Eric Vollenweider

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Augmented Reality in Robotic Applications

1. Introduction

Augmented Reality (AR) can help us to communicate with robots in three dimensions. With rapid advancements in the field of robotics during the last few years [1], innovative ways to program, develop and operate these highly complex systems need to be researched. This literature review focuses on the combination of Augmented Reality and robotics in academic research and in real-world applications. Both robotics and AR have been researched heavily for the last 20 years, but their combination has mostly remained untouched. Lately though, it has become a new focus area in research.

AR technology must not be confused with virtual reality (VR). Whereas VR completely immerses users, the former still allows the real world to be seen together with superimposed 3D objects projected into the user's view. T. Azuma crafted a very general definition of AR-Systems very early on [2]. He wrote that, in order for a system to be classified as an AR system, it has to fulfil three characteristics. Namely, the system has to combine real and virtual objects, be interactive in real time and spatially map physical and virtual objects to each other. The term Augmented Reality is often used as a synonym for the also commonly used expression “Mixed Reality”.

2. Advantages of AR during development and testing

Wolfgang Hönig et al. examined three different use cases of Augmented Reality [3]. The research team primarily focused on the benefits offered by the co-existence of virtual and real objects during the development and testing phase. They documented three individual projects where the implementation of AR as a main feature resulted in lowered safety risks, simplified debugging and the possibility of easily modifying the actual setup.

Another important dimension of development and testing is of financial nature: upfront investments and operating costs. For example, robotic aerial swarms tend to be quite expensive due to the high cost of drones. Hönig et al. successfully scaled up the number of objects in their swarms without adding physical hardware, thus, saving money and space [3]. However, it is stated that this approach might not be applicable to all experiments since simulations are never perfect replicas of actual systems. This small delta in physical behaviour might be enough to raise doubts regarding the correctness of the experiment results.

All projects by Hönig et al. focus on isolating certain aspects of the system to analyse and test them more flexibly, less expensively or with improved safety for all participants involved (humans and machines). Similarly, Wünsche et al. have created a software framework for simulating certain parts of robotic systems [4]. These researchers from Auckland worked on methods to combine real world and simulated sensor data and navigate a real-world robot in the combined environment. Although the team concluded that their project was successful, it is mentioned that there is the still unresolved problem that real-world objects cannot be included in the simulated space after leaving trackable areas. Without knowing the real world object’s exact location the AR-application does not precisely know the properties of the object and thus may not be able to fulfil its task.

3. Operating robotic systems with AR support

A well-known bottleneck in robotics is the controlling of and thus, the communication with robots. In all previously cited cases, Augmented Reality was not used to enhance the interaction between humans and robots but to mitigate the current challenges in developing robotic systems. Very early work by Milgram et al. [5] shows that even the most basic implementations of AR technology, with the objective to improve the information exchange, enhance the bidirectional communication in multiple ways. The team proposed means to relieve human operators by releasing them from the direct control loop and using virtually placed objects as controlling input parameters. This replaces direct control with a more general command process.

As Gary Klein et al. stated, communicating intent is a key issue in effective collaboration within teams [6]. Whenever robots and humans collaborate in a close manner, it is critically important to know each other's plans or strategies in order to align and coordinate joint actions. For machines lacking anthropomorphic and zoomorphic features, such as aerial and industrial robots, it is unclear how to communicate the before-mentioned information in natural ways.

In order to solve this problem, Walker et al. [7] explored numerous methods to utilize Augmented Reality to improve both efficiency and acceptance of robot-human collaborations via conveying the robot's intent. The group of researchers defined four methods of doing so, with varying importance being put on "information conveyed, information precision, generalizability and possibility for distraction" [7]. The conclusion was that spatial Augmented Reality holograms are received much more intuitively than simple 2D projected interfaces in terms of acceptance, usability and efficiency. Both objective and subjective results shown in the research paper seem to support this statement statistically.

Communication with robot swarms is another possible use of AR for information exchange. Payton et al. from the HRL Laboratories developed ways for search-and-rescue professionals to work with swarms of survivor seeking robots [8]. In their work, each robot draws a virtual gradient arrow along their individually known shortest path to the end target. The end-user is then presented numerous arrows pointing in the desired direction. It is of note taht the proposed systems were implemented in a distributed manner, utilizing all methods of swarm intelligence. Payton et al. state that partly concealed swarm parts cannot contribute to the system from a technical point of view [8] and thus, mentions a significant problem with vision-based technologies in robotics.

4. Conclusion

This literature review outlines dated and more recent research on the use of Augmented Reality in robotic applications. Many advantages of such a utilization where discussed. AR technology can improve working with robotic systems, not only in operation [5, 8, 7] but also during the development phase [3,4].

However, there are barriers to overcome in future projects. There is still the unresolved problem of real-world entities leaving the trackable area causing the AR system to temporarily lose the link between the real and simulated space [4, 8]. In many cases, this renders the virtual augmentation useless, since important information depending on these non-trackable objects can no longer be transferred anymore.

Furthermore, head-mounted AR displays with sufficient usability are still a very recent development. Therefore many research projects are being initiated all over the robotic community, to find meaningful and efficient ways to implement new AR capabilities into the robotic systems. This steadily emerging field needs standardization to avoid excessive numbers of potentially incompatible variants in communication systems. A very general framework suitable for a variety of use cases is required. The framework would not only offer standardization but also minimize the initial effort developers and researchers experience when starting their work on Augmented Reality systems by guiding them through the initial phase of their projects. Furthermore, a unified technology base allows more sharing and re-use of other project outcomes, which could improve development and research speed significantly.

