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Sensor-supported game mechanisms for augmented reality

Bachelor’s Thesis

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**Abstract.** bla

# Table of Contents

Table of Contents 2

1 Background 2

1.1 Introduction 2

1.2 Motivation 3

2 Literature review 4

2.1 Augmented Reality 4

2.1.1 Definitions and taxonomies 4

2.1.2 Applications 4

2.1.2.1 Industrial 4

2.1.2.2 Education and expertise transfer 4

2.1.2.3 Augmented reality games 4

2.1.3 Current technology 4

2.1.4 Outlook 4

2.1.4.1 Possibilities 4

2.1.4.2 Limitations 4

2.2 Sensors 4

2.2.1 Overview – sensors and actuators 4

2.2.2 Sensors in games 4

2.2.3 Sensors in augmented reality 4

3 Development of a framework for sensor-supported augmented reality games 4

4 Declaration of authenticity 4

5 Appendix 4

# Background

## Introduction

Augmented Reality is bigger than ever before. The recent success of the game Pokemon Go, coupled with advancements in the related domain of Virtual Reality, has spurred popular interest in the combination of real and virtual content which has long been an area of academic interest. Microsoft’s Hololens, a Mixed Reality HMD (head-mounted display), a development version of which was released in 2016, shows great potential despite a currently high price point.

This research paper seeks to provide an introduction into Augmented Reality and sensor technology and applications, with a special focus on video games, before attempting to design and implement in the Unity game engine a framework for sensor-supported Augmented Reality games.

## Motivation

This paper builds on the work the author performed during an internship at the Open University of the Netherlands, as part of the WEKIT project. WEKIT (Wearable Experience for Knowledge Intensive Training) is a European research project that aims to develop a new approach to expertise transfer by means of wearable technology, by means of task-sensitive Augmented Reality. During this internship, the author was able to familiarize himself with topics such as Augmented Reality and the combination of various sensors.

A focus group survey (see appendix) was conducted in preparation for this paper with 18 participants – current and former game design students, as well as one professor for game design, with at least one year of game development experience each. This revealed interest but inexperience in the usage and development of augmented reality applications; although all but one of the participants knew the term Augmented Reality, only half of them reported having used AR applications before and only three out of the 18 participants had experience developing them, 12 of the remaining 15 expressing interest in doing so. Despite this, the participants showed mixed (though generally positive) expectations of the field in regards to both the gaming industry in general and education in particular: When asked whether Augmented Reality games would be important in these domains in the future, both averaged a score of 3.388… on a Likert scale from 1 (disagreement) to 5 (agreement). The response to whether they thought using additional sensor data could improve Augmented Reality applications, especially data relating to the user such as data on movement or body posture, was more uniformly positive, averaging a score of 4.388…, although some participants noted a lack of knowledge of sensor technology.

This combination of interest offset with lack of experience and skepticism towards the future suggested that an investigation into the prospects of augmented reality gaming could prove beneficial to current game design students.

# Literature review

## Augmented Reality

Johnson et al. (2011): “Augmented reality, a capability that has been around for decades, is shifting from what was once seen as a gimmick to a bonafide game-changer. (...) While the most prevalent uses of augmented reality so far have been in the consumer sector (for marketing, social engagement, amusement, or location-based information), new uses seem to emerge almost daily, as tools for creating new applications become ever easier to use.”

Bower et al. (2014): Augmented Reality is yet another example of technology rendering lower order thinking tasks redundant (...)”

### Definitions and taxonomies

Azuma: 1. Combines real and virtual

* 2. Is interactive in real time
* 3. Is registered in three dimensions
* -> Keine 2D Overlays (Text scheint zu widersprechen - 2D Overlays okay, solange sie an Elemente im Raum gebunden sind?)

Kontrast Azuma (2001):

* combines real and virtual objects in a real environment;
* runs interactively, and in real time;
* and registers (aligns) real and virtual objects with each other.

Dictionary: "Vision technologies that superimpose a computer-generated object on an image of a real-world scene."

