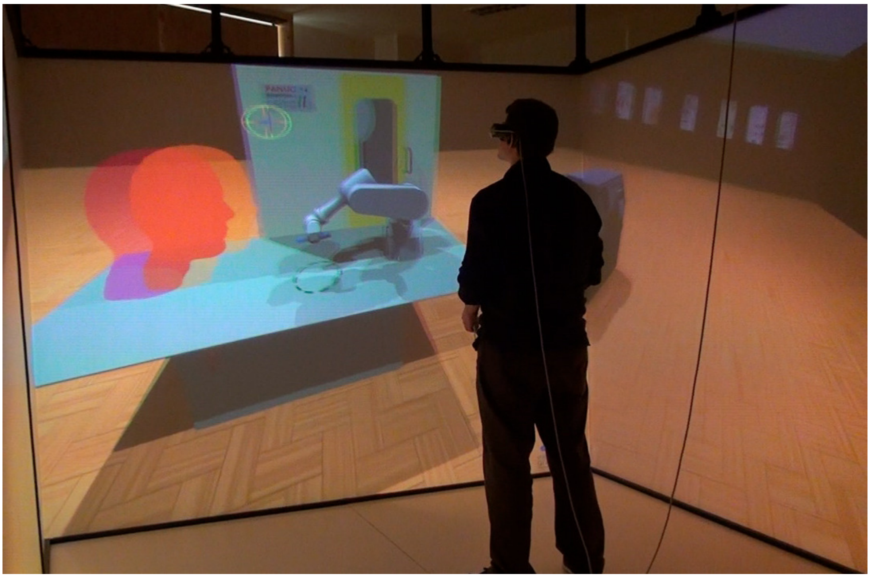

Figure 5
The design session from the viewpoint of a collaborator using immersive projection system

6 Challenges During Collaboration from a CogInfoCom Perspective

The challenges discussed earlier bring to light various issues from two points of view:

- design questions related to supporting collaboration, e.g. in terms of triggering signals that encourage communication and collaboration in the first place
- design question related to supporting feedback through multi-sensory channels

The difficulties associated with these points of view are considered in the remainder of this section.

6.1 Issues related to supporting collaboration

Setting guidelines for the dynamic characteristics of the communication process between systems and users is a key challenge [47]. VirCA is naturally affected by such considerations, given the abundance of interaction modes which can be used by users to communicate with various objects and computational processes.

An important aspect of the challenges which pertain to supporting collaboration is the question of what information VirCA should communicate and when. Considering an industrial environment, for example, the question of when and how a robot communicates its internal state to users is a crucial one. A key concept related to this issue is the concept of CogInfoCom triggers, which can be designed with a number of different characteristics depending on the level of volition and directness they represent in communication [48].

Related to the above, the following questions may arise with respect to the collaborative planning scenario:

- **Visualization aspects**: should each user be notified of possible discrepancies within the visualization of the shared model? For example, if a given region on the shop floor is being manipulated by a user while other users are working in different areas, the set of dependencies which are influenced by those actions may be important to the entire community; thus, it can be argued that the user should be notified. On the other hand, if only a single user is working at a given time, notifications might be spared and/or postponed to a later time, as the user's actions will not directly contradict other users' actions.
- **Feedback aspects**: during interactions between users and the system, how should volition and directness of communication be treated? How can indirect communication be complemented so that users can obtain enough information reflecting the context of interaction?
- **User-user interaction**: how can both contextual communication (e.g., on users' relative locations) and flexible user-to-user communication be supported? For example, how can a user obtain information on how busy other users are at any given time, so as to be able to refrain from disturbing others?

6.2 Issues related to CogInfoCom channels

CogInfoCom channels are multi-sensory signals that reflect information on semantic concepts [47]. A key issue related to CogInfoCom channels is that the cognitive capabilities available to users can be utilized to different extents depending on how the channels are designed. Hence, the following questions may arise:

- **Visualization aspects**: how should users be notified of possible discrepancies within the shared model? If a given area is under active manipulation, what kinds of visual cues should be used? What cues can be used to signal the level of difficulty being tackled by other users?
- **Feedback aspects**: how should the physical parameters of objects be represented? How should concurrency among user actions be handled through feedback?

- **User-user interaction**: how should users be allowed to influence what part of their actions should be communicated to others using the system?

Conclusion

In this paper, the Virtual Reality based multi-user remote collaboration was studied through realistic use-case scenarios in the field of manufacturing system design. The requirements against the collaboration system were identified from the viewpoint of manufacturing engineers as end-users. Furthermore, some of the challenges which arise during augmented/virtual collaboration has been identified and classified from the perspectives of CogInfoCom. The basis of our discussions was taken from the VirCA NET extension built on the Virtual Collaboration Arena (VirCA) developed at MTA SZTAKI. We demonstrated how VirCA and VirCA NET belong to the CogInfoCom paradigm and how they are related to the Future Internet by identifying key features of infocommunication in collaborative scenarios related to production system design. Via the presented use-case study it is shown that the VirCA NET approach can be beneficially utilized in the investigated scenarios wherein the component selection, the shop floor layout design and process simulation/evaluation are integrated in one versatile collaboration system. Based on the features of VirCA NET and the specifics of the scenarios, we drew a list of challenges — some of which are already solved by the system to some extent and some of which remain to be solved in future work. The challenges were presented in relation to the theoretical aspects of CogInfoCom engines and CogInfoCom channels in order to further strengthen the link between augmented/virtual collaboration and the goals of CogInfoCom.

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