Digital Companion for Industry

Artificial meets human intelligence

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ABSTRACT

The industrial domain offers a high degree of standardization, a variety of very specialized use cases, and an abundance of resources. These characteristics provide perfect conditions for Digital Companion systems. A Digital Companion is a cognitive agent that assists human users by taking on three roles: as guardians, assistants or mentors, and partners. This paper describes the characteristics, conceptual architecture, use cases and open challenges regarding Digital Companions for industry.

KEYWORDS

Digital Companion, Digital Twin, Cognitive Agent, Semantic Technologies, Human Machine Interaction.

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1 Introduction

Digital innovation in industry will result in the creation and collection of massive amounts of digital machine data during a machine's lifetime. New ways of human machine interaction enable proactive machines that evolve from bare tools to smart companions [3]. The challenge is to provide actionable information for human users and to find the right balance of proactivity for machines such that humans and machines can collaborate more effectively and meaningfully together. We propose the development of a Digital Companion, which will digest, integrate, share, and act upon information with humans so that they can focus on meaningful tasks.

A Digital Companion [1] is a helpful cognitive agent that knows the habits of its users, talks to them, entertains them, and can assist them in performing tasks. A Digital Companion considers the implications of empathy, and theory of mind: they learn by imitation and assist in everyday tasks. The term companion has been around for almost two decades now [2]. It builds upon the earlier concept of social robots [4] which describes autonomous robots able to interact and communicate with humans using human-like qualities of interactions, such as trust and empathy. These companions provide useful assistance in a socially acceptable manner. Sociable robots focus on imitating human interaction, and non-verbal communication (e.g., nodding, acknowledgement by posture, and feedback emphasis).

A Digital Companion must have an understanding of machines, components, connectivity, component functionality, component assembly, procedures, and of human-related concepts such as needs/goals/responsibilities, plans, actions, roles, themes, etc. It has to have access to and choose from various forms of presentation and explanation (modality) about a specific problem domain such that it can seamlessly assist users in their work, guide them through new situations, and provide help when and how necessary. Additionally, it has to have the ability to understand its surroundings/context, i.e. terminology, involved objects, users, and roles, and how they relate to the task at hand. A Digital Companion enhances the decision-making capabilities and actions of a person instead of merely taking over. To provide seamless interaction between humans and machines, Digital Companions need to be trustworthy, act for

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the benefit of humans, take care of privacy issues, follow safety guidelines, and above all not be annoying or waste our time in any way.

Popular digital assistants (e.g., Alexa, Google home, Google duplex) are good examples of how humans are getting used to relying on devices to perform simple daily tasks. Those assistants respond to specific requests based on simple pattern matching but do not actually understand what is being said to them. Even with such obvious limitations they have proven quite useful and people are beginning to treat them as though they have greater intelligence and understanding than they do. A Digital Companion, instead, is an entity that understands the situation a human is in, understands the role he is currently playing, his needs, and his goals. A Digital Companion is contextually responsive and able to react to current events.

In this paper we describe the characteristics, a conceptual architecture, industrial use cases, and conclusions on open challenges for developing Digital Companions for industry.

2 Characteristics of a Digital Companion

A Digital Companion consist of three key characteristics: (1) access to shared knowledge (knowledge base), (2) adaptability to users and their context (adaptability), and (3) embodiment as an autonomous entity (embodiment).

2.1 Knowledge Base

In order to enable a Digital Companion to provide useful recommendations and assistance to human users, it needs to have access to a shared knowledge base which describes the properties of entities and the relations between them as well as procedures to transition from one status to another. The underlying foundation of the knowledge base is a set of ontologies, which specify the semantic models underlying data. By integrating different ontologies, different types of data can be related through inference. The ontologies forming the knowledge base can be extended and revised as new data arrives, either explicitly edited or implicitly obtained by observing the user [5]. In a world of agents, it is important that the concepts represented in ontologies be validated by open communities, so it is advantageous to use standardized or standard-compliant ontologies such as SSN, and QUDT whenever possible [10].

Another source of information is established repositories of data and ontologies, such as DBpedia, which provide some generic relationships between entities and terminology even if the ontologies aren't standardized. With the help of machine learning and natural language processing, the companion can extract useful relations from repositories such as these and conceptualize them into the knowledge base. Using these approaches, a Digital Companion can evolve with the ever-changing world (domain) and remain aware of the current context. There is also a need to account for the provenance of data (using, for example, the PROV-O Provenance ontology) such that the knowledge can be assessed by its consumers in terms of credibility and trustworthiness. The knowledge base can answer what it knows, and from where the knowledge was obtained. A Digital Companion represents a helper and mediator that navigates a user through various tasks and seamlessly obtains relevant information by shielding the user from the complexity of underlying systems.

