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INTEGRATION OF VIRTUAL ROBOTS WITH PHYSICAL ROBOTS BASED ON WIRELESS COMMUNICATIONS

Aurel FRATU[1,*]

[1)] Prof., PhD, Dept. of Automatics and Technology of Information, "Transilvania" University of Brasov, Brasov, Romania

Abstract: *In this paper, we propose the idea of integration of virtual robots prototypes with physical robots, based on wireless communications. The goal of this paper is to discuss how the virtual prototyping can be effectively employed for design challenges dealing with non-material concepts, in form of virtual prototypes, that permits to examine on a computer monitor, the behavior of the physical robots using her virtual prototype to predictive programming idea. Virtual prototypes as non-material systems can communicate wirelessly with physical robots by transferring the virtual path of virtual robot prototypes in domains of the work space of the physical robots. In this paper we discuss the requirements and opportunities of such an approach.*

Key words: *virtual prototyping, virtual robot, wireless communication, wireless robots networks, robot programming.*

1. INTRODUCTION

Virtual prototyping is an aspect of information technology that is considered to be an effective technique to create the conceptual models that become visible by means of simulation and visualization. Virtual prototypes enable end- users to experience first hand whether the innovative concepts fulfill their needs. With this conceptual model we attempt to make possible new robots programming philosophy.

Prototypes are an important element of the design thinking process. Different prototypes can provide different representations of design and specific characteristics of each prototype have a major impact on the way designers understand and react on the inventive design ideas. Additionally, virtual prototypes can help to establish a common understanding between design thinkers and end users as well as between design thinkers themselves. Virtual prototyping typically aims at creating concrete representations of design ideas. Depending on how well end-users can experience and perceive a prototype, they are able to judge and evaluate the design idea or even the rationale behind it.

Current virtual prototyping practices are based on development software systems focused on the graphical user interfaces (GUI). However, these prototypes usually represent an individual and isolated end-user’s perspective on the system to create. Therefore, such prototypes are not suitable to obtain feedback about the underlying concepts of how activities are executed or how an innovative software solution could support them.

Thus, while the end-users can judge whether the system is built right, i.e., usable for them, they can hardly answer whether the right system is built, i.e., suitable for the task it was designed for, since only a holistic view of all the perspectives could answer this question.

2. PHYSICAL ROBOT PROGRAMMING BASED ON VIRTUAL MODEL

We present a description of the theoretical aspects of the physical robot motion programming using a virtual model. The advantages of such approach as an alternative to the classical methods (e.g. vision guided trajectory imitation [5]) are on-line adaptation to the motion of the virtual prototype. A solution to the above problem is to construct a virtual prototype model and to transfer the virtual trajectory by interacting with the physical robot model.

This approach also estimates the response of each action through a predictive motion virtual model to more accurately predict theirs consequences. Our approach represents a technique for generating animated navigation offline, by pre-computing layered trajectories for a physical robot. Pre-computed trajectories sets come from the virtual prototype and are used to autonomously guide the robot. Designing a virtual model would be an option; however, the behavior of the robots is very difficult to model. Moreover, the use of system knowledge is contrary to our research aim. Therefore we focus on creating a virtual prototype model from experimental data obtained from the physical robot model.

Users interact with the simulation environment through the visualization. This includes, but it is not limited to computer screen. Optimization of the real robots behavior is performed in the low dimensional virtual space using the virtual robot prototypes. In the virtual space one simulate even the intersecting of the virtual robot and its environment. The intersecting of two virtual objects is possible in the virtual world, where the

[*] Corresponding author: Str. Mihai Viteazu nr. 5, Corp V, et III, 500174, Jud. Brașov, Romania
Tel.: +40 268 418 836,
E-mail addresses: *fratu@unitbv.ro* (A. Fratu).

virtual objects can be even intersected and there is no risk to be destroyed [4].

The visualization provides an interface to develop interactive implementations based on simulated behavior of the model. In our work we assume that learning of the deterministic part for description motion dynamics should be sufficient to design the corresponding robot control.

We particularly refer to the ability of the system to react to changes in the environment that are reflected by motion parameters, such as a desired target position and motion duration. Therefore, the system is able to manage with uncertainties in the position of a manipulated object, duration of motion, and structure limitation (e.g., joint velocity and torque limits) [3].The proposed method aims at adapting to spatial and temporal perturbations which are externally-generated. This aspect will be investigated in our future works.

It is easy to recuperate kinematic information from virtual robot motion, using for example motion capture [1]. Imitating the motion with stable robot dynamics is a challenging research problem [8].

