



Bachelor's Thesis

**Concept and development of a  
human robot interface  
using parametrised Augmented Reality**

**Konzept und Entwicklung einer  
Mensch-Roboter Schnittstelle  
mit parametrisierbarer Augmented Reality  
(GERMAN)**

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# 1 Introduction

## 1.1 Reasons for- and problems with Human-Robot collaboration

Today's world is highly automated in each and every aspect of our lives. One of the most important advancements within the last 30 years were robots. They allow us to minimize costs, while maximizing output, quality and efficiency. With the rising need of agile production plants, classic robotic systems do not seem to fulfil all requirements anymore. Industrial robots do have numerous abilities but adapting to new situations easily is certainly not one of them. In contrast, the human's strength always was exactly that - to learn quickly. Thus, Human-Robot (HR) collaboration is an inevitable step towards the future of humanity.

Robotics needed to adapt to the new situation where humans and robots share a perimeter, thus compliant robots were developed. For machines to feel natural it is not enough to be compliant and not hurt humans. As Gary Klein et al. stated, communicating intent is a key issue in effective collaboration within teams [1].

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 [2], innovative ways to program, develop and operate these highly complex systems need to be researched. Both robotics and AR have been heavily worked on for the last 20 years separately, but their combination has mostly remained untouched. Lately though, it has become a new focus area in research. While it is a known fact that AR can improve communication in certain use cases, the way how we develop these applications is not as clear. Most projects involving AR re-do most of the same steps over and over again, requiring software engineers along the way to do everything. Thus, the time-to-market is long and expenses are high.

According to the U.S. Department of Labour, there is a massive hunt for talent in the software industry [3]. The department reported an expected growth of over 30% within the next 10

years. One possible reason could be, that acquiring the necessary skills to develop software applications takes a long time and is not viewed as an easy path. Specifically AR applications currently require a wide variety of skills. On top of that, many processes and steps have to be repeated for each new AR-application and it is increasingly hard to build upon other peoples work.

The lack of programming talent is also seen in the robotics industry, which requires its developers to posses an even wider set of skills, including software development, mechanical and the basics of electrical engineering. Due to the lack of developers the speed of innovation and time-to-market is slowed as stated by multiple companies worldwide. [Citation maybe?]

## **1.2 Parametrised development as an approach to solve AR-developer shortage**

Today, most industrial robots are only parametrised and not actually programmed, which results in lower requirements for employees and thus in less time and money spent on training. Employees only set certain locations, points and actions utilizing an easy to understand User-Interface. Applying a similar methodology to the development of Augmented Reality applications could lead to similar effects. If non-programmers could setup, configure and thus develop Human-Robot interfaces involving AR and robot controlling all by themselves, without the need to write a single line of code, the cost efficiency and speed of innovation can be improved.

This bachelor thesis aims to research the feasibility and practicability of such an abstract development environment. First there will be a "State of the Art" section, where current research and progress is displayed. From there some gaps will be identified, a concept proposed, implemented and tested in a real application.

## 2 State of the Art

### 2.1 Augmented Reality in a nutshell

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 [4]. 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".

There are various types of AR devices and principles. In this bachelor's thesis the term AR should be understood as head-mounted superimposing Augmented Reality devices, such as the Microsoft HoloLens, that actually create the illusion of three dimensional holograms being projected into the real world.

#### 2.1.1 AR-Standardisation

C. Perey et. al [5] examined existing standards and some best-practice methods for AR. They clearly identified some gaps in the AR value-chain. The researchers lay out numerous standards for low level implementations such as geo-graphic location tracking, image tracking, network data transmission etc.

Figuerola et. al [6] researched about a "Conceptual Model and Specification Language for Mixed Reality Interface Components". They want to lay a foundation for other developers to standardize 3D interface assets, for others to build upon. The team developed an xml based data structure called "3DIC" that defines the look and some smaller behaviour actions of UI control elements. Although their work goes into the right direction, it lacks certain features

that robot-human AR interfaces need, and contains unwanted components like pseudo-code. "3DIC" is a specification language that cannot be fully processed automatically, since pseudo-code is not executable.

Concluding from this general overview, there does not seem to be an existing standard for HR Interfaces utilizing parametrised Augmented Reality, that allow the development of complete HR-AR-applications that can actually be processed, executed and used.

## 2.2 AR in Robotic applications

### 2.2.1 AR during development and testing

Wolfgang Hönig et al. examined three different use cases of Augmented Reality [7]. 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, physical 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 [7]. 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 [8]. 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.



### 2.2.2 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. [9] 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 [1]. 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. [10] 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" [10]. The conclusion was that spatial Augmented Reality holograms are received much more intuitively than simple 2D projected interfaces.

## 2.3 Parametrised Development in other disciplines

Numerous disciplines utilize parametrised development environments heavily. For example the CAD software *CADENCE* (integrated electrical circuits) offers parametrised cells to optimize the development process [11]. Users can place these cells and adjust certain parameters. Generally there is no coding skill required.

In architecture Parametric Design is taking overhand since the late 2000s. New capabilities in computer rendering and modelling opened up a whole new world for architects at the time. Using parametrised mathematical formulas with boundary constraints allows architects to generate building structures easier and more efficient [12]. Adapting to a changing

environment during the design process is much easier, since a substantial portion of work can be completed by algorithms and software applications. Additionally the reusability of components increases massively due to the very formal way of representation. Architecture studios also begin to include Virtual and Augmented Reality technologies actively in their design processes to further incorporate and better understand these new design styles called *Parametric Design*.