A Digital Companion is also able to extract tacit knowledge from the real world and from the user, e.g. operational knowledge a user exhibits by his actions but would not necessarily be able to express explicitly. When Digital Companions are widely adopted into a particular domain, all the observed data such as best practices, rules of thumb, and common-sense knowledge can be statistically derived and then stored back into a structured information model.

2.2 Adaptability

Another important aspect of Digital Companions is the ability to continuously learn about their users and the associated processes in real-world contexts. Each user has different preferences, backgrounds and experiences. Therefore, Digital Companions have to adapt to the individual user, construct a model about the user, and follow specific preferences and needs. A Digital Companion establishes trust with its user by providing the right information in the right manner at the right time. This requires constructing a model about the users' skills and experiences, history of actions, needs and preferred ways of interaction. A Digital Companion has the means to estimate a user's physiological, emotional, and affective state and builds up a model of the user's level of support and affective responses. A Digital Companion knows how often a user needs to be commended and what forms of appreciations work for them.

A Digital Companion will also adopt the concept of reinforcement learning, which allows users to encourage or discourage certain behaviors using repetition. Users can give feedback to their Digital Companion whenever an action is taken. If an action was repeatedly deemed inappropriate under the same kinds of situation, the companion can learn and avoid performing such an action. In addition to user induced learning, a Digital Companion can learn on its own by observing and collecting data, and then generalized it into the knowledge base. Since a Digital Companion is contextually aware, a user can teach the companion by adding more specific instances of knowledge into the information model. A companion can remember things like preferred route of travel, personal schedule, and instructions to perform specific tasks.

2.3 Embodiment

A Digital Companion can have many embodiments and appearances, which means it resembles a character with a name referring to an entity. This manifestation supports the notion of familiarity and encourages users to interact with a Digital Companion and to engage in dialog with it. The appearances of an embodiment of a Digital Companion range from a simple chatbot to a simulated face in Augmented Reality.

Depending on the domain, the human-computer interface will have to feel natural to its intended users. For example, a factory operator's Digital Companion has access to an information model of a SCADA system based on the OPC UA standards and related companion models. The Digital Companion can then potentially interoperate with more OPC UA certified devices but also allows subsequent queries into the system. Meaningful actions such as maintenance reminders, anomaly alerts, and troubleshooting support can be generated according to the role or the skillset of the operator. The operator can communicate with the Digital Companion via voice commands that are received, for example, by a wearable wrist watch.

3 Conceptual Architecture

The architecture of a Digital Companion (shown at Figure 1) must acknowledge that it interacts with a human user (at 2) and the world (at **3**). Users interact with the world through their senses. Humans acquire information using sensory perceptors, such as their eyes and ears, and humans affect the world using perceptual effectors, such as speech and touch. A Digital Companion interacts with a user using the same kinds of sensory information, depending on the context. That is, through language, visual, tactile, etc. information. At the same time, a Digital Companion also interacts with the world (at **3**) but is less restricted than a user might be since it can work directly with raw signals and it can interact directly with systems using well-defined APIs. An example of what a Digital Companion can do that a human user cannot, is to go beyond human sense, e.g. sense frequencies as input outside the human perception spectrum between about 20Hz and 20,000Hz.