In this paper, we propose a predictive control structure for physical robots that uses capture data from their virtual prototypes and transfer them -via communication wireless- to track the motion in the real space.

We will demonstrate the tracking ability of the proposed controller with dynamics simulation that takes into account joint velocity and torque limits. We apply the controller to tracking motion capture clip to preserve the original behavior of virtual robot.

First, a motion capture system transforms Cartesian position of virtual robot structure to virtual joint angles based on kinematic model. Then, the joint angles are converted in binary words and transferred to real robot using a wireless communications. We employ the control loops structure to establish relationships between the virtual and real robot control systems. We present results demonstrating that the proposed approach allows a real robot to learn how to move based exclusively on virtual robot motion capture, viewed as predictive control strategy.

3. WIRELESS COMMUNICATIONS BETWEEN VIRTUAL ROBOTS AND PHYSICAL ROBOTS

The availability of low power, reliable wireless communications platforms that can be link the physical robot with her virtual prototype is an attractive proposition. This paper address both the potential for new applications of the virtual prototypes and the challenges that currently inhibit more common integration of wireless communications with robot-agents and intelligent devices. Key issues are identified and strategies for closer integration of robots' programming and wireless communications systems discussed.

Rapid developments in wireless communications are opening up opportunities for new ways to perform many types of applications that up to now have been restricted in scope due to the need to have access to centralized facilities. It facilitates communication between different entities during the early design process, and also provides quality illustrations that help implementation the design or program.

By moving a properly scaled robot through the facility, we can ensure that controls and work can be reached comfortably and safely. This technique was proposed in robot programming by path optimization, using her virtual prototype to predictive programming of the physical robot.

In parallel of the robots' development, the area of wireless communications has also been evolving towards devices that are increasingly smaller and capable of long-term operation.

These devices, known as an intelligent interface offer features like ad hoc networking, wireless communications, signal acquisition and processing.

The integration of sensing and wireless networking capabilities provides the basic building block of wireless robots control concept, which envisages the autonomous working collaboratively of the physical robot with her virtual prototype to accomplish a specific target task. In its ultimate manifestation, this happens at 'internet-scale' with access points functioning as nodes in local-area networks that are themselves linked into wide-area networks, through existing communications infrastructure.

However, despite the obvious needs and opportunities that exist in areas like mobile robots programming and monitoring, integration of virtual robots with physical robots based on wireless communications has not really happened.

It is now clear that without the capability of long-term (years) autonomous operation, even rather modest deployments are not feasible. Not surprisingly, significant effort has been directed at developing routes to enable the robots' cooperation in terms of save operate in a changing environment. Interest is growing rapidly, and coupled with the importance of mobile robots' control, it is not surprising that large-scale projects that seek to develop distributed networks for robots monitoring have begun to appear,

3.1. Wireless access point

Conventional Wi-Fi networks are typically based on the presence of controller devices known as wireless access points. These devices normally combine three primary functions: physical support for wireless and wired networking, bridging and routing between devices on the network, and service provisioning to add and remove devices from the network. The remove devices in our application are the controllers dedicated for each physical joints robot arm.

Wireless access point technique is applied to typical deployments in which data is being transferred between two endpoints of which at least one is typically connected to a wired infrastructure and the other endpoint is connected to an infrastructure via a wireless link. With the creation of the wireless Access Point (AP), network users are now able to add devices that access the network with few or no cables. An AP normally connects directly to a wired Ethernet connection and the AP then provides wireless connections using radio frequency links for other devices to utilize that wired connection. Most APs support the connection of multiple wireless devices to one wired connection. Modern APs are built to support a standard for sending and receiving data using these radio frequencies.

3.2 Synchronizing of the behavior of the physical robot agent with her virtual prototype

Designers and manufacturers of robotic systems incorporate radio communication – including wave propagation, antennas, transmitters, receivers, short-range radio systems – to assure save-communication between virtual robot agent and physical robot agent.

One can add a wireless interface just for wires eliminate, on an existing wired system. To adapt a wireless subsystem is easy to integrate electrically into robotic systems. It is for these adapters of wireless subsystems are aimed at what are generally defined as short-range wireless applications. Some information about is given below with special reference to short-range applications.

Short Range Devices (SRD) are radio devices that offer a low risk of interference with other radio services, usually because their transmitted power, and hence their range, is low. The definition 'Short Range Device' may be applied to many different types of wireless equipment, including remote control.

