The Institution of Engineering and Technology

Digitisation of Complex Manufacturing Knowledge Using Gaming Technologies

How gaming technologies can come to the rescue of the skill-starved manufacturing industry of the future by enabling the capture and digitisation of human skills.

The world of gaming

The world spends three billion hours each week playing games[1]. Modern-day gaming solutions such as Microsoft Xbox™ and Sony PlayStation™ have driven the growth of the gaming industry with the global market for gaming hardware, software, and games expected to swell to an astounding $111 billion by 2015[2] growing faster than film, music and television.

High-tech gaming consoles, combined with powerful game engines such as Unity™ and human motion capture sensors such as the Kinect™ enable people to immerse themselves completely into the game environments. This enables them to accomplish complex tasks using real human actions and analysis of game situations based on observations and instinctive reactions.

Global high-speed connectivity also allows multiple players from around the world to compete with each other in a game or even collaborate to solve a common problem within the gaming environment.

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Gaming beyond games

Creative games and the sophisticated underlying ICT have succeeded in engaging people, entertaining, and fascinating them to an unprecedented magnitude. But can gaming serve a greater purpose beyond pure entertainment? Can it revolutionise the social, educational and industrial sectors in the same manner as the entertainment sector?

A 'Serious Games' movement over the past decade and organisations such as 'Games for Change' have encouraged the development of games for social causes, where values such as harmony, kindness and environmental sustainability are intermingled with the fun component[3]. The gamification of learning has resulted in educational games being used to enrich the academic curriculum. Learning is embedded within a game environment to either enable learners to engage in activities that would not be feasible or affordable in the physical world or provide a facade of fun to routine educational tasks[4]. Beyond the world of gaming, the use of gaming technologies such as gesture recognition is enabling users to interact with their TVs, computers and machines using natural human interfaces. With the entry of big corporations such as Apple and Samsung in the natural interface space, the use of gaming technologies is expected to become pervasive in the consumer appliance industry.

Gaming and manufacturing

Modern game design is human-centric and aims to involve a gamer in the game not only mentally but also physically. This is achieved by observing the gamer's body motion (using Kinect™-type devices) as he/she navigates through the game, for instance while playing a game of virtual tennis. This motion is analysed to extract specific human actions and reactions and to tweak the game situations accordingly. Different gamers act and react differently in a game. More advanced games can adapt dynamically to the varying skill-levels of the gamers, determined by how deft their decisions are as the game progresses, for example in the game 'Resident Evil' [5].

A similar scenario exists in the manufacturing industry where the skill-levels of workers impact directly on the product quality and on the operational productivity, especially for skill-intensive manual operations. It is therefore worthwhile to explore the possibility of using gaming interface technologies such as the Kinect™ to observe skilled workers perform manual operations on the shopfloor and decipher how they use their specialised skills to successfully complete their complex tasks. Digitisation of manufacturing knowledge, specifically its hidden aspect such as human skill, is a conceivable possibility.

Why digitise manufacturing knowledge?

Automation is widespread in modern manufacturing. However, manual labour is still high in demand and will continue to be so in the future for a large variety of complex tasks that combine human skill and dexterity with sophisticated cognition such as in aircraft engine assembly. Manufacturing in the UK employs more than 2.5 million people and is thriving today due to an increased focus on high-value manufacturing.

However, it also faces a huge threat to its continued global competitiveness due to a skill supply crunch[6]. There will be around 800,000 job vacancies created over the next 6 years as people retire or leave manufacturing. Considering that the average training expenditure per employee in manufacturing was £1,425 in 2011, the total training cost to the UK over the next 6 years will be more than £1 billion[7] [8].

Notwithstanding this cost, the skill deficit threat can only be mitigated in the medium term by rapid up-skilling of the workforce. In the long term however, automating some critical skill-intensive manual manufacturing operations could reduce skill demands. The main barrier in adopting these solutions is the lack of effective methods to capture, digitise and transfer human skill; a tacit dimension that is yet to be mined and documented.