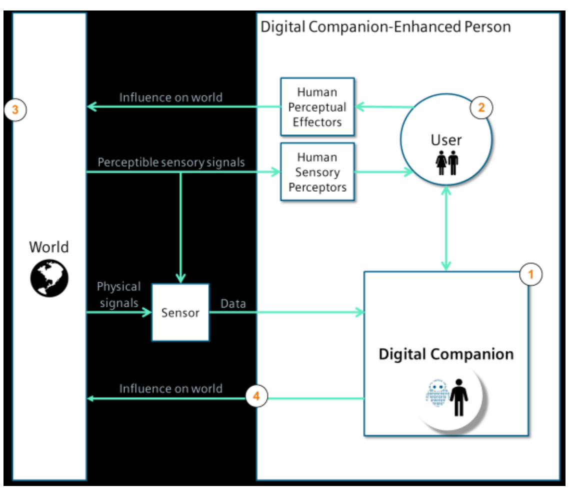

Figure 1: Digital Companion - overall interaction model

The Digital Companion portion (at **1** in Figure 1) is expanded in Figure 2. In this diagram, a user is depicted as a *Human-Machine Interface* (at **2** in Figure 2) which receives and translates perceptual information from a user, such as speech, into a *Conceptual Model* (at **3**), and translates conceptual information back into perceptual information for a user. As mentioned in the discussion of Figure 1, a Digital Companion can interact with the world. In Figure 2 this is shown with a *Data Interface* (at **4**). Also mentioned in Figure 1, the *Data Interface* enables a Digital Companion to interact with many kinds of information and APIs.

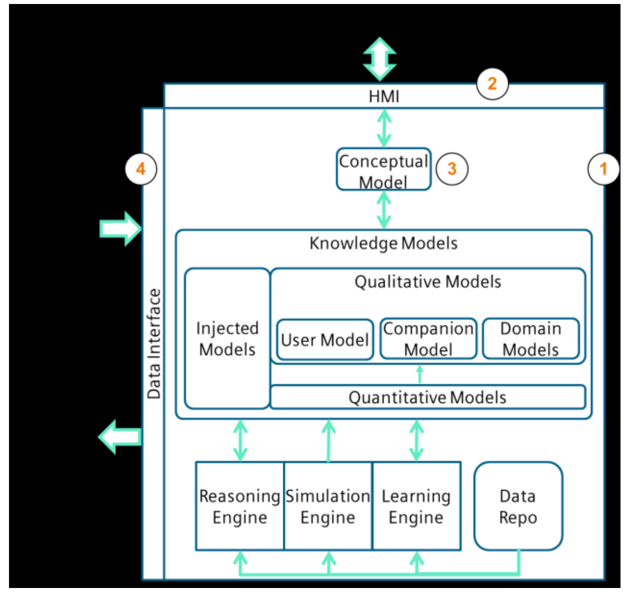

Figure 2: Digital Companion - internal components

Core to a Digital Companion is the ability to operate on conceptual information from a user (by using a Conceptual Model, at **3**) and digital information from the world (at **4**), to understand each type of information, but also to react to it. In order to do so, a Digital Companion must have a model of a user as well as a model of the world, each of these, along with the companion's own model must be malleable, in that they can change over time. These models are shown expanded in Figure 3:

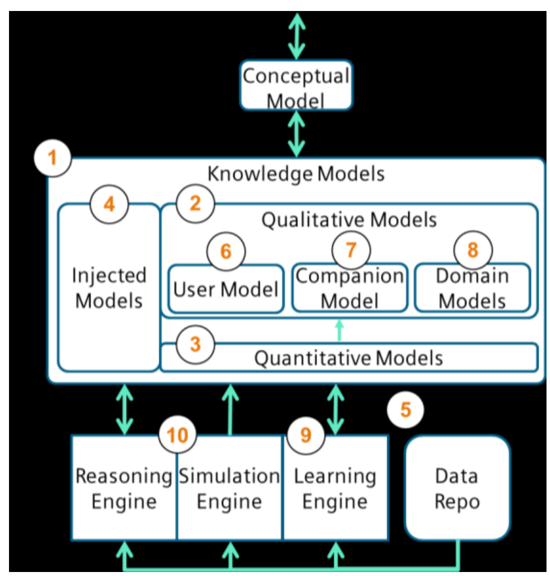

Figure 3: Digital Companion - system architecture

A focal point of the Digital Companion is its knowledge of the world, shown in Figure 3 as an integrated set of *Knowledge Models* (at **1**). These models are further divided into 3 types: *Qualitative Models* (at **2**), *Quantitative Models* (at **3**), and *Injected Models* (at **4**).

Qualitative models are what we think of as conceptual or symbolic models and can be used to represent and integrate any kind of concept. Quantitative models are algorithmic and numerical. Think of a CAD model of geometry or a differential equation as quantitative models. In Figure 3 we show *Quantitative Models* feeding *Qualitative Models* because there can be a mapping from the features and values of *Quantitative Models* to *Conceptual Models*, but not the other way around. *The Injected Models* (again, at **4**) are a specialized form of models used to represent commonsense rules, which differ from the other models in that they are immutable. They can be used but not modified. We use the term injected because they are not learned in this architecture but represent culturally-relevant commonsense knowledge.

