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Remote real-time collaboration through synchronous exchange of digitised human–workpiece interactions

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HIGHLIGHTS

- A platform for remote real-time collaboration between geographically separate teams.
- The unique use of low-cost gaming depth imaging sensors and virtual environments.
- The capture of human actions and their effects on workpieces and task environment.
- The sharing of task contexts, knowledge, skills and transfer of expert services.
- An automotive use case was used to validate the developed platform.

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ABSTRACT

In this highly globalised manufacturing ecosystem, product design and verification activities, production and inspection processes, and technical support services are spread across global supply chains and customer networks. Therefore, collaborative infrastructures that enable global teams to collaborate with each other in real-time in performing complex manufacturing-related tasks is highly desirable. This work demonstrates the design and implementation of a remote real-time collaboration platform by using human motion capture technology powered by infrared light based depth imaging sensors and a synchronous data transfer protocol from computer networks. The unique functionality of the proposed platform is the sharing of physical contexts during a collaboration session by not only exchanging human actions but also the effects of those actions on the workpieces and the task environment. Results show that this platform could enable teams to remotely work on a common engineering problem at the same time and also get immediate feedback from each other making it valuable for collaborative design, inspection and verifications tasks in the factories of the future. An additional benefit of the implemented platform is its use of low cost off the shelf equipment thereby making it accessible to SMEs that are connected to larger organisations via complex supply chains.

1. Introduction

A new wave of globalisation has resulted in product Research and Development hubs of various Multinational enterprises (MNE) being located to countries such as India and China as well as sourcing knowledge from globally dispersed knowledge hubs [1,2]. Furthermore manufacturing of products have also been offshored to foreign countries where the low-wage economy enables MNEs to take advantage of lower production costs [3–5]. This has resulted in the need for MNE employees to travel to countries to collaborate on design tasks, address production problems as well as carry out maintenance tasks on production lines. This leads to longer downtimes in production plants as well as delays in design tasks.

In order to address these challenges, a technological solution for businesses to engage in collaborative activities as well as a platform to remotely provide expert services is needed. Such a solution should enable true collaboration between teams and

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facilitate a closed loop process through immediate feedback on the tasks being performed using bi-directional information flow. This requirement is highlighted by a large MNE automotive company as follows: "with the unprecedented expansion of our business across the globe, a cost-effective real-time collaboration solution is essential to enable an agile response to the growing demands of remotely located business units such as manufacturing sites, retailers and service centres".

This paper investigates the possibility of equipping geographically dispersed teams with the capability to work collaboratively on the same physical task at the same time by sharing the task context with each other. Even though there has been some work on collaborative virtual prototyping as in Xiao et al. [6] and He et al. [7], there are currently no solutions that can offer a true remote real-time platform for collaborative physical tasks other than the traditional means of communication using text and voice calls, video conferencing and file sharing.

In this work, a true collaboration platform is built on the theoretical foundation of digitisation of human–workpiece interactions as discussed in Prabhu et al. [8]. According to this theory, any physical task can be broken down into a series of human–object interactions where every human action is followed by object feedback, which is analysed by the human on the fly, and the next appropriate action is chosen and implemented towards channelling the task to successful completion. In this work, human actions and corresponding changes to the workpieces are simultaneously tracked in real-time to produce a digital data stream that represents the task. This data stream is synchronously exchanged over a computer network between sites to enable remote collaboration. The proposed method is capable of hosting collaborations between virtual and virtual, real and real and virtual and real task environments. The unique aspect of this work is the use of off-the-shelf human motion-capture technology provided by depth imaging sensors to not only capture human actions but also their effects on the objects during the task together with a synchronous data transfer protocol.

This work contributes new knowledge as follows: (i) a method to share task contexts in a real-time collaborative environment, (ii) a method to digitise human activities during a task in simple data structures and the ability to convert them back to rich task information. The data is exchanged between multiple sites using a synchronous data transfer protocol. This enables low latency, low bandwidth internet transmission across two geographically separated sites, (iii) the use of low-cost gaming interface sensors to capture and digitise collaborative tasks and (iv) a method to extend the theory of human–workpiece interactions in simultaneous multi-site collaborations and map collaborative human actions to the corresponding changes to task workpieces in real-time.