Dedicated Short-Range Communications (DSRC) provides communications between the virtual robot agents and the physical robot agents in specific locations.

A new direction in short-range applications is about to appear in the form of high-rate data communication devices for distances of several meters. Short-range devices are often used to replace hard wiring, so when similar performance is expected, the limitations of radio propagation compared to wires must be accounted for in each application.

The radio channel for short-range applications is short, and for a large part the equipment is used indoors. Practically all short range devices have built-in antennas, so their transmission lines are relatively short and simple.

The interface between the transmitter, attached to virtual robot agent and the receiver attached to physical robot agent and therefore is antenna, which is a deciding factor in the performance of a radio (wireless) communication system. The principal properties of antennas-directivity, gain, and radiation resistance-are the same whether referred to as transmitters or receivers. Computer accessories send continuous digital data over the short range link. These data are organized according to protocols that include sophisticated error detection and correction techniques.

4. MULTIPLE ACCESS AND MULTIPLEXING FOR JOINT DATA

Wireless communication systems are typically designed with the intention that many robotic agent users will share the available bandwidth, thus requiring many separate communication links to be established. In order for a wireless system to share resources among robotic agent users without interference, multiple access and multiplexing techniques are used.

Multiple access is the ability of a wireless system to allow multiple robotic agent users to share the same communication capacity with minimal interference from other users. Multiple access refers to multiple transmitters sending information to one or more receivers.

Multiplexing refers to a single transmitter sending information to one or more robotic agent receivers. Multiplexing is the process of a single user combining a number of signals into one signal, so that it can be transmitted to other robotic agent user over a single radio channel. Multiplexing can be done at base band or at radio frequency. Often multiplexing will involve combining different types of traffic, including video and data.

There are three basic multiple access techniques (see reference [13]). In Frequency Distribution Multiple Access (FDMA) all users share the available bandwidth at the same time, but each user transmits at a unique allocated frequency and within an allocated bandwidth.

In Time Distribution Multiple Access (TDMA) each user is allocated a unique time slot for transmission, but all users transmit at the same frequency.

In Code Distribution Multiple Access (CDMA) each user transmits on the same frequency and at the same time. Each user transmits pseudo randomly coded spread spectrum signals that can be separated at the receiver by correlation with the known transmitted code.

Similarly, there are three basic multiplexing techniques, including Frequency Distribution Multiplexing (FDM), Time Distribution Multiplexing (TDM) and Code Distribution Multiplexing (CDM). The fundamental properties of the basic multiplexing techniques are the same as the corresponding multiple access schemes.

All of these communicating techniques are useful for communication between the robotic virtual agents and robotic physical agents.

4.1. Time Distribution Multiple Access (TDMA)

TDMA systems divide the entire transmission interval into time slots, and in each slot only one user-joint is allowed to either transmit or receive a breakage of data. All transmitter sending transmit at the same frequency. Typically, each user-joint is allowed to use a large part of the available bandwidth at one time, and thus TDMA systems are generally considered wideband communication systems.

Guard times are provided between user bursts so that collisions are avoided. Longer guard times are beneficial to avoid collisions; however, more potential user-joint time is wasted. Users must transmit their burst at precisely the correct time so that the burst is located in the correct position within the TDMA frame. This requires all users to have very precise timing synchronization for both entry into the TDMA network as well as maintaining correct burst timing after network entry.

4.2 Frequency Division Multiple Access (FDMA)

In FDMA systems each user-joint is allocated a unique frequency band or channel for transmission. This allows all users to transmit at the same time. If a user is inactive and has nothing to transmit, no other user can use the bandwidth and thus resources are wasted. FDMA is typically implemented in narrowband communication systems.

Guard bands are provided between user channels and are essential in FDMA systems by allowing receive filters to select individual user channels without excessive interference from other users.

A special case of FDMA that is highly bandwidth efficient is Orthogonal Frequency Division Multiple Access (OFDMA). In OFDMA the users are assigned orthogonal sub carriers. OFDMA is currently being used or considered for various standards including IEEE 802.16. FDMA typically applies to radio carrier, which is more often described by frequency.

4.3. Code Division Multiple Access (CDMA)

CDMA systems uses expand spectrum techniques to allow users to occupy all of the available channel bandwidth at the same time and at the same frequency. CDMA is often referred to as extend spectrum. The most common form of CDMA is Direct Sequence CDMA (DS-CDMA).

In DS-CDMA each user is allocated a unique CDMA code that is orthogonal to other user codes. The bits of a CDMA code are called fragments, and the fragment rate is always much greater than the data rate.