Users and Digital Companions each have a *Qualitative Model* that is used by a Digital Companion to make sense of information that becomes available to the system (all incoming data at **5**). Both, the model and the data represent why a user acts the way he does, or why he asks the kinds of questions he asks, which provides a baseline for how to interact with him. This *User Model* (at **6**) must be adaptive, because a Digital Companion will learn how to interact with its user over time, and so the model must change over time as well. Likewise, the *Companion Model* (at **7**) will change over time. The last group in this cluster are the *Domain Models* (at **8**), which represent all the domain knowledge the system has access to. These models are also mutable.

The *Learning Engine* (at **9**) is used to improve all *Qualitative Models*. The *Simulation Engine and Reasoning Engine* (at **10**) are similar but different. They are similar because they are comprised of similar computational mechanisms. They are different because the *Simulation Engine* is used to perform thought experiments and integrate the results, while the *Reasoning Engine* is used to ask and answer questions about known information. The mechanisms associated with decision making, autonomous behavior, model improvement, planning, and problem solving are modules that take model information and data, analyze it, map it into an action model, and act.

4 Roles and Use Cases

This section provides various use cases and matches them to classification of [2] distinguishing between Digital Companions as guardians, assistants or mentors, and partners.

4.1 Digital Companions as Guardians

Performing certain tasks in the workplace does not only require specific skills but also exposes workers to different types of hazards, e.g. drilling requires training and continuous drilling in loud environment can cause hearing loss. Successful task completion requires selecting the right worker and ensuring safe execution. Potential hazards should be mitigated with existing knowledge about safety from recommendation standards. This can be accomplished by combining a semantic reasoner with knowledge models that codify complex workplace safety constraints published by the Occupational Safety and Health Administration (OSHA) while integrating real-time data from sensors (e.g., a visual physiology tracking device) [7]. A mobile system that knows OSHA rules and locations can be used to track personal protective equipment at job sites [6].

Building a Digital Companion based on well-known regulations and standards allows users to trust not only the suggestions of the Digital Companion but also the execution of instructions. This example shows the importance of contextual knowledge as different physical limitations and different workstations require different plans and personal protective equipment.

4.2 Companions as Assistants/Mentors

A Digital Companion can help human users by providing personal assistive services to fulfill tasks, which they themselves would otherwise be unable to perform. With the help of a Digital Companion a user can then develop new skills based on their individual requirements while having a safe guard in place that prevents more severe failures or even harm to the user.

An approach to design scalable and flexible agent-based manufacturing systems that integrates automated planning with multi-agent-oriented programming is presented in [9]. The system uses the Web as an application architecture (and not just as a transport layer), which facilitates the seamless integration of geographically distributed production cells. In a prototypical production cell featuring an industry-grade robot, an augmented reality interface assists the human workers with instructions and guidance following through the manufacturing process.

4.3 Companions as Partners

A Digital Companion can be embodied as an intuitive gateway to complex, distributed information and support during the decision-making process and discuss alternatives. For example, a factory manager needs to make sure that the geographic workforce distribution is sufficient and that the status of factory assets is all in good condition. Therefore, managers need to have easy and intuitive access to the locations of their workforce and to product lifecycle information. To create a partner-like Digital Companion, Semantic Technologies and Augmented Reality are combined to provide context-specific information and allow for hands-free and ubiquitous access to distributed information sources anywhere on a factory floor. This integrated information platform acts as a partner for managers in their decision-making process regarding workforce, assets or tasks [8].

5 Conclusions and Next Steps

This paper introduced the idea of a Digital Companion for industry and outlines its characteristic, architecture and selected use cases. The presented use cases illustrate the various Digital

Companion roles of guardian, assistant, mentor, and partner which extend the capabilities of human users instead of replacing them.

The creation of Digital Companions provides several technical challenges for the research community. Firstly, knowledge and data are the core powering the logic, thus, what kinds of data sources and knowledge bases are suitable for a Digital Companion? Secondly, for a Digital Companion to adapt to new contexts, how can a Digital Companion understand the appropriate context and learn only when and what is meaningful? Thirdly, a Digital Companion interacts with diverse users, how can a Digital Companion strike a balance between being useful and being overwhelming to the users? Lastly, users have to trust that the companion will provide accurate information, keep personal data private, prioritize the users' safety and comfort, and not waste user's time. This trust has to be established and maintained throughout the life cycle of a Digital Companion. How can the Digital Companion evolve within a boundary of trust?

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