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YOUR NEW COLLEAGUE IS A ROBOT. IS THAT OK?

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Human robot collaboration is a concept under development that will be applied within manufacturing environments in the near future to increase efficiency and quality. While there have been significant advances in technology to enable this progress there is still little known about the wider human factors issues of employing such systems in High Value Manufacturing environments. This paper sets out our current understanding of key organisational and individual factors which need to be explored.

Introduction: Human Robot Collaboration – where are we now?

Combined developments in technology and standards (such as the ISO 10218-2; ISO, 2011) have increased the potential for closer interaction between humans and robots in industry. Improved sensor and high speed computer processing capabilities will allow real time monitoring of the environment around automated equipment to remove the need for traditional fixed guarding and move towards true human-robot collaboration (HRC). These developments mean it is almost inevitable that HRC will become particularly attractive as a means of improving work flow in high value manufacturing (HVM) systems. In recent work at Cranfield University a HRC demonstrator system has been developed for the aerospace manufacturing sector with integrated 3D vision monitoring and control safety systems as a safer alternative to traditional physical guarding (Walton, Webb and Poad, 2011). However, although much previous research has shown us that workforce reaction and acceptance of new technology is a significant determinant of success (Venkatesh and Davis, 2000) little is currently known about the human factors challenges of introducing such a radical manufacturing change.

Our concept of HRC differs from other human-robot interaction (HRI) in that it represents working cooperatively at the same time and in the same work space through perception, recognition and intention inference, whereas HRI can be considered as anything requiring communication in close proximity or remotely. HRC needs to reflect human-human collaboration in which people use many different ways to communicate successfully and share adequate feedback which has a major impact on task performance (Horiguchi, Sawaragi, and Akashi, 2000). This will allow robots to be used in cases of process variability where current fixed, non-collaborative systems cannot. Literature from comparable contexts, such as the implementation of advanced manufacturing technologies (AMTs), has shown that failure to address human factors has proved detrimental to successful adoption (Lewis and Boyer, 2002; Castrillón and Cantorna, 2005; McDermott and Stock, 1999; Zammuto and O'Connor, 1992). In absence of an existing guiding structure Charalambous, Fletcher and Webb (2013) developed a theoretical framework of human factors that are likely to affect implementation of industrial HRC at *organisational* and *individual* levels.

Organisational level factors

A broad review of the literature initially revealed that the key organisational factors relevant to industrial automation and technology implementation are: (i) *communication of the change to employees*, (ii) *operator participation in implementation*, (iii) *training and development of workforce*, (iv) *existence of a process champion*, (v) *organisational flexibility through employee empowerment*, (vi) *senior management commitment and support*, (vii) *impact of union involvement*. The importance of these factors to successful adoption of new automation and technology was then supported by the findings of an exploratory case study in an aerospace HVM facility where a traditionally manual work process was being replaced by automation. In addition this study revealed factors not previously identified in the literature, such as: *awareness of the manual process complexity by the system integrator* and *capturing the variability of the manual process prior to introducing the automated system*. It also highlighted that organisational factors should not be considered as a selective 'tick-in-the-box' activity, but rather as a set of inter-related issues. For instance, capturing the variability of the manual process in advance will serve as a vehicle to provide sufficient information to the system integrator to understand the complexity of the process and provide a process capable automated system.

Individual level factors

Additionally, a set of key individual level factors were also identified from the literature: (i) *trust in automation*, (ii) *mental workload*, (iii) *situation awareness*, (iv) *levels of automation*, (v) *automation reliability*, (vi) *attitudes towards automation*, (vii) *perceived attentional control.* All of these issues directly concern the workforce / individuals who will interact with HRC systems and new automation and not only involve human aspects that are more often addressed by engineers, such as physical ergonomics and human computer interaction, but also comprise deeper psychological constructs. This is an important problem as HRC raises interesting questions and challenges regarding user psychology. Early work in the development of the Cranfield HRC demonstrator cell confirmed the potential relevance of key psychological constructs, such as mental workload, situation awareness, and users' subjective comfort (Walton, Fletcher and Webb, 2012). Building on this early work we now focus on operator 'awareness' and 'trust and acceptance' as our work thus far indicates these are fundamental.