## 2.4 Current methods programming industrial robots

Almost all industrial robots are mainly programmed in three distinct ways.

- 1.) Teaching Pendant
- 2.) Simulation / Offline Programming
- 3.) Teaching by Demonstration

According to the British Automation & Robot Association over 90% of all industrial robots are programmed using the Teach Pendant method [13]. In the case of Fanuc controllers they basically are touch-tablets fitted for industrial use. They allow the operator to jog the robot into certain configurations, save the positions and offer a number of other possibilities. For easier operations Fanuc offers specific User Interfaces where the operator simply enters parameters and positions. More complex tasks can also be completed with the Teach Pendant, but I will not go into detail here.

Teach Pendants are great for trivial and simple tasks, that do not require lots of collaboration between factory components. Reprogramming the robot leads to downtime, since the actual real robot has to be used. Important to note is, that parametrised programming already is an industry standard in industrial robotics.

The other two methods are used for more complex tasks and production lines and each have their Pro's and Con's. While Offline Programming is very precise and powerful, it does require a substantial amount of schooling time for the operator. Teaching by Demonstration is the exact opposite. Everybody could succeed quickly, but the complexity of achievable tasks and the precision is limited.

## 2.5 Parametrised AR in Robotic applications

Many industries adopted Augmented Reality in their daily process already. It's advantages and challenges are clearly known and being worked on. Developing AR applications is generally speaking still a very costly task. On the other hand there is the design principle of "Parametrisation" that may involve increased initial investment but can lower the cost of changes and adaption to changing environments. Combining the perks of both AR technology and parametrised architecture may bear great potential.



### 3 Bibliography

- [1] G. Klein, P. J. Feltovich, J. M. Bradshaw, and D. D. Woods, “Common ground and coordination in joint activity”, *Organizational simulation*, vol. 53, pp. 139–184, 2005.
- [2] C. Laschi, B. Mazzolai, and M. Cianchetti, “Soft robotics: Technologies and systems pushing the boundaries of robot abilities”, *Sci. Robot.*, vol. 1, no. 1, eaah3690, 2016.
- [3] U. S. Bureau of Labor Statistics. (2018). Occupational outlook handbook, software developers, [Online]. Available: <https://www.bls.gov/ooh/computer-and-information-technology/software-developers.htm> (visited on 03/28/2019).
- [4] R. T. Azuma, “A survey of augmented reality”, *Presence: Teleoperators & Virtual Environments*, vol. 6, no. 4, pp. 355–385, 1997.
- [5] C. Perey, T. Engelke, and C. Reed, “Current status of standards for augmented reality”, in *Recent Trends of Mobile Collaborative Augmented Reality Systems*, Springer, 2011, pp. 21–38.
- [6] P. Figueroa, R. Dachsel, and I. Lindt, “A conceptual model and specification language for mixed reality interface components”, in *VR 2006, In Proc. of the Workshop “Specification of Mixed Reality User Interfaces: Approaches, Languages, Standardization*, 2006, pp. 4–11.
- [7] W. Hoenig, C. Milanes, L. Scaria, T. Phan, M. Bolas, and N. Ayanian, “Mixed reality for robotics”, in *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, 2015, pp. 5382–5387.
- [8] I. Y.-H. Chen, B. MacDonald, and B. Wunsche, “Mixed reality simulation for mobile robots”, in *2009 IEEE International Conference on Robotics and Automation*, IEEE, 2009, pp. 232–237.
- [9] P. Milgram, S. Zhai, D. Drascic, and J. Grodski, “Applications of augmented reality for human-robot communication”, in *Proceedings of 1993 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS’93)*, IEEE, vol. 3, 1993, pp. 1467–1472.

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- [10] M. Walker, H. Hedayati, J. Lee, and D. Szafr, “Communicating robot motion intent with augmented reality”, in *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*, ACM, 2018, pp. 316–324.
  - [11] V. Grozdanov, D. Pukneva, and M Hristov, “Development of parameterized cell of spiral inductor using skill language”, Apr. 2019.
  - [12] M. Stavric and O. Marina, “Parametric modeling for advanced architecture”, *International journal of applied mathematics and informatics*, vol. 5, no. 1, pp. 9–16, 2011.
  - [13] B. A. R. Association. (2018). Robot programming methods, [Online]. Available: <http://www.bara.org.uk/robots/robot-programming-methods.html> (visited on 04/07/2019).







# Declaration

The submitted thesis was supervised by Prof. Dr.-Ing. Birgit Vogel-Heuser.

## **Affirmation**

Hereby, I affirm that I am the sole author of this thesis. To the best of my knowledge, I affirm that this thesis does not infringe upon anyone's copyright nor violate any proprietary rights. I affirm that any ideas, techniques, quotations, or any other material, are in accordance with standard referencing practices.

Moreover, I affirm that, so far, the thesis is not forwarded to a third party nor is it published. I obeyed all study regulations of the Technical University of Munich.

## **Remarks about the internet**

Throughout the work, the internet was used for research and verification. Many of the keywords provided herein, references and other information can be verified on the internet. However, no sources are given, because all statements made in this work are fully covered by the cited literature sources.

Munich, December 1, 2016

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YOUR NAME