Milgram & Kishino (1994) erwähnen Möglichkeiten von Audio, Haptic, Vestibular AR („**haptic AR can almost be considered the natural mode of operation** in this sense. **Vestibular AR** can similarly be considered a **natural mode of operation”).** Benko et al. (NormalTouch und TextureTouch) als Beispiel für mögliche Haptic-Anwendung, auch wenn für VR angelegt

Durlach, Ternier (2012) (Audio VR)

(Ternier, De Vries et al. (2012) Begründung: “Just like a user should - while driving a car - use sight as much as possible to drive, we believe that with location based learning, a learner’s eyes must be primarily used to examine the environment. ARLearn therefore builds on hearing to support location-based learning through mobile phones.”)

* Azuma (2001): “**AR can potentially apply to all senses**, including hearing, touch, and smell.”

Azuma et al. (2001) “Certain AR applications also require removing real objects from the perceived environment, in addition to adding virtual objects. For example, an AR visualization of a building that stood at a certain location might remove the building that exists there today. Some researchers call the task of removing real objects **mediated or diminished reality**, but we consider it a subset of AR.”

Specht et al. (2011):”Milgram and Kishino (1994) describe augmented reality (AR) as “relating purely virtual environments to purely real environments” (p. 1321). Rice (Shute, 2009) gives an even broader perspective on augmented reality, stating that it should cover any media that is specific to your location and the context of what you are doing. We find these definitions **too generic and in direct conceptual conflict with closely related systems such as context-aware or immersive systems, mixed reality, and personalized adaptation.** For the purpose of this article, at least, we therefore want to specify augmented reality as **a system that enhances a person’s primary senses (vision, aural, and tactile) with virtual or naturally invisible information made visible by digital means** (…)where ‘view’ also includes other primary human senses.”

Milgram (1994): Spectrum => Sheridan (1992), Robinett (1992) taxonomies  
Milgram aber auch: “[AR] refers to all cases in which the display of an otherwise real environment is augmented by means of virtual (computer graphic) objects.”

Milgram (1994): “An (approximately) three dimensional taxonomy is proposed, comprising the following dimensions: **Extent of World Knowledge** ("how much do we know about the world being displayed?"), **Reproduction Fidelity** ("how 'realistically' are we able to display it?"), and **Extent of Presence Metaphor** ("what is the extent of the illusion that the observer is present within that world?")”

Chronologisch ordnen?

Sheridan (1992) (Faktoren für Presence):

* “Extent of sensory information
* control of relation of sensors to environment
* ability to modify physical environment

Robinett (1992) (synthetic experience) (“a taxonomy for classifying systems that incorporate an HMD”): Klassifizierung nach causality, model source, time, space, superposition, display type, sensor type, action measurement type, actuator;

Klassifizierung AR:

* Causality: Transmit
* Model source: Scan
* Time: 1-to-1
* Space: Registered
* Superposition: Merge
* Display: HMD
* Sensor: FLIR (forward-looking infrared)
* Action Measure: -
* Actuator: -

Johnson et al.(2011): ”Augmented reality (AR) refers to the addition of a computer-assisted contextual layer of information over the real world, creating a reality that is enhanced or augmented.” -> Sehr allgemein

### Technology

Sutherland als erster - “**Eventually we would like to allow the user to walk freely about the room**, but our initial equipment allows a working volume of head motion about six feet in diameter and three feet high.”

* HMD/HWD vs Desktop
* Feiner et al. (1997) als erstes MARS (Mobile Augmented Reality System (So genannt in Papagiannakis et al. (2008), aber wahrscheinlich nicht zum ersten Mal)

Azuma (1997)

Yamabe et al. erwähnen (Projector)

Video vs optical (projection erwähnen (ist noch in Kruijff et al. (2010)))

* Azuma (2001): “**Another approach for projective AR relies on headworn projectors, whose images are projected along the viewer’s line of sight at objects in the world**. The target objects are coated with a retroreflective material that reflects light back along the angle of incidence. Multiple users can see different images on the same target projected by their own head-worn systems, since the projected images can’t be seen except along the line of projection.”

Location-Based (geolocated/marker-less/gravimetric(Johnson et al. (2011))) vs Vision-Based (artefact-based /marker-based) (Munnerley et al. (2012), FitzGerald et al. (2013)) -> Hololens hervorheben als alternativen dritten Ansatz

Marker-based: You & Neumann listen Arten von Fiducials (5.1) (corner features, square shape markers, circular markers, and multi-ring color markers)

marker, computer vision, outdoor Probleme und Lösungsansätze (Schall et al. (2009), Hol et al. (2006))

Moderner Vergleich

Hololens speziell?