The manufacturing informatics research group at Cranfield University aims to develop a holistic ICT framework for capture, modelling and transfer of complex tacit knowledge from skill-intensive manufacturing operations. The use of commercial, low cost, and widely available ICT hardware and software tools in this framework would make it highly attractive for the manufacturing industry to adopt as a skill-transfer platform.

The Cranfield research

This manufacturing informatics research at Cranfield is based on the concept that every manual manufacturing task is an interaction between the human worker and the workpiece(s). In this interaction, every human action step on the workpiece is followed by feedback from the workpiece to which the worker reacts in the next step. This feedback could be visual, audible and/or tactile.

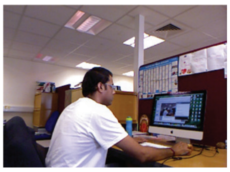
A series of such action-feedback-reaction loops (see Figure 1) results in the workpiece being processed from start to finish. By observing these interactions and capturing human actions and their effects on the workpiece over the duration of the task and for multiple runs of that task, expert human gestures in executing the task and adept human responses to unexpected problems in the task, can be extracted and digitised. The capture of human-workpiece interactions is made possible by the use of portable 3D sensing devices, such as the Kinect™ and PrimeSense 3D™ and the

InfoBox 1: 3D Sensing Products

There are several 3D sensing products from brands such as Microsoft, Asus and PrimeSense in the market, primarily for the gaming sector (none costs more than £200 per device).

Microsoft Kinect™ Asus Xtion™ PrimeSense 3D™

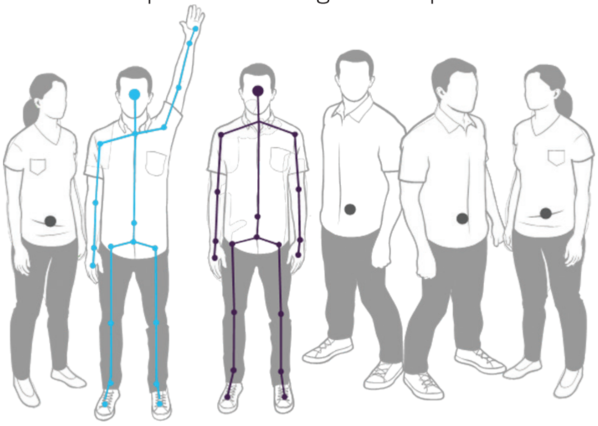
These devices comprise an RGB camera for full colour imaging and an infrared camera for depth imaging. Typical resolution of both these cameras is 640 x 480 pixels and each pixel contains its red, green and blue colour values as well as its depth value (in mm) from the sensor. Therefore, a complete 3-dimensional representation of the scene can be achieved. The Kinect™ also contains microphones for recording audio.



RGB Image

Depth Image

A significant advantage of these 3D sensing devices is that their software development libraries provide standard functions for recognising humans (up to 6 simultaneously) and tracking human skeletal motion (up to 2 simultaneously) in real time. The next generation of these devices, such as Kinect for Windows V2 promises even greater capabilities.



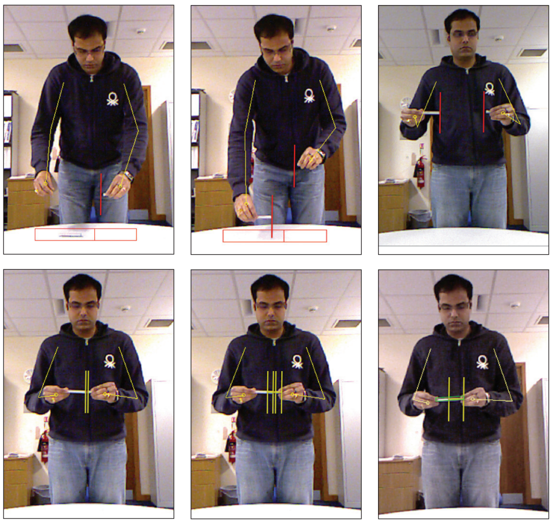
InfoBox 2: Digitisation of a manual pen assembly operation [9]

Aim: To digitise the knowledge associated with a manual pen assembly task and extract insights into the human skill used.