The fragment sequence modulates the data bits of the message to transmit and spreads the signal over a wide bandwidth. When the modulated message is received, the receiver correlates the sequence with the transmitted user CDMA code to retrieve the original data bits.

The spreading and de-spreading of DS-CDMA cause transmissions to be very hard to detect as well as provides a resistance to blocking.

Another form of CDMA that is commonly used is Frequency Hopping CDMA (FH-CDMA). FH-CDMA does not use a spreading code to spread the signal, but rather uses a pseudo-random pattern to hop to different frequencies at predetermined times.

The frequency hopping helps to avoid narrowband interference by not spending very much time at any specific frequency.

For FH-CDMA is also very important for all users to be precisely synchronized in both time and frequency. FH-CDMA is mostly used for shorter-range wireless systems and is currently used in the Bluetooth standard.

4.4. Space Division Multiple Access

Space Division Multiple Access (SDMA) utilizes the spatial separation of users in order to optimize the use of the frequency spectrum. A common example of SDMA is when the same frequency is reused in different cells in a cellular wireless network.

A more advanced application of SDMA uses smart antenna arrays backed by some intelligent signal processing to steer the antenna pattern in the direction of the desired user, placing nulls in the direction of interfering signals. This enables frequency reuse within a single cell as long as the spatial separation between the users is sufficient.

In typical cellular systems it is improbable to have just one user fall within the receiver beam width. Therefore it is necessary to use other multiple access techniques, such as TDMA, FDMA or CDMA, in conjunction with SDMA.

5. COMMUNICATION AMONG AGENTS

As mentioned robots agents communicate through the AP using a local area network (LAN). An LAN is a computer network that connects computers and devices in a limited geographical area such as computer laboratory or manufacturing hall.

In wireless environments, the delays in delivering messages are very difficult to anticipate.

There are several reasons for the asynchrony of communications in wireless environments, such as the delays required to access the shared environment. To access the wireless environment causes message loss due to interference, collisions between messages, and fading. Therefore, a retransmission strategy is needed to ensure message delivery in wireless environments.

6. COMPUTING COMMUNICATION ARCHITECTURE

Give a robotic agent that move free in work space while being controlled using her virtual homonym and transfer data wirelessly. Robots are designed to execute tasks within a defined environment.

The physical entity required to receive real-time digital data while being guided by her virtual prototype homonym. Normally, they shall not have any umbilical cable connections to the PC-Base. Wireless data connection is therefore necessary and the chosen technology must offer enough flexible to insure the communication while the robotic agent works / moves during to accomplish her task.

The complex architecture of the physical robot agents requires that several wireless access points be used in a complementary scheme to offer a global coverage around its structure.

The computing architecture of the integration of virtual robot with physical robot, based on wireless communications is illustrated in Figure 1.

Figure 1 shows our experiment involving the integration of virtual robot with physical robot, each agent with three degrees-of-freedom (DOFs) for performing the manipulate tasks.

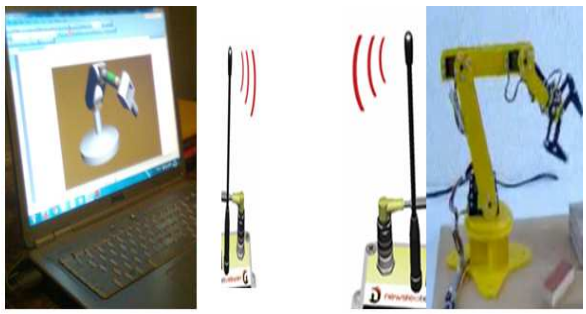

Fig. 1. Robot joint trajectory transfer via wireless technology from virtual environment into real environment.

Initially, a set of virtual postures is created for the virtual robot and the pictures' positions are recorded for each posture, during motion. These recorded pictures' positions provide a set of Cartesian points in the 3D capture volume for each posture.

To obtain the physical robot postures, the virtual pictures' positions are assigned as positional constraints on the physical robot. To obtain the physical joint angles one use standard inverse kinematics (IK) routines. The IK routine then directly generates the physical joint angles on the physical robot for each posture.

We start with a three degree-of-freedom (DOF) discrete movement system that models point-to-point attained in a 3D Cartesian space.

We demonstrated the imitation of elbow, shoulder and wrist movements. Importantly, these tasks required the coordination of three DOFs, which was easily accomplished in our approach.

The imitated movement was represented in joint angles of the robot. Indeed, only kinematic variables are observable in imitation learning.