Furmanski et al. (2002) unterscheiden: “Processing methods can be classified into image enhancement and image understanding techniques. With image enhancement, qualities such as contrast, brightness, and transparency are manipulated to improve visibility of important features or highlights. Image understanding attempts to recognize structures and features with the aim of automatically describing the contents of an image.”

Azuma (2001): “One category for new developments is enabling technologies. Enabling technologies are advances in the basic technologies needed to build compelling AR environments. Examples of these technologies include **displays, tracking, registration, and calibration.**”

Sharma et al. (2016) unterscheidet (Smart glasses): Monocular, bi-ocular, binocular.

* “In the following section, smart glasses are classified in three different categories: **virtual reality, binocular augmented reality, and monocular augmented reality**.”

### Applications

Erwähnen, dass es auch z.B. Militär, Medizin gibt, die Arbeit sich aber nicht darauf richtet

Allgemein: Patterns?

Antonacci et al. (2015): “Below some design patterns already identified by the authors of this paper, which take advantage of AR potential, are listed:

• Localization: adding information related to the user’s position and orientation;

• Video recording and view sharing: sharing the user’s view with another user or an expert;

• Synchronous communication: using communication features while performing a task;

• Contextualization: enriching the current view by providing contextual information (e.g. distance to specific points);

• Object recognition: enhancing or enriching an object in the field of vision of the user;

#### Industrial

Schall et al.: „[V]isualization of underground infrastructures, such as water mains and electricity lines” (=Obscured Information Visualization (OIV) (Furmanski, Azuma & Daily (2002)))

Azuma (1997 und 2001)

#### Education and expertise transfer

Johnson et al. (2011) – Horizon Report 2011: Time-to-Adoption 2-3 years (“likely time frames for their entrance into mainstream use for teaching, learning, or creative inquiry.)

* Johnson et al. (2016) – Horizon Report 2016 Higher Education Edition listet es auch als Two to Three Years.

“While the most prevalent uses of AR and VR thus far have been in the consumer sector, tools for creating fresh applications are becoming even easier to use and more viable in the education sector.”

“While AR has appeared in several previous editions of the NMC Horizon Report, recent advancements in VR technology are bringing about fresh perspectives.”

Dunleavy et al. (2009): “Three complementary technological interfaces are now shaping how people learn, with multiple implications for K-12 education (Dede 2002).

* “The familiar ‘‘world- to- the- desktop’’ interface”
* “Emerging multi-user virtual environment (MUVE)”
* “Augmented reality (AR) interfaces””

Azuma (1997) erwähnen? Besser nur moderne Vergleiche?

Dunleavy (2009) (Alien Contact)

Yamabe et al. (2013): Augmented Reality Go, EmoPoker, Augmented Calligraphy, AR Drum Kit

Ishii et al. (Athletik speziell erwähnen, hier können andere eingebunden werden, z.B.: Soga et al. (2011), Rahman et al. (2011), )

Ternier et al. (2012) (ARLearn)

Schmitz et al. (2012) (Ed. potential): “For the review we focused on motivational and knowledge learning outcomes. Learning outcomes that relate to manual or physical learning outcomes, e.g. exergames (Lucht et al., 2010; Yang and Foley, 2011) or console games we did not consider, as they have a different didactic approach. (…) Due to the educational focus of our analysis, we excluded any study focusing at technology aspects, such as the study on ‘The Eduventure’ by Ferdinand et al. (2005) or the ‘Museum Scrabble’ by Yiannoutsou et al. (2009).”

Dunleavy (2014): “A review of the literature reveals the following three design principles as instructive: 1. Enable and then challenge (challenge): 2. Drive by gamified story (fantasy); and 3. See the unseen (curiosity).”