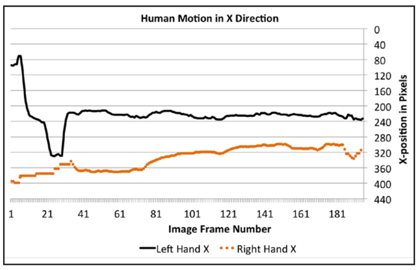
Approach: The Kinect™ is used to capture and record the manual pen assembly task. The sequence of steps in the task is: (1) Find the two components of the pen on the table. (2) Grasp the two components, one in each hand and move them in the front of the body for assembly. (3) Move the two components towards each other until they mate. (4) Rotate one component while the other is held still, to complete the threaded fit assembly of the pen.

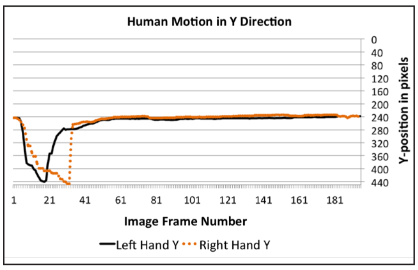
The human-workpiece interaction during the assembly task is captured as continuous digital data (x, y and z coordinates of the human hands and of the pen components being manoeuvred by the hands) and recorded.

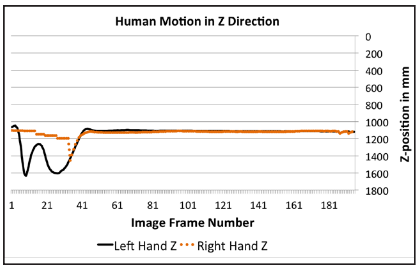
Results: Motion charts are generated from the continuous coordinate data. Since both the human and pen component motion were captured synchronously, the effect of human actions on the components during a specific time period can be analysed by looking at the changes in workpiece positions during the same period. Apart from the known assembly sequence, it can also be observed that the human hands have covertly aligned the two pen components in both y-axis and z-axis simultaneously while bringing them together for assembly.

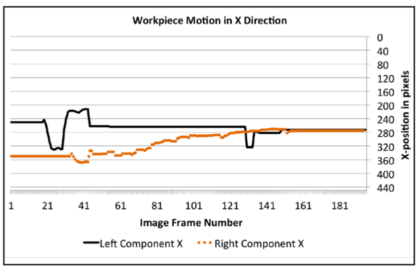


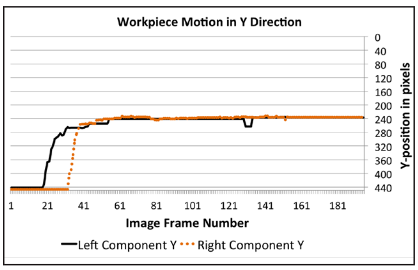
This aspect of the task though comes naturally to us humans (instinctive skill), has to be taught to a robot for automating this task in the future. This aspect was uncovered only when the human-workpiece interactions within the task were digitised and analysed.

