Enhancing Human-in-the-Loop Adaptive Systems through Digital Twins and VR Interfaces

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Abstract: This work has been published as a full paper at SEAMS'21 [Yi21]. In the context of self-adaptive systems, there are situations where human involvement in the adaptation process is beneficial or even necessary. For such "human-in-the-loopädaptive systems, two major challenges, namely transparency, and controllability must be addressed to include the human in the self-adaptation loop. Transparency covers the context information about the adaptive system and its context while controllability targets the decision-making and adaptation operations. As existing human-in-the-loop adaptation approaches do not fully cover these aspects, we investigate alternative human-in-the-loop strategies by using a combination of digital twins and virtual reality (VR) interfaces. Based on the concept of the digital twin, we represent a self-adaptive system and its respective context in a virtual environment. For integrating the human in the decision-making and adaptation process, we have implemented and analyzed two different human-in-the-loop strategies in VR: a procedural control where the human can control the decision making-process and adaptations through VR interactions and a declarative control where the human specifies the goal state and the configuration is delegated to an AI planner. We evaluate our approach based on an autonomic robot system that is accessible through a VR interface.

Keywords: Self-Adaptive Systems; Human-in-the-loop; Virtual Reality

1 Introduction

In this paper, we discuss the benefit of human involvement in self-adaptive systems and the need for increased transparency and controllability in such human-in-the-loop adaptive systems. To address these issues, we have presented a solution approach for enhancing human-in-the-loop adaptive systems through digital twins and VR interfaces. For supporting the aspect of transparency, based on the concept of the digital twin, we represent a self-adaptive system and its respective context in a virtual environment. With the help of a virtual reality (VR) interface, we support an immersive and realistic human involvement in the self-adaptation loop by mirroring the physical entities of the real world to the VR interface. For supporting the aspect of controllability and integrating the human in the decision-making and adaptation process, we have implemented and analyzed two different human-in-the-loop strategies in VR: a procedural control where the human can control

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the decision making-process and adaptations through VR interactions (human-controlled) and a declarative control where the human specifies the goal state and the configuration is delegated to an AI planner (mixed-initiative). The solution approach which combines digital twin and VR interfaces has been evaluated regarding efficiency, effectiveness, and user satisfaction and shows great potential in increasing the transparency and control of human-in-the-loop adaptive systems.

2 Main Findings

Concerning efficiency, the results show that declarative control provides 35.2% faster task completion. This is an expected result because the number of interactions is less compared with declarative control. The effectiveness of the VR interface is the same with each control strategy. Differences can be seen regarding the effectiveness of the VR interface and the execution on the real Dobot Magician system. This is expected, due to potentially imprecise sensor data. In general, the user satisfaction data show promising results for the practical usage of the VR interface for human-in-the-loop involvement.

Our results show that using a graphical representation, such as a VR interface, it is possible to provide transparency about the system state. This approach does not require users to have extensive domain knowledge to reason about the system. Moreover, with our approach, people who used the system for the first time, were able to intervene in the system to complete a task by involving in its self-adaptation loop. We report that with procedural control, the users need more time to complete the task, but they have more freedom to define what exactly the system should perform. On the other hand, with declarative control, the users save a significant amount of time to complete the task, gain a slight precision benefit due to automated motion calculation, but they have less freedom to express their intentions.

3 Data Availability

The code repository of our developed solution for enhancing human-in-the-loop adaptive systems and corresponding evaluation data can be found on GitHub[5].

Literaturverzeichnis

[Yi21] Yigitbas, Enes; Karakaya, Kadiray; Jovanovikj, Ivan; Engels, Gregor: Enhancing Human-in-the-Loop Adaptive Systems through Digital Twins and VR Interfaces. In: 16th International Symposium on Software Engineering for Adaptive and Self-Managing Systems, SEAMS@ICSE 2021, Madrid, Spain, May 18-24, 2021. IEEE, S. 30–40, 2021.

[5] https://github.com/kadirayk/HiL-VR-DT