**Wichtige Übersichten**: FitzGerald et al. (2013), Bower et al. (2014), Radu (2014)

Soga, Nishino & Tashi: Skeletal tracking (Bogenschießen, Visualisierung des Experten) **(Quelle eingeschränkt, also am besten nur am Rand erwähnen)**

Dede (2009): Immersive Learning (Referenziert von Ternier et al. (2012) (Brown & Cairns könnten erwähnt werden, ist aber fragwürdig (auch weil Ternier das gleiche macht)))

Bower et al. (2014) kritisiert Ansätze: “In the vast majority of instances described above, Augmented Reality is being used by educators to provide students with pre-packaged learning experiences. This can lead to the situation where Augmented Reality only develops lower order thinking skills by supporting understanding and application, without encouraging higher order integrative thinking skills such as analysis, evaluation and creation.”

Bower et al. (2014) schlägt stattdessen Design als Alternative vor (und gibt Beispiel dafür): “The students, accompanied by their teachers, were invited to select a sculpture of their choice from the University Sculpture Park and then, using the Aurasma Augmented Reality platform (http://aurasma.com), design and create an Augmented Reality overlay that would be triggered by the sculpture. These Augmented Reality designs could then be used by visitors to the sculpture park so as to enhance their artistic experience.”

Bower et al. (2014): “Augmented Reality technology is advancing so rapidly that educational research has not been able to keep pace. Future research needs to move beyond Augmented Reality as a novel learning technology to examine learning and teaching issues of import.”

#### Augmented reality games

Wetzel (2013): “The advance of modern smartphones has finally made it possible to develop such games outside the realm of research and for the first time a large base of potential users can be reached to make such games economically feasible (at least in theory). This rather young strain of game development has however not yet formed a cohesive and structured understanding of what makes these games fun to play, how they function and what needs to be taken into consideration when designing, developing and staging them.”

Wetzel (2013): “Terms with similar definitions are Location-based Games (which require spatial change) [20] or Pervasive Games (which do not necessitate technology) [17]. All three terms are often used interchangeably, and the majority of games from each group arguably also belongs to the other two.”

*(Full definition of location-based and pervasive games?)*

Wetzel (2013) gibt Beispiel (Füllmaterial), unter anderem Geocaching *(Passt das in einen strikten AR-Bereich?)*

Wetzel (2013): “Commercial games which fully exploit the power that modern smartphones enable are still few and far between with Shadow Cities and Ingress perhaps the only two with a large player base. This lack of successful games is on the one hand certainly caused by the aforementioned complications concerning the development of MMRGs, but arguably also because the games are still relatively new and therefore knowledge is lacking about how best to design and develop these games, what pitfalls and common errors to avoid and how to best engage players.”

Johnson et al. (2011): “Augmented reality is an active, not a passive technology” -> Geeignet für Games

Trennung zwischen akademisch und kommerziell, Edugames erwähnen (auch oben schon)

Eye Toy als erstes kommerzielles? (Zitat Wetzel et al., 2008)

Pokemon Go

Design Prinzipien von Wetzel el al. (2008)

Dunleavy (2014): Dino Dig (“Although the main purpose of Dino Dig was to entertain, these same design principles of enabling and then challenging could be used in an AR experience with specific learning objectives.”)

Antonacci et al. (2015): “[L]ittle is known on how to systematically apply game-design patterns to augmented reality.” – Ansatz für Patterns für AR Serious Games.  
Wetzel (2013) proposes patterns for Mobile Mixed Reality Games: “While on the one hand the language covers direct game mechanics and therefore game design considerations, it also aims to provide similar for other aspects of mobile mixed reality games, namely authoring, content creation, interfaces, orchestration as well as testing and logging. Eleven patterns based on these aspects are described in more detail.”

Ibid (Struktur für Pattern): “Name, Categories, Problem, Solution, Examples, Description, Effects, Connections”

### Outlook

#### Possibilities

Dunleavy (2014): “This ability to scaffold and support positive interdependence to accomplish an objective situated within a physical space is the most frequently reported affordance of AR (Dunleavy, Dede, & Mitchell, 2009; Facer, Joiner, Stanton, Reid, Hull, and Kirk, 2004; Klopfer and Squire, 2008; Squire, 2010; Perry et al., 2008; Squire, Jan, Matthews, Wagler, Martin, Devane and Holden, 2007).”

Robinett (1992) sieht großen Einfluss auf Gesellschaft voraus: “There will be many databases registered with the real world and able to be superimposed onto it, for example, labels, maps, notes to specific people, diagrams, paths, grafitti, as well as the actions from earlier times recorded in the experience database. It will be a matter of choice which, if any, of these overlays are viewed by each human at any given moment.”

