MANAGEMENT AND PRODUCTION ENGINEERING

AMMIN/DIGEP - Towards an AI-Driven Paradigm of Adaptive Virtual-Human Interaction: Personalized and Context-Evolving Data Representation

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Context of the research activity	Virtual-Human Interaction (VHI) represents an emerging paradigm of interaction in which humans engage with machines through intelligent virtual environments, immersive interfaces, or digital entities capable of mediating, enriching, and adapting the informational experience. Concrete examples include the use of extended reality environments in surgery, where clinicians visualize anatomical information overlaid onto the operative field; interactive digital twins in industrial settings, enabling the monitoring and simulation of complex systems; and advanced virtual assistants supporting operators in dynamic contexts. This type of interaction offers significant advantages in terms of cognitive augmentation, reduction of information overload, enhancement of situational awareness, and real-time decision support. The increasing availability of immersive technologies and artificial intelligence is rapidly accelerating the adoption of VHI, making it a key component of next-generation systems. In high-complexity domains such as healthcare, advanced manufacturing, aerospace, and robotics, there is a growing need for adaptive human-virtual interaction systems capable of supporting fast and reliable decision-making while dynamically adapting to evolving operational conditions and to intra- and inter-individual variability among users. However, current solutions are predominantly characterized by static or weakly adaptive approaches, where data representation and interfaces are designed according to average or predefined models, without systematically accounting for user-specific characteristics or the evolution of tasks and operational scenarios. This limitation reduces system effectiveness, usability, and safety, especially in critical contexts, where information overload or inadequate representations may negatively impact performance. In this context, it becomes essential to develop approaches that are not based only on information filtering and prioritization, but also make explicit the processes through which data are transformed and combined. Information representation should therefore not be considered as a final stage, but rather as the outcome of a continuous sense-making process, in which content,

	level of detail, and modes of presentation are dynamically adapted.

Objectives	For the reasons explained above, the concept of adaptive data representation becomes crucial, defined as the system's ability to dynamically modulate what is presented, how it is presented, and why, based on the operational context, the task, and the user's state. Several open challenges remain: (i) real-time and dynamic user modeling; (ii) the definition of data representation adaptation strategies that are contextually relevant, interpretable, and verifiable; (iii) the integration of user-centric and task-driven adaptivity in evolving operational scenarios; (iv) the transparency and explainability of information transformation processes; and (v) the quantitative validation of the impact of such systems on performance, safety, and user experience. To address these challenges, this research proposes the development of a novel paradigm for adaptive human-virtual interaction based on Artificial Intelligence (AI) techniques, aimed at enabling personalized and evolving data representations that continuously adapt to both individual characteristics and the operational context. In particular, the research will investigate an integrated framework combining multimodal user profiling models, real-time adaptation algorithms, and interactive virtual environments. The goal is to move beyond the traditional one-size-fits-all approach by introducing systems capable of co-evolving with both the user and the task, ultimately improving decision-making effectiveness, safety, and overall interaction quality. In this scenario the objective of this PhD project is to develop a novel paradigm of adaptive human-virtual interaction, grounded in the synergistic integration of artificial intelligence, user modeling, and dynamic information representation. The overarching goal is to overcome the limitations of current approaches by introducing systems capable of continuous, personalized, and context-aware adaptation, transforming data representation into an active and co-evolutionary process involving the user, the task, and the environment. In particular, the project aims to pursue the following research objectives: Development of advanced user profiling models based on heterogeneous data, capable of capturing in real time the user state and behavior during interaction. Design of innovative adaptive data representation strategies able to dynamically modulate content, granularity, and visualization modalities according to the context, the task, and the user's characteristics, enabling advanced sense-making processes. Integration of user-centric and task-driven adaptivity, to support a human-system co-evolution, in which interaction dynamically reconfigures based on operational goals and scenario events. Introduction of mechanisms for transparency and explainability (XAI) in data transformation and presentation processes, making explicit the rationale behind adaptive decisions and increasing trust and system reliability. Development and integration of immersive virtual environments and interactive digital twins as enabling platforms for the experimentation of advanced Virtual-Human Interaction paradigms in high-criticality contexts.

	The ideal candidate should hold a master's degree in engineering (mechanical, biomedical, industrial, or computer science), with proven

Skills and competencies for the development of the activity	knowledge or interest in the following areas: Knowledge of Human-Computer Interaction (HCI) and Human-Machine Interaction (HMI) principles Familiarity with user-centered design methodologies and usability evaluation techniques Basic understanding of data processing and information systems, including data integration and transformation Interest in Extended Artificial Intelligence, combining Artificial Intelligence and advanced interaction technologies for adaptive and context-aware systems Competence in experimental design and data analysis, including both quantitative and qualitative approaches Programming skills (e.g., Python, C#, or similar)