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Eric Vollenweider

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Augmented Reality in Robotic Applications

Introduction

Augmented Reality (AR) can help us ~~humans~~ to communicate with robots in three dimensions. With rapid advancements in the field of robotics within the last years ([2]) innovative ways to program, develop and operate these highly complex systems need to be researched. This literature review will focus on the use of Augmented Reality combined with robotics in academic research and in real world applications. Both robotics and AR have been researched heavily for the last 20 years, but their combination remains almost untouched and is topic to brand new research.

AR technology must not be confused with virtual reality (VR). Whereas VR completely immerses users, the former still allows the real world to be seen—composited with 3D objects projected into the users view. T. Azuma crafted a very general definition for AR-Systems very early on ([1] T. Azuma 1997). He wrote that in order for a system to be classified as an AR system it has to fulfil three characteristics. Namely, the system has to combine real and virtual objects, be interactive in real time and spatially map physical and virtual objects to each other.

Advantages of AR during development & testing

Wolfgang Hönig et. al. examined ~~the possibilities of~~ Augmented Reality in three different use cases [3]. The research team primarily focused on the benefits that the co-existence of virtual and real objects delivers during the development and testing phase. They documented three individual projects implementing AR as a main feature, showing that eliminating safety risks, simplifying debugging and modifying the actual setup (chapter IV) is indeed possible and has a positive impact in each individual case.

Keele

Other important aspects during development and testing are costs. For example, robotic aerial swarms tend to be quite expensive due to the nature of drones. Hönig et. al. successfully scaled up the number of objects in their swarms without adding hardware, ~~and~~ thus, saving money and space. It is stated though, that this approach might not be applicable to all experiments, since simulations are never a perfect replica of the actual system. This small delta in ~~different~~ physical behaviour might be enough to obscure experiment results.

cost

causes doubts regarding the usefulness of these experimental results.

All projects by Hönig et. al. ~~are~~ focused on isolating certain aspects of the system to analyse and test them more flexible, cheaper or to increase safety for all participating parts (humans and machines). Similarly to ~~that~~, Chan, MacDonald and Wünsche created a software framework for simulating certain parts of robotic systems [4]. The researches from Auckland worked on methods to combine real world and simulated sensor data and then navigate a real world robot in the combined environment. Although the team concluded their project as successful, it is mentioned that there is the unsolved problem of real world objects leaving trackable areas and thus loosing the possibility of including them in the simulated space.

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cannot be included in the simulated space after leaving trackable areas..

Operating robotic systems with AR support

A well-known bottle neck in robotics is the controlling and thus, ~~communicat~~ing with robots. In all previously cited cases, Augmented Reality was not used to enhance the interaction between humans and robots but to mitigate the current challenges in developing robotic systems. Very early work from Milgram et. al. ([7] 1993) shows that ~~also~~ even the most basic implementations of AR technology, with the target to improve information exchange, enhances the bidirectional communication in multiple ways ([7] Conclusion). The team proposed means to Off-Load the human operator by releasing him/her them from the direct control loop and using virtually placed objects as controlling input parameters. This ~~morph~~s replaces direct controlling into a more general commanding.

of Communication

control with a more general command system/process

Off-Load -> rephrase

Communicating ~~an entities~~ intent is a key point of effective collaboration within teams [Gary Klein et. al. 13]. The team states that whenever Robots and humans share a work together common ground it is utterly important to know each other's plans to coordinate joint actions. For machines lacking anthropomorphic and zoomorphic features, such as aerial and industrial robots, it is unclear how to communicate the said information in a natural way.

In order to solve this problem,

Building upon that knowledge, Walker et. al. (12, University of Colorado) explored numerous ways to utilize Augmented Reality to improve both efficiency and acceptance of robot-human collaborations via conveying the robots intent. The group of researches defined four methods of doing so, with varying importance put on "[...] information conveyed, information precision, generalizability and possibility for distraction [...]" (quotation 12). The drawn conclusion was that spatial Augmented Reality Holograms are received much better than simple 2D projected interfaces in terms of acceptance, usability and efficiency. Both objective and subjective results shown in the research paper seem to support this statement statistically.

Communication with robot swarms is another possible use for AR concerning information exchange. Payton et. al. from the HRL Laboratories developed ways for search-and-rescue professionals to work with swarms of survivor seeking robots ([6] 2002). In their work each robot draws a virtual gradient arrow along their individually known shortest path to the end target. The end-user is then presented ~~confronted~~ with numerous arrows pointing into the desired direction. It is of note ~~to notify~~ that the proposed systems were ~~is was~~ implemented in a distributed way, utilizing all methods methodology of swarm intelligence. [6] Payton et. al. states that partly concealed swarm parts cannot contribute to the system from a technical point of view and thus mentions a big problem with vision-based technologies in robotics.

Conclusion

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This literature review outlines older and recent research on the possibilities of Augmented Reality in robotic applications. Many advantages of such a utilization where discussed. AR technology can

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improve the work with robotic systems not only in operation ([12, 6,7]) but also in development phases [3,4].

However there are barriers to overcome for future projects. There still is the unsolved problem of real world entities leaving the trackable area and thereby temporarily losing the link between the real and simulated space [4, 6]. In many cases this renders the virtual augmentation useless, since no

no longer

meaningful information can be transferred anymore.

Head-mounted AR displays with sufficient usability are still a very recent development, therefore

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many research projects are being initiated all over the robotic community. This steadily emerging

excessive ~~various~~ communication system variants.

field needs standardization to avoid a unobservable variety of communication systems. A very

is suitable for multiple / many / is required

general framework that can be concretized into specific use cases must be proposed by experienced

use

and knowledgeable teams.

(1090 words)

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