Dunleavy et al. (2009:”**Unique affordances of AR** include the greater fidelity of real world environments, the ability of team members to talk face-to-face with its bandwidth on multiple dimensions, and the capacity to promote kinesthetic learning through physical movement through richly sensory spatial contexts.”

Dunleavy et al. (2009): “One of the more intriguing findings from this study is the documented engagement and motivation of students who had previously been disengaged and disinterested in school. Across sites, teachers reported a significant difference in the behavior and engagement of students during the AR implementation as compared to their normal classroom behavior.”

Schmitz et al. (2012) -> Patterns und Einordnung motivational effects, cognitive effects. ABER: „ The studies we reviewed did not explicitly focus on this but on a set of diverse patterns embedded in the games. Therefore, **the impact of one particular pattern on knowledge gain is difficult to determine.”**

#### Limitations

Azuma (2001): “**Problem areas in AR displays.** See-through displays don’t have sufficient brightness, resolution, field of view, and contrast to seamlessly blend a wide range of real and virtual imagery. Furthermore size, weight, and cost are still problems.”

Ibid: “We’ve grouped the major obstacles limiting the wider use of AR into three themes: t**echnological limitations, user interface limitations, and social acceptance issues.**”

Kruijff et al. (2010) (“created with a visual processing and interpretation pipeline in mind.”): “We organize issues into ones related to the **environment, capturing, augmentation, display, and individual user differences.” ->** Genauere Klassifizierung auch in Research Diary

Antonacci et al (2015)

Furmanski et al. (2002) (Interfaces überdenken)

Dunleavy (2014): “One of the most frequently reported AR design challenges is preventing student cognitive overload during the experience” (+Quellen);

Ibid: “The mobile device as a lens rather than a screen is a critical design metaphor as **several studies have documented that students have the tendency to become fixated on the mobile device rather than observing the environment** (Dunleavy et al., 2009, Dunleavy & Simmons, 2011; Perry et al., 2008; Squire, 2010). While location-based and vision-based AR can provide powerful and compelling experiences, **it is critical that designers do not create experiences where the technology becomes a barrier to the environment. Rather the technology needs to drive the students deeper into the authentic observation and interaction** with the environment and with each other if AR is to grow beyond a novelty technology.”

Dunleavy et al. (2009): “However, while the AR simulation provided potentially transformative added value, it simultaneously presented unique technological, managerial, and cognitive challenges to teaching and learning.”

Dunleavy et al. (2009): “As students navigated through the game space, they were frequently observed ignoring the physical space around them to focus exclusively on the data being presented via the handheld. The research team recorded multiple examples of students being **so engaged in the game environment that they lost track of their real environment.** Beyond the obvious safety concerns related to students ignoring their environment while walking in an urban setting, **this engrossment could actually be counterproductive** if the AR simulation is designed to incorporate the physical space into the learning experience.

* Ternier, De Vries etc. (2012) sehr ähnlich (über andere Quelle): “The Locatory app absorbed all of the attention of the users, which might lead to dangerous situations. While playing the game, observers had to highlight the danger of cars entering and leaving the campus. We found that the way users perceived the game environment relates to tunnel vision.”

Dunleavy et al. (2009) erwähnt Wetter als Störungsfaktor

Dunleavy et al. (2009): “The findings from this study emphasize how engaged students become simply by using similar tools to learn. While this use will continue to be a motivating factor regardless of content due to the inherent novelty effect, we can safely predict that this **novelty engagement will fade as the students become accustomed** to this method of learning.”

Julier et al. (2000): “If a graphics-based AR system is to be effective, care must be taken to ensure that its display is not cluttered with too much information.” -> Lösungsansatz: Filtertechnik.  
“An informal domain analysis of our application scenario suggested to us that the filtering mechanism should take into account the following properties:

* Users will perform a broad range of tasks, from maintaining general situational awareness of their environment, to searching for specific objects, to attending to a specific set of objects involved in an activity.
* Any object, of any type, at any point in time, can become sufficiently important that it must be able to pass the filtering criteria.
* Certain objects are important to all users at all times.
* Certain objects are important to all users whenever they are performing a particular task.
* Some objects (such as the way points that define a route) are only important to the activities of a particular user.
* All things being equal, the amount of information shown to a user about an object is inversely proportional to the distance of that object from the user. (...)”