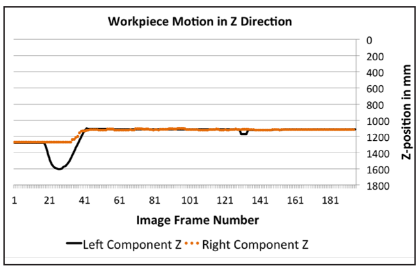












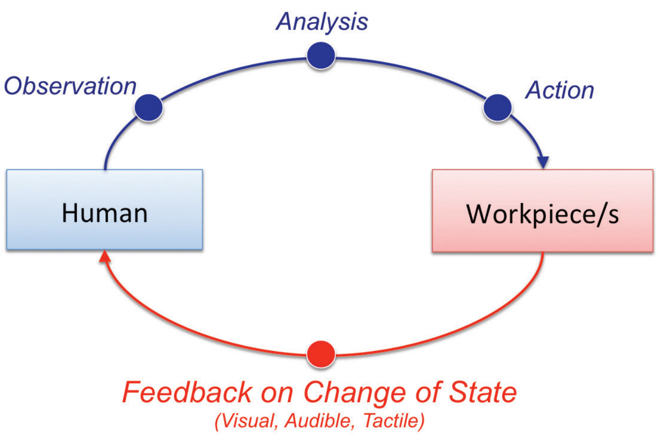


Figure 1

software libraries that enable human skeletal motion tracking, such as Kinect™ for Windows SDK and PrimeSense OpenNI™ (see InfoBox 1 for details).

Until 2010, the year when Kinect™ was launched, simultaneous human and workpiece tracking was a difficult task and almost impossible to undertake in a manufacturing environment. Human motion capture using stereovision systems was not portable and commercially viable on the production shopfloor whereas workpiece tracking was computationally expensive using only RGB data without having any depth perception.

Now the availability of human skeletal motion data and the ability to acquire the depth perception to track changes to the workpiece (size, orientation, features) simultaneously makes it possible to capture human-workpiece interactions on a shopfloor in an inexpensive manner. Workpiece changes are tracked by using custom-developed object recognition software that tracks edges, surfaces and features of the workpiece from the RGB and depth image streams. The case study in InfoBox 2 shows the first work at Cranfield University where human-workpiece interactions during a manual pen assembly task were digitised.

The simultaneous tracking of human actions and the effect of those actions on the workpiece/s during a manual task and the digitisation of this real-time knowledge has been demonstrated by Cranfield using a gaming interface technology. The next steps in this research are the spatio-temporal segmentation of the captured continuous digital data into human and workpiece states and subsequent human-workpiece state interaction modelling. These steps will enable deeper investigation of manual tasks, decoding of associated human skills and eventually the prediction of human actions in response to given task scenarios, paving the way for intelligent automation of skill-intensive manual manufacturing tasks.

Applicability of Cranfield research

One of the pilot adopters of this research is the composites manufacturing sector, specifically in the aerospace industry. Today, the process of laying composite fibre tapes on to moulds or tools involves significant manual tasks.

Even with the automated fibre placement machines being used, manufacturing defects such as misalignments, overlaps, knots, and non-uniform coverage in sharp corners need highly skilled and experienced craftsmen to intervene and repair these defects.

This slows down production and burgeons production costs. Moreover, with the heavy reliance on skilled and experienced craftsmen, who cannot be replaced easily, it is essential to digitise the knowledge and skills associated with such tasks so that the knowledge can be used to effectively train the next generation of craftsmen and to automate tedious parts of the composite manufacturing process.

The case study in InfoBox 3 shows the work done by Cranfield University in collaboration with Airbus Group Innovations Works and Aertec Solutions UK where process knowledge in composites structure repair was digitised. This work can be applied to other sectors in which important outcomes depend on detectable human movements, such as the Built Environment and Energy. As an example, the Cranfield team is contributing to the development of an advanced home monitoring solution for the care of older people [11].

Immersive virtual reality in manufacturing

The advent of virtual factories is a boon to the manufacturing industry where digital representations of production workstations and process workflows can be designed, virtual prototypes can be developed and evaluated and discrete events within factory operations can be simulated to understand the impact of internal and external factors on production efficiencies.