The physical robot was equipped with a controller (a PD controller) that could accurately follow the kinematic strategy (i.e., generate the torques necessary to pursue a particular joint angle trajectory, given in terms of desired positions, velocities, and accelerations) [11].

Figure 1 also displays (left image) the user interface of a virtual robotic manipulator arm, which has been created which a dynamical simulator.

Referring the Figure 1 we comment the following: on programming platform, a robot program is carried out off-line, and one sends into the data registers of a port of the hardware structure, the numerical values of the joint variables of the virtual prototype of the robotic arm and displays on a graphical user interface, the evolution of the virtual prototype during the carrying out of the robotic task.

Via wireless channel the virtual joint dataset, from the data registers of the port of the hardware structure of the programming platform are transferred into the data registers of the numerical comparators of the controllers. These datasets are reference inputs of the pursue loops, resulting a system control.

The reference datasets are obtained using a motion capture channel taking into account the joints motion range.

The easiest way to generate the spatial relations explicitly is the interactively programming of the behavior of the virtual prototype in her virtual environment, in order to specify suitable positions.

This kind of specification provides an easy to use interactive graphical tool to define any kind of robot path; the user has to deal only with a limited and manageable amount of spatial information in a very comfortable manner.

The applicable robot tasks are designed and the desired pathways are programmed off-line and stored in the buffer modules.

The comparative modules furnish, to the pursuit controllers, the datasets involving the expected state of the virtual robot prototype and the measured state of the physical robot.

Our system requires an essential step in that one converts the position errors into motor commands by means of the PD controller.

We assume to use the virtual robot prototypes and the motion capture systems to obtain the reference motion data, which typically consist of a set of trajectories in the Cartesian space [7].

The data is obtained using a motion capture channel taking into account the joint motion range. Due to the joint limits and the difference between the kinematics of the virtual robot and real physical robot, the joint angle data are pre-processed.

In our pre-processing, we assume that both virtual and physical robots are on the scene at the same time and estimate the correct arms position and orientation. We then compute the inverse kinematics for new posture to obtain the cleaned joint angles and retain the difference from original joint angles.

At each frame during control, we add the difference to the original data to obtain the cleaned reference joint angles. This correction is extremely simple and our controller does not require supplementary cleanup.

A distributed low-level actuating system handles robot attitude and power monitoring. The main processing unit is currently implemented on a Personal Computer (PC) with a built-in wireless interface. The PC runs the operating system with the timeliness support necessary for time-stamping, periodic transmissions and task temporal synchronization provided by a specially developed user-level real time scheduler, the Process Manager [6]. This approach provides sufficient timeliness support for soft real-time applications, such as multiple robot coordination, and allows profiting from the better development support provided by general purpose operating systems [3].

The group virtual robot – physical robot communicate with each other by means of a wireless network as is illustrated in Figure 1. The communication is managed, i.e., using an Access Point (AP), and it is constrained to using a single channel shared by the physical robot at each task.

In order to improve the aptness of the communications, our robots agent team uses an auxiliary transmission control protocol that minimizes collisions of transmissions within the team. Each robot is equipped with own antenna and regularly transmits its own data while the remaining ones receive such data and update their local structures. Beyond the robotic agents, there is also a monitoring station connected to the team that allows following the evolution of the robots status on-line and issuing high level team coordination commands.

A wireless access point on a sender offers the robot agent the possibility to transmit internal monitoring data to the observer without the physical wired leap to the sender. The sender robot agent shares its data handling system through this interface and simplifies the integration of the receiver robot agent within the work space while reducing the risks of failure at collision.

This scenario requires that the physical robot agent have a wireless interface to its data from the virtual prototype system as well as a compatible communication protocol that can forward the physical robot agent condition data to the physical scene.

7. CONCLUSIONS

Virtual prototyping is an aspect of information technology that permits analysts to examine on a computer monitor the behavior of the physical robots using her virtual prototype.

By virtual prototyping one uses a virtual model in lieu of a physical robot model, for test and evaluation of specific characteristics of a candidate design.

There is a trend to use of virtual prototypes during the design analysis process. A virtual prototype is a digital model with a degree of functional realism comparable to a physical model. The value of virtual prototyping is rapidly being recognized for a wide range of engineering applications.

The robot predictive programming is a new application illustrating the potential of a system early in the design process to detailed analysis of mature designs. This paper addresses to an analysis of robot joint trajectory transfer, via wireless channel, from virtual environment into real environment.

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