## Sensors

### Overview – sensors and actuators

EMG (z.B. bei Rahman et al.)

Schmitz et al. (2012): “By now, supplementary core technologies, such as Global Positioning System (GPS), portable displays, Radio Frequency Identification (RFID) reader or augmented devices such as the smart phone’s Bluetooth, Infrared or camera, are an integral part of almost any up-to-date mobile device.”

Wetzel et al. (2013): “Locationing technology utilizes a wide **variety of sensors** like GSM cells, GPS, fiducial markers, natural feature tracking, NFC/RFID as well as WiFi and Bluetooth-based proximity sensing”

Sharma et al. (2016) (WEKIT): “Next, we provide a mapping of high level functions or tasks (associated with experience transfer from expert to trainee) to low level functions such as: **gaze, voice, video, body posture, hand gestures, bio-signals, fatigue levels, and location of the user in the environment.** In addition, we link the low level functions to their **associated sensors.** Moreover, we provide a brief **overview of the state-of-the-art sensors in terms of their technical specifications, possible limitations, standards, and platforms.**

We outline a set of recommendations pertaining to the sensors that are most relevant for the WEKIT project taking into consideration the environmental, technical and human factors described in other deliverables.”

Ibid:“Finally, we highlight common issues associated with the use of different sensors.“

Ibid: “In design synthesis, the product or system is defined in terms of the hardware and software components which together make up and define the system. The result of this phase is the process output in the form of the physical architecture, or the system prototype where each component must meet at least one functional requirement, and any component can support many functions [[3]](https://paperpile.com/c/ufunOV/jxDQ). “

Ibid: “The **transfer mechanisms** include: remote symmetrical tele-assistance, virtual/tangible manipulation, haptic hints, virtual post its, mobile control, in situ real time feedback, case identification, directed focus, self-awareness of physical state, contextualisation, object enrichment, think aloud protocol, zoom, and slow motion. In this section, we decompose the different transfer mechanisms to low level functions and their associated state-of-the-art sensors.”

Ibid – Kinect funktioniert nicht mit anderen

* **Einschränkungen in der Kombination von Sensoren!**
* Hier auch (Ibid): “In the design of a system recombining the various different sensors identified above (all using different data rates and different standards for storage and communication), several notable challenges arise:
  + Compatibility and support of Unity development engine across different hardware sensors
  + Support of sensors across different operating systems and programming platforms
  + Compatibility of the different hardware drivers associated with the sensors.
  + Interference due to, e.g., noise generated by sensors.
  + Local and efficient storage of raw and processed data of the various sensors.
  + Synchronization of data owing to different data rates of the sensors (e.g., EEG, Augmented reality glasses, microphone).
  + Compatibility of the communication standards and protocols (for instance, Bluetooth, and WiFi) and their data transmission range.
  + The computational complexity and processing load needed for processing the data associated with different sensors.
  + Design of the WEKIT capturing system that integrates all the sensor hardware as a wearable system.”

Jesse Schell – Design Outside the Box: “Sensors are what’s happening now”

“There’s gonna be sensors everywhere, detecting so many things in your life, and these things are gonna be able to be used for gameplay”

“We’re before too long gonna get to the point where every soda can, every cereal box is gonna be able to have a CPU, a screen and a camera on board it, and a wi-fi connector so that it can be connected to the internet”

### Sensors in games

Johnson & Wiles (2003): “With less cognition required for remembering or finding input commands, the user is better able to achieve concentration and engagement, and thereby flow, when completing the task.”

Johnson et al. (2011) (Horizon Report): “Thanks in part to the Nintendo Wii, the Apple iPhone and the iPad, many people now have some immediate experience with gesture-based computing as a means for interacting with a computer. The proliferation of games and devices that incorporate easy and intuitive gestural interactions will certainly continue, bringing with it a new era of user interface design that moves well beyond the keyboard and mouse.”

### Sensors in augmented reality

Papagiannakis et al. (2008): Übersicht.