Awareness

When a human interacts with a system they accumulate knowledge and build mental models from which they infer the state of the system and their expectations; awareness is therefore vitally important in order for operators to develop and apply working strategies. In the example of a human-robot system, the human would have a level of knowledge about the processes, rules and procedures relating to their job (however they may not be routinely the same) as well as a level of knowledge about the robot and associated safety features. When a human carries out a task and repeats it several times, they develop a rich knowledge of the task, and of peripheral aspects. In HRC systems it should be possible to identify the system state when an action has occurred and when it was given and maintain awareness of state and state changes. However, this may become problematic if the robot does not follow this same learning process as the knowledge becomes unbalanced. It will, therefore, be important for robots to learn how to adapt to the actions and changing states of the human operator in a similar way to how a human learns to respond. Operators will need to be able to teach robots how to perform tasks by demonstration, without engaging in complex robot programming, and maintain fluid interaction thereafter using shared plans and expectations of future states. The technology required for this level of sophistication in a HRC system is available but it is also important to remember that failures become more complex; if failure occurs it is not necessarily the human or robot at fault, but could be a software failure. When the user has built an adequate level of awareness, they can start to use their mental models and existing knowledge to start to predict situations. The type, complexity, familiarity and workload of a task will also influence system efficiency. In the case of collaborative environments, existing models do not describe adequately the state of situation awareness in relation to automation, let alone multi-robot or multi-operator systems. The aforementioned early Cranfield work considered awareness merely in terms of a single human operator's cognisance of robot activity (Walton et al., 2012) and some distributed models of situation awareness start to touch on this issue (e.g. Salmon, Stanton, Walker and Jenkins, 2009). However, there appears to be no current model of situation awareness in true collaborative environments that mutual awareness of human or robot state changes. Thus, further work to explore awareness between humans and robots in real time dyadic and multi-agent HRC systems is needed.

Trust and Acceptance

Trust and acceptance are often considered as related constructs (Lee and Moray, 1994), or acceptance a direct result of high trust (Venkatesh and Davis, 2000). Trust between humans and robots has been considered in many domains but very little has been explored in the specific context of HVM applications. Freedy DeVisser, Weltman, and Coeyman (2007) developed a performance model that captured key components of the human-robot system considering team performance and processes at three levels (the individual human; the team human; and the collective human/robot team) and found the most important construct to be trust. Muir and Moray (1996) propose six components to a good level of operator automation trust (predictability, dependability, faith, competence, responsibility, and reliability) and found that trust is sustained if initial faith is in place but the other components can then be developed through experience. However, low reliability has the potential to undermine developed trust in a system and outweigh any potential benefits that the system could provide by increasing mental workload due to 'workarounds' that can quickly become 'the norm' (Parasuraman and Riley, 1997). By considering an individual's trust in a system and having adequate tools to do so, designers and implementers of HRC can start to predict the level of acceptance of a system at an individual level, and therefore consider the impact at an organisational level. More recent work to develop a psychometric tool to measure human trust in industrial robots has identified a three-factor structure (Charalambous, 2014). Further work will continue to explore how these antecedent factors affect the initiation of trust, and their relevance in the development of operator acceptance and situation awareness in HRC environments.

Conclusions

HRC seems an inevitable step for optimising HVM in the near future but asking people to work so closely with robots raises new questions in the psychology and human factors domain at both individual and organisational levels. This paper highlights some initial investigations and indications for issues that must be addressed to bring this concept closer to reality and ensure the technology can be implemented safely and successfully. In particular, we have emphasised the critical importance of fully investigating the psychological and social prerequisites for effective HRC adoption and use within close-knit teams.

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