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# Human–Agent–Robot Teamwork (HART) Over FiWi–Based Tactile Internet Infrastructures

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## INTRODUCTION

In the current digital Darwinism era, technologies are evolving faster than the business organization can naturally adapt (Daugherty, 2018). In the past, business executives focused on using machines to automate specific workflow processes. Traditionally, these processes are linear, stepwise, sequential, and repeatable. But performance gains from that traditional approach have recently been leveling off, as companies wring the last bits of efficiencies from mechanistic automation. The traditional approach (either human-only activity or machine-only activity) has been to view humans and machines as rivals, each side fighting for the other's job. The truth is that companies can achieve significant boosts in performance, when machines and humans work together as allies, not adversaries, to capitalize on each other's complementary strengths. For instance, performing routine tasks and detecting hidden patterns in an image can be easy for machines, whereas dealing with unsatisfied customers can be easy for humans. To achieve higher productivity gains than traditional systems, currently leading firms in many industries are re-imagining their business processes to be more flexible, faster, and adaptable to customer behavior, preferences, and needs of their workers in a given moment. This trend of exploiting the adaptive system for symbiotic collaboration between humans and machines is unlocking what is known as the third wave of business process transformation. This collaboration allows weak workers to transfer tedious tasks to powerful machines and by enabling them to perform their work faster and more efficiently through expert guidance, advice, and support from artificial intelligence (AI) based systems. Hence, to realize beneficial human-machine coactivity in different business processes, the fundamental question that naturally arises is how to enable real-time collaboration and communication between humans and machines. To answer this question, some of the key technological terms are described below in greater detail:

To unleash the full potential of many real-time cyber-physical systems (CPSs) that harness human-machine interaction, including virtual and augmented reality, an extremely low round-trip latency of 1-10 milliseconds is required to match human interaction with the environment. This vision of ultra-low latency communications gives rise to the so-called *Tactile Internet*, which has recently emerged to steer/control virtual and physical objects (e.g., remote-controlled robots) and to transmit touch and actuation in real-time (Maier, 2016). Key Tactile Internet applications include real-time gaming, wireless controlled exoskeletons, remote surgery, elderly/disabled people care, driver-assistance systems to support humans in arriving safely and comfortably at their destinations. By enabling ultra-low latency communications between humans and machines in conjunction with carrier-grade robustness and availability, the Tactile

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Internet represents a paradigm shift from traditional wired and mobile Internet based content-delivery to labor-delivery networks via tactile/haptic devices. At the nexus of computerization, automation, and robotization lies the emerging Tactile Internet, which will be centered around human-to-machine/robot (H2M/R) communications by providing the medium for transporting haptic (i.e., touch and actuation) and non-haptic (data, video, and audio) traffic in real-time (Maier, 2018). By offering highly reliable and responsive network connectivity for real-time human-machine interaction centric applications, the Tactile Internet holds great promise to have a profound socio-economic impact on our everyday life, ranging from healthcare (e.g., remote robotic surgery), transport (e.g., driver assistance system) to entertainment (e.g., online gaming) and manufacturing industry. The long-term goal of the Tactile Internet is to enable emerging products and services that complement humans rather than substitute for them. Recently, Stanford University launches its inaugural report on "*Artificial Intelligence and Life in 2030*," in which they predicted that within next 10-15 years a vast amount of intelligent human-aware systems will be developed. Unlike the Internet of Things (IoT) without any human involvement in its underlying machine-to-machine (M2M) communications, the Tactile Internet involves the inherent human-in-the-loop (HITL) nature of haptic interaction and thus allows for a human-machine cooperative design approach towards creating and consuming novel immersive experiences via the Internet.

Recently, Garry Kasparov emphasized the need fora strong coordination process for better human-machine co-activity in his book "*Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins*," where he shows that a strong human worker + machine worker + weak coordination process is less effective than its weak human worker+ machine worker+ strong coordination process counterpart. In other words, an intelligent process with inferior technology and inferior knowledge outperforms a less intelligent process with superior technology and knowledge. This observation of Garry Kasparov was recently also appreciated by Google and other Silicon Valley companies. In fact, leading technological companies have been putting more efforts in developing AI systems that augment human capabilities (see, e.g., IBM's Watson) instead of replacing them with autonomous systems. According to Kasparov, this isn't just user experience (UX), but entirely new ways of bringing human-machine coactivity into diverse fields (e.g., business process and organization management) and creating the new tools/intelligent process we need in order to do so.

A promising approach toward achieving advanced human-machine coordination by means of a superior process for fluidly orchestrating human and machine coactivity may be found in the so-called *human-agent-robot teamwork (HART)* research (Johnson, 2011). In HART, the dynamic allocation of functions and tasks between humans and machines (e.g., robots and cloud servers) is crucial, which may vary over time or be unpredictable in different situations. HART differs from the traditional humans-are-better-at/machines-are-better-at (HABA/MABA) approach, which only allows human-only activity/machine-only activity without driving any symbiotic human-machine development in search for synergies (Bradshaw, 2012). Conversely, with a HART-centric Tactile Internet design approach, humans, collaborative robots, remote cloud, and decentralized cloudlet resources together acting as an intelligent multi-agent system exploit the different characteristics of requested tasks and jointly execute them by using smart orchestration techniques. Considering the underlying human-machine interaction in HART-centric Tactile Internet applications, the main challenge is to orchestrate how tasks can be best shared in concert. Collaboration and communication among HART members are essential to cope with dynamic changes in the task environment, thereby improving the task execution latency. Note that depending on location awareness, a HART task can be either a location oriented physical task (e.g., sensing at a given task location, moving and carrying products to another location), a location independent cognitive task (e.g., caching or object recognition, which might be offloaded for computation onto a powerful cloud server/agent

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