Hier z.B.: “RFID (radio frequency identification) tags have also been recently used in mobile AR systems. RFIDs consist of a simple microchip and antenna which interact with radio waves from a receiver to transfer the information held on the microchip. RFID tags are classified as either active or passive, with active tags having their own transmitter and associated power supply, while passive tags reflect energy sent from the receiver.”

Auch hier: “The use of inertial sensors such as rate gyroscopes and accelerometers is wide-spread in virtual and augmented reality applications.”

Auch hier: “The complementary nature of visual and inertial sensors has led to the development of a number of hybrid tracking systems.”

“**How to interact with wearable computers effectively and efficiently** is an area of active research. Mobile interfaces should try to minimize the burden of encumbering interface devices. **The ultimate goal is to have a free-to-walk, eyes-free, and hands-free interface** with miniature computing devices worn as part of the clothing”

Sharma et al. (WEKIT) kann auch hier nochmals (?) erwähnt werden

Robinett (1992): “[The HMD] is not simply a visual display technique, but rather a multisensory display technique (involving vision, the vestibular system, and the proprioceptive system) in which the visuals depicting the surrounding three-dimensional (3-D) virtual world are generated so as to match the user's voluntary head movements.”

Hol, Schön, Gustafsson et al. (2006): „Tracking in unprepared environments requires unobtrusive sensors, i.e., the sensors have to satisfy mobility constraints and cannot modify the environment. The currently available sensor types **(inertial, acoustic, magnetic, optical, radio, GPS)** all have their shortcomings on for instance accuracy, robustness, stability and operating speed [14]. Hence, **multiple sensors have to be combined for robust and accurate tracking**.”

Sensor Fusion zur Verbesserung von AR-Genauigkeit (Kalman/EKF erwähnen): You, S., & Neumann, U. (2001): Vision + Gyro. Referenziert andere, z.B. Feiner, S., MacIntyre, B., Höllerer, T., & Webster, A. (1997) (erstes(?)outdoor MARS(GPS+compass+tilt sensor)), Schall et al. (2009): „fusion of Differential GPS (DGPS) or Real-Time Kinematic (RTK) based GPS with barometric heights and also for an inertial measurement unit with gyroscopes, magnetometers and accelerometers to improve the transient oscillation (…) we additionally apply a visual orientation tracker which is drift-free through online mapping of the unknown environment.”

Benko et al. (NormalTouch, TextureTouch, Vibrotactile) als Beispiel für Sensor (Location, Finger Force Sensor (FSR)) + Aktuator – System -> „ [O]n several occasions we observed people trying out our devices when they were not well calibrated (…). To our surprise, people often claimed that the device accurately rendered the surface when in fact it was obviously incorrect.”

Sharma et al.: “At the moment, there are few solutions available for using **eye tracking with augmented reality glasses**, for example, Pupil labs[[116]](https://paperpile.com/c/ufunOV/Zawg), provide eye tracking add-ons for Oculus Rift DK2, HTC Vive Binocular, and Epson Moverio BT-200. However, there are no eye-tracking solutions available for Microsoft Hololens.”

Ternier, De Vries etc. (2012): “Augmented reality browsers like Layar and Wikitude² support filtering dependent on the sensors available on the mobile device. These browsers have implemented a Point Of Interest (POI) browsing interaction pattern, delivering the same experience for every user.”

Bower et al. (2014): “Future developments in Augmented Reality will undoubtedly include new trigger types **(sound, temperature, smell, voice recognition, etc.)**, more intelligent input recognition **(e.g. more accurate gesture detection** as is already being evidenced by products such as Leap Motion) and increased sophistication of expression types (for instance, **vibration, more complex 3D interactive models, scripts to networked devices** such as printers and lights as outlined by “Internet of Things” proponents).”

Wetzel (2013): “[Mobile Mixed Reality] games have certain peculiarities that make them arguably more complex to develop and maintain than traditional videogames (e.g. **reliance on inaccurate sensor data**, close coupling to the real world context they are played in).”

Wetzel (2013): “It is fair for a videogame developer to assume that the players have precise interfaces for input (controller, mouse, keyboard, etc.), have perfect view of the screen, good sound equipment as well as a fast and reliable internet connection. None of this is true for MMRGs. **Different sensors have different strengths and weaknesses that completely change the way a game might work.**”

# Development of a framework for sensor-supported augmented reality games

# Declaration of authenticity

# Appendix