

Nectar: Multi-user Spatial Augmented Reality for everyone: Three live demonstrations of educative applications

Jérémy Laviolle, Jérémy Albouys-Perrois, Lauren Thévin, Anke Brock

► To cite this version:

Jérémy Laviolle, Jérémy Albouys-Perrois, Lauren Thévin, Anke Brock. Nectar: Multi-user Spatial Augmented Reality for everyone: Three live demonstrations of educative applications. VRIC 2018 Virtual Reality International Conference - Laval Virtual, Apr 2018, Laval, France. 10.1145/3234253.3234317 . hal-01769706

HAL Id: hal-01769706

<https://hal.inria.fr/hal-01769706>

Submitted on 18 Apr 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

Nectar: Multi-user Spatial Augmented Reality for everyone.

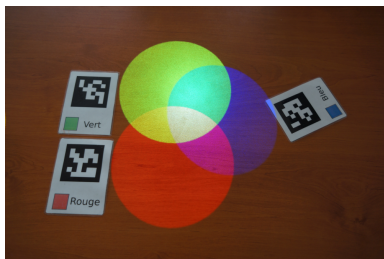
Three live demonstrations of educative applications.

Jeremy Laviolle
RealityTech
Bordeaux, France
laviolle@rea.lity.tech

Lauren Thevin
Inria
Talence, France
lauren.thevin@inria.fr

Jeremy Albuys-Perrois
Inria
Talence, France
jeremy.albuys-perrois@inria.fr

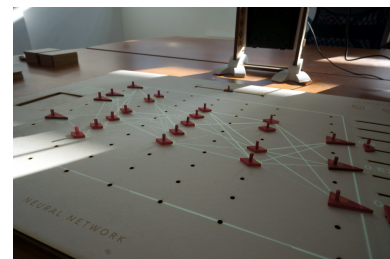
Anke Brock
ENAC
Toulouse, France
anke.brock@enac.fr



(a) Discovery of color models.



(b) Map exploration and creation for visually impaired people.



(c) Tangible artificial neural networks.

Figure 1: Photos of the three spatial augmented reality demonstrations.

ABSTRACT

In this demonstration we showcase a new spatial augmented reality device (interactive projection) with three applications: education and experimentation of color models, map exploration for visually impaired people and scientific vulgarization of machine learning.

The first exhibition is an interactive exploration about the nature of light. Visitors can experiment with additive subtractive color models. We engage them with questions, and they have to reply using cards to find out answers. This exhibit is suitable for children.

The second exhibition is about map exploration and creation for Visually Impaired Persons (VIP). VIP generally use tactile maps with braille to learn about an unknown environment. However, these maps are not accessible to the 80% of VIP who don't read braille. Our prototype augments raised-line maps with audio output.

The third exhibition is destined to be used for scientific outreach. It enables the creation of artificial neural networks (ANN) using tangible interfaces. Neurons are represented by laser-cut diamond shaped tokens, and the data to learn is printed on cards. The ANN

learns to differentiate shapes, and the whole learning process is made visible and interactive.

These three applications demonstrate the capabilities of our hardware and software development kit in different scenarios. At ReVo, each demonstration will have its own setup and interactive space.

KEYWORDS

Spatial Augmented Reality, tangible interaction, object tracking, mapping, multi-user, tabletop, open-source, visual impairment, machine learning, education, scientific visualization, child-computer interaction

ACM Reference Format:

Jeremy Laviolle, Lauren Thevin, Jeremy Albuys-Perrois, and Anke Brock. 2018. Nectar: Multi-user Spatial Augmented Reality for everyone.: Three live demonstrations of educative applications.. In *Proceedings of April 04-06, 2018 (VRIC'18)*. ACM, New York, NY, USA, 6 pages. <https://doi.org/>

1 INTRODUCTION

Augmented Reality (AR) is the field where the physical and the digital world merge in one place. It enables to combine virtual elements in reality or physical elements to interact with digital applications (tangible interfaces). This is usually described in the Reality-virtuality continuum[13]. The demonstrations we propose are on the far-left of the continuum, where the digital elements merge with the physical environment.

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

VRIC'18, Laval, France,

© 2018 Copyright held by the owner/author(s).

ACM ISBN 978-1-4503-5381-6...\$15.00

With the advent of see-through augmented reality helmets the possibilities of AR are converging with Virtual Reality. Holograms and “flying” 3D graphics are visually appealing, but they do not generally fit in context. The physical space is where the rendering and interaction takes place but the application is independent. An example of this is reading emails, or running programs designed for screens in a head mounted display.

We propose to experiment with applications that are both physical and digital. The first research applications were described in the