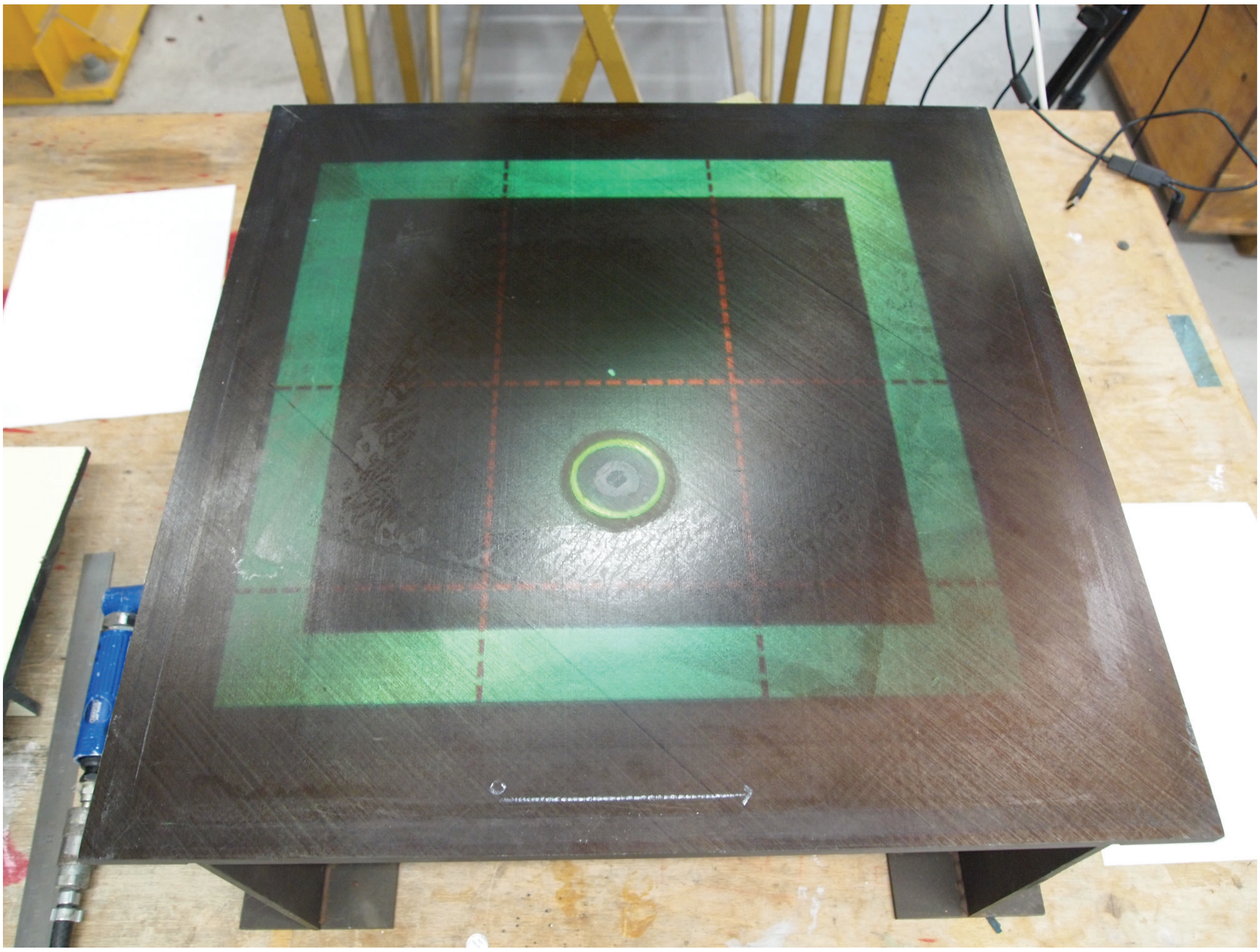
InfoBox 3: Digitisation of industrial composite repair process [10]

(Cranfield University, Airbus Group Innovations Works and Aertec Solutions UK)

Aim: To look into the possibilities offered by gaming technology for digitisation of repair instructions along with repair inspections, such that a non-specialist worker can undertake the repair work to the required standard.

