Robotics and Computer-Integrated Manufacturing 39 (2016) 43–55

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Regular Articles

Towards a griddable distributed manufacturing system with augmented reality interfaces

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ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
13 September 2015
Accepted 10 December 2015
Available online 23 December 2015

Keywords:
Augmented reality
Manufacturing grid
Manufacturing system
Smart objects
Ubiquitous computing

ABSTRACT

Rapidly changing demand and mass customization require highly flexible and adaptive manufacturing systems. Manufacturing operations have evolved in order to keep up by organizing themselves into smaller units of specialized production processes that are combined in different ways to create different products. Human workers are integral in the manufacturing systems and they too must be flexible and adaptive. This paper describes an augmented reality manufacturing system that aims to greatly improve the information perception of the different types of workers in a manufacturing facility and to make interaction with manufacturing software natural and efficient. In this approach, traditionally paper-based and computer-based tasks are augmented to the workers' interactions in the environment. The system is distributed and modular as the different functions of CAD/CAM software are provided by individual physical or virtual objects in the environment or by a combination of them working cooperatively. This modularity allows the individual resources and facilities to be linked via internet onto a manufacturing grid with universally-accessible augmented reality interfaces to their services.

1. Introduction

Driven by fierce global competition, rapidly changing demand, and increasing calls for mass customization, manufacturing today is characterized by temporary virtual enterprises comprising different manufacturing companies and the sharing of their resources. Monolithic factories built for very specific products have given way to smaller and more flexible facilities. To stay competitive, these facilities have to be flexible not just in terms of product mix and volume output, but also in terms of manufacturing processes and labor [10].

Computer-integrated manufacturing systems bring automation and computational power that are invaluable in speeding up and reducing errors in production and decision-making. The use of CAD/CAM software is vitally important for bringing designs to reality, and it is important that designs output using CAD software can be interpreted by CAM software to be manufactured. The role of skilled human workers is more significant than ever for they are the ones who use the software, ensure product specifications and deadlines are met, and keep the machines running. As a consequence of rapidly changing product specifications, there is a much greater load on the workers to be constantly switching between different production modes and job scopes. It is crucial that everyone is kept up-to-date with the latest information, such as inventory levels and machine sensor data, in order to keep the manufacturing facility running smoothly.

It is not just at the local facility level that humans play a large part in manufacturing. In the forming of virtual enterprises, there are important decisions to be made, such as the selection of resources and services that are required in bringing the product to fruition. The concept of grid technology has recently been applied to manufacturing [23] which puts individual manufacturing resources and services on a wide-area network that anyone can access as easily as turning on a switch to extract power from a power grid. However, the potential abundance of resources on the grid and the different software and corresponding data exchange formats that independent resource owners employ can make it daunting for grid users to access their services.

This paper proposes a manufacturing system that replaces all paper-based and computer-based tasks with augmented reality (AR) tasks that are performed naturally by the users in their physical environment. The objects that workers interact with within their physical work environment are implemented as smart objects with their own graphical user interfaces (GUIs) augmented onto the workers' perception of their work environment. The GUI elements can be directly manipulated by hands and are used to represent critical real-time information specific to the objects, and thus the task at hand, to the worker. The objects, such as CNC machines and CAD designs, can be physical or virtual and interact with each other to provide computer-aided technologies to the users. Using this same framework, manufacturing resources which have their own AR user interfaces can be connected to the internet

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http://dx.doi.org/10.1016/j.rcim.2015.12.002
0736-5845/

to form a manufacturing grid (MGrid).

2. Background

Ubiquitous computing is a new computing paradigm in which traditional computers give way to physical objects in the environment that are embedded with computational capabilities. A modern factory architecture, commonly known as "smart factories", applies the concept of ubiquitous computing by embedding machines and sensors with intelligence and connecting them to a network so that workers can retrieve real-time production information through mobile devices that they carry or computers on the facility [8]. This access to real-time information is very powerful as it allows workers and managers to monitor inventory levels, production performance, and machine conditions in order to make snap decisions and prevent breakdowns. However, workers either need to be holding a mobile device or locate a computer in order to access the information.