The outcome of this work has the potential to significantly enhance the quality of manufacturing operations in the factories of the future by virtue of it facilitating the real-time sharing of best practices between global manufacturing sites at low cost. These operations range from product and process design, verification, assembly, and inspection to through-life engineering and maintenance services.

The remainder of this article is organised as follows; Section 2 presents related research in the area of remote real-time collaboration. Section 3 describes the methods used to carry out this work and Section 4 reports the results. Section 5 presents a discussion on the work conducted and its outcomes followed by the conclusion.

2. Related work

The internet has resulted in the possibility to achieve collaborative work between two geographical separated sites of a NME. Most collaborative work is often done using traditional communication media of e-mail, phone, video conferencing and fax. Even though useful this medium has been found to be ineffective and time consuming in tasks that involve physical artefacts due to the lack of tactile feedback from the artefact and inability to grasp the physical constraints and dimensions of the task environment as well as the artefact [9].

In order to address these challenges, the online gaming community could offer some insights. A form of collaboration occurs in massive player online gaming (MMORPG) communities where players co-operate or compete to fulfil various virtual game objectives generated by a computer [10–12]. Currently, these environments are mostly used for pleasure or entertainment purposes but could in future be used for the purposes of training a group of geographically separated individuals in collaborating to handle a physical task.

For such a technology to be useful for physical tasks on shop floors, there is still a need to relate what is happening in the real world with the virtual world and vice versa. In other words, a mechanism is needed to capture the effects of human physical actions on physical workpieces and convert this into a virtual form that is visible to a collaborator at a remote site towards generating feedback and next action steps. Furthermore, a way of transmitting the actions of the collaborator on virtual workpieces at the remote site to information that can be seen by the trainee in the physical world is required [13].

Some researchers have made some progress towards this. For example, Galambos et al. [14] discusses a virtual collaboration arena software frame that use a virtual reality engine for the purposes of training new employees in manufacturing and production engineering. Though, in their work only head movements and gaze direction were implemented.

In order to capture full body human motion, several research attempts tend to use gaming interface sensors such as the Microsoft Kinect. With the Microsoft Kinect sensor, detecting and tracking of physical objects as well as obtaining the physical constraints of workspaces is possible. This makes it possible to accurately project the physical world into a virtual space and vice versa. In Adcock et al. [15] for example, Kinect sensors are used to scan the physical workspace and detect object changes using fusion point cloud technique and a Spatial Augmented Reality (SAR) mechanism to project a remote expert's instructions as graphical annotations overlaid on the workspace. Similarly, Tecchia et al. [16] proposed a Kinect-based method to provide real-time aid to another person based on the capture and rendering of remote workspace and of the helper's hands using tele-presence. In their work, Kinect sensors were used to capture the point cloud of the objects manipulated in the workspace to create their digital versions, which are then transmitted to the remote expert who can view them in immersive space. The expert then uses hand gestures to provide instructions on the task, which the user can view on a computer screen with the expert's virtual hands overlaid on top of his/her own live video of the task.

Piumsomboon et al. [17] proposed a framework that enabled face-to-face collaboration, allowing users present at the same site to use their hands to naturally interact with each other using virtual objects, enabled by Kinect sensors and AR viewing cameras. Users' hands are tracked and the manipulation of the virtual object rendered using AR is captured by mapping the real hand coordinates with virtual object positions in 3D space. Similarly, Sodhi et al. [18] reported a method that allows users to manipulate virtual objects in a real physical environment. Their work uses a mobile phone integrated with depth sensors to track the location of the user's fingers, as well as to capture the 3D shape of the associated objects. A second user can see this information on his/her mobile phone and using finger gestures provide instructions on the task to the first user, who can see these gestures on his/her own mobile phone, superimposed on the real video feed thereby enabling real-time collaboration.