Approach: Enhance the presentation of the repair instructions to a remote repair worker. This is done by creating a Kinect-controlled projected Augmented Reality (AR) by linking a standard media projector, a Kinect™, and a computer. Through this rig, repair instructions are projected directly on the top of a surface to be worked on.

The picture below shows the projection of a grinding step, with a yellow circle indicating the extent of the grinding.The projection provides the repair worker with step-by-step guidance along with detailed, contextual, and geometrically calibrated instructions. The record of the process that is automatically captured by the projector-linked Kinect™ can augment repair certification. The captured process data include RGB images and skeleton data of the workers performing the tasks.



Results: The repair worker would be able to avert mistakes while following the instructions as closely as possible thanks to the projected instructions. The projector-linked Kinect™ data simplifies cross-checking of whether the instructions have been actually performed as instructed.

Currently, such virtual factories can only be visualised on a computer screen, which does not provide a contextual and immersive experience, or in a virtual reality (VR) cave, which does provide an immersive experience but without the convenience of portability or affordability to Small and Medium Enterprises (SMEs) (some advanced VR caves cost in the order of a couple of million pounds). Exciting prospects open up when digitisation of manufacturing knowledge meets the visualisation potential of Virtual Reality (VR) headsets such as the Oculus Rift™ (see InfoBox 4 for details) and Sony Morpheus™.

The capability for immersive visualisation of production operations and a walk through in virtual factories will be brought to people's desks and with the digitisation of human actions, people could also participate in virtual design collaborations with engineering teams from different parts of the world in real time. With the Oculus Rift™ development kits currently selling at around £300, this technology is within easy reach of SMEs unlike the VR cave.

Conclusion

Digitisation of complex manufacturing knowledge using gaming technologies has the potential to boost the competitiveness of the manufacturing industry. In the near term, digitised knowledge of human postures and actions during manual manufacturing operations can be studied to assess the ergonomics of such operations and redesign workstations that facilitate ergonomically correct tasks.

In the medium term, skills acquired and digitised from experienced craftsmen can be effectively transferred to apprentices via skill demonstrations in virtual workstations, minimising the need for long apprenticeships. The outcomes of Cranfield's project on digitisation of industrial composite repair process [InfoBox 3] will be tested and validated by the Airbus Group over the next year with an eye towards an industry-wide uptake expected over 3 to 5 years. Rapid up-skilling of the workforce can reduce the heavy dependence of companies on skilled manpower and effectively ease the future skill supply crunch.

In the long term, human skill models generated by capturing and modelling human-workpiece interactions from complex manufacturing tasks could provide the intelligence behind successful automation of such tasks.

InfoBox 4: Oculus Rift™

The Rift™ is a head-mounted virtual reality display, being developed by Oculus VR with the aim to revolutionise the way we experience interactive content by letting us step inside our favourite games and virtual worlds.

Development Version 1

The Rift™ creates a stereoscopic 3D view by presenting unique and parallel images for each eye (resolution of 640×800 per eye) in the same way our eyes perceive images in the real world. It provides an approximately 100° field of view, stretching the virtual world beyond our peripheral vision.

It uses custom tracking technology to provide ultra-low latency 360° head tracking, allowing us to seamlessly look around the virtual world just as we would in real life. It is designed to be comfortable and lightweight. A USB interface allows the Rift™ to be compatible with standard PC hardware on both the Windows and MAC OS platforms. The final version of the Rift™ will feature a HD resolution viewing experience.

Therefore, if the sophisticated yet inexpensive and proven technologies for human motion capture and immersive visualisation from the world of gaming are leveraged effectively, the future of the manufacturing industry could be rescued from the threat of skill-supply crunch.

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