Designing a Digital Twin for Human-Robot Collaboration

LogDynamics
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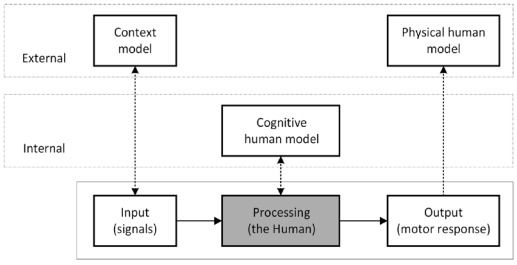
The traditional production systems produce large batches and standardized products. However, there has been increasing demand for personalized and individualized products. Hence, the traditional production systems are rigid and thus have difficulties fulfilling the requirements. In order to add flexibility to the production system, the human-robot collaboration has been introduced. Human-robot collaboration can combine the flexibility of humans and the efficiency of robots, but bring the concern of human safety. Many researchers have applied the digital twin technology in the human-robot collaboration domain. The modelling of human behaviour for digital twin have potential to increase safety in human-robot collaboration.

Human behaviour models in human-robot collaboration

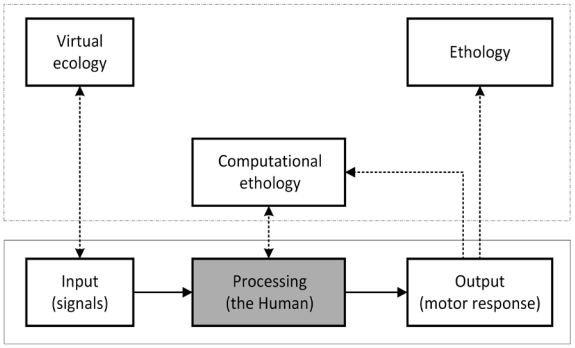
Current human-robot collaboration research focuses on the external context and physical human model, because these are essential elements of digital twin. However, the behaviour has not been analysed in depth to reveal personal preference, ability and skill. In contrast, researchers claimed the internal cognitive human model needs to be considered for safety, smooth collaboration and human welfare. The efforts have been put into applied psychology and neuroscience methodology for cognitive human modelling. The purpose was to understand the causal effect of cognition on human behaviour. Nevertheless, these research outcomes are limited to being implemented in industrial environment.



Human-information processing model in human-robot collaboration

Human behaviour models in ethology

Traditional ethology focused on observation and analysis of the naturalistic behaviour of animals. Computation Ethology is the extension of ethology which can link the observed behaviour with neural activities. Virtual ecology has been proposed to model naturalistic stimuli of the behaviour, but still has difficulty representing the complex natural environment. Furthermore, the ethology studies focus on how the behaviour adapted to the environment. The study of controlling the environment to fit the behaviour is out of the scope of ethology.



Human-information processing model in ethology

Research question

Current human-robot collaboration focused on recognition and monitoring of human behaviour, the deep analysis of human behaviour in human-robot collaboration is still lacking. Computation Ethology could be an effective way to fill the gap due to the sound base in the biology and neuroscience domain. Firstly, Computation Ethology considered the action sequence, transform possibility and hierarchical structure, which is useful for human action prediction at different time-scale. Secondly, Computation Ethology focus on behaviour observation from every individual. In contrast, the physical human model in human-robot collaboration

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lacks consideration for personal profile. Thirdly, unsupervised learning has been stressed for discovering behaviour, while the human annotation of behaviour is still widely utilized in human-robot collaboration.

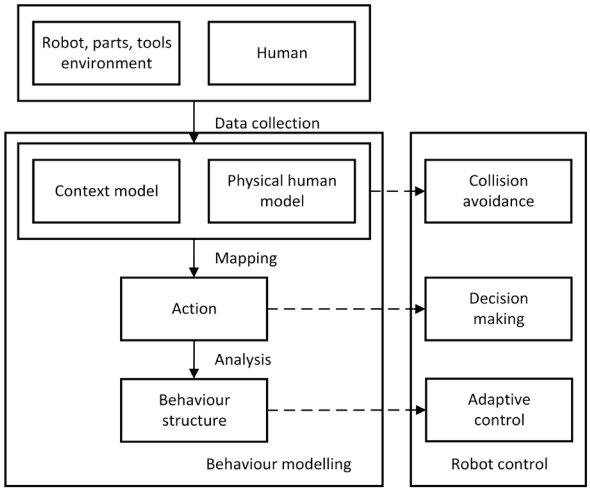
Nevertheless, Computation Ethology has difficulty to model naturalistic environmental, which could influence the behaviour. In contrast, digital twin of human-robot collaboration can model the relevant context. Hence, the knowledge could be extended by modelling the context-associated behaviour. On the other hand, Computation Ethology just focuses on observation and analysis but without any consideration to control the environment. Therefore, designing strategies for adaptive robot control to ensure safe working environment is another problem that should addressed. Therefore, the proposed research question is as follows:

How to model human behaviour for human-robot collaboration in industry environment based on physical human and context model?

Research methodology

The physical entities of this work are humans, robots, tools, parts and the environment. The overall research methodology includes data collection from these entities, behaviour modelling and robot control strategy design. On the one hand, behaviour modelling has three levels: context and physical human modelling, action mapping and behaviour structure analysis. These levels are adapted from the Computation Ethology, the context model together with physical human model can provide information such as human position, velocity and robot position and velocity. This can contribute to a deep understanding of human behaviour. Moreover, the data collection and action mapping already have good practice and foundation in human-robot collaboration. The further step behaviour structure analysis has potential to model action sequence, transform probability and structure to represent individual behaviour in different time scales.

On the other hand, in order to ensure a safe collaboration environment, the three levels of behaviour modelling will have corresponding robot control strategies. The context and physical human model can indicate the relative position and velocity of human and robot, and thus could be used for real-time collision avoidance. The action mapping can inform the robot of what the human is currently doing, so the robot can plan its path accordingly. The behaviour analysis can provide personal profiles such as preference, ability and skill, so the robot can be controlled adaptively.



Research methodology

The possible contribution of this work will be two parts: firstly, this work will provide human behaviour model based on physical human model and context model. The model can be used for safety measure design. Moreover, the model can contribute to the human-centric production environment design. Secondly, this work will design robot control strategies based on human behaviour model. This will not only ensure a safe collaboration environment but also have potential to increase the efficiency of production systems.