Augmented Reality (AR) has been put forward as a highly promising technology that allows for visualization of computer graphics placed in the real environment, which will be a boon to workers negotiating a busy environment. The first AR systems appeared in the 1990's. Caudell and Mizell [2] reported the use of AR in aircraft manufacturing where a see-through head-mounted display device could overlay diagrams on real-world objects during aircraft manufacturing operations. A system of "virtual fixtures" developed by Rosenberg [21] improved the performance of tele-operated tasks via exoskeleton by augmenting the operator's vision with a view of the remote environment, having the exoskeleton restrict the operator's motion thus providing a haptic fixture, and playing sound over the operator's view of the remote environment to aid in the perception of the haptic fixture. AR application development and research was made widely accessible by the release of ARToolKit [1] in 1999. The ARToolKit platform works by searching for square planar markers called fiducial markers with known patterns to obtain their 3D pose (position and orientation) in the camera image [12], and then rendering 3D computer graphics based on the pose of the markers so that virtual objects appear to be sitting on the markers in the physical space. Since then, new markerless tracking techniques [14,6] and applications have been developed. The manufacturing applications of AR include assembly, maintenance, product design, layout planning, robotics, and machining [19].

Providing universal access to heterogeneous resources is one of the challenges in realizing an MGrid. Many research works take the approach of encapsulating resources as web services [15,7] or by the use of middleware technologies and ontology languages [24,9]. Compared with service and data description encapsulation, the issue of user interfaces has not been dealt with as much, with most of these systems employing a 2D application interface on mobile devices or computers. In practice, however, the number of manufacturing resources is simply so large and varied that having to conform to standard user interfaces may be too limiting and does not give a chance for resource owners to add value to the services they provide.

The manufacturing system described in this paper will make use of ubiquitous computing technology to realize smart manufacturing facilities, adding AR user interfaces to objects and computer software that are seen and interacted with through wearable computers to make access to information and computer-aided software convenient and natural. It will also be shown that this framework allows manufacturing resources to be "griddable", i.e., shared on an MGrid, so that facilities can have access to these resources as if they were physically present in the facility.

3. System architecture

In a localized environment like a manufacturing job shop, the system would consist of smart objects that are connected on a local-area network. A smart object can be based on a physical object or be completely virtual, but both types of smart objects have a virtual 3D appearance that can be seen in an AR view of the environment. The AR view contains the actual physical environment with virtual elements added into it by viewing devices. Apart from their virtual appearance, smart objects have underlying behavior and functions which can be accessed by users through the AR interface. Each smart object is independently implemented. It can function on its own and also communicate and interact with other smart objects. Some elements of the virtual appearance of a smart object can be used as user interface elements for triggering underlying behavior and functions. Users can view and interact with the user interface through viewing devices, such as tablets or wearable computers. At least one server is required for keeping track of smart objects and passing on their data to viewing devices and for relaying interactions from viewing devices via remote procedure calls (RPCs). Some smart objects can serve as hosts to other smart objects, thus allowing them to share resources. The overall system architecture is depicted in Fig. 1.

3.1. Communications protocol

A high-level communications protocol has been defined with a list of standard commands to facilitate the basic functionality that all smart objects need to possess in order for them to work in the environment. This protocol is implemented on top of a lower level protocol like TCP [3], which takes care of data transmission, error detection, packet splitting and reassembly. Smart objects can broadcast their own additional functionality by providing a list of RPCs which are also handled by the communications protocol.

Most of the standard commands can either be categorized as a "GET" command, for requesting specific pieces of data, or a "SET" command, for transferring data to an object. A message sent between smart objects and servers takes the following general format: <command>, <target address>, <sender address>, <parameters>. Some commands that are meant to be broadcast to all objects do not include the target address in the message. Table 1 lists the standard commands, most of which are required to be sent or handled by smart objects.

The external address of an object is an index number that uniquely identifies the smart object hosted at that network location. This address is different from the network address used by the lower level communications protocol, such as an IP address and port number used by the TCP protocol to route messages to specific programs. The external address allows smart objects that are hosted at a single network location to be addressed uniquely. For example, a PC uses its network address to transmit messages to other PCs; however, the specific smart object being hosted on that PC is identified by its external address.

A "New" command is used to announce the existence of an

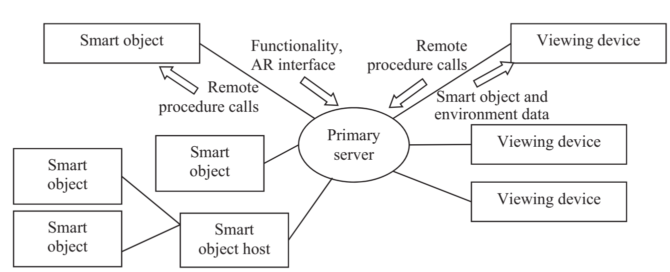

Fig. 1. System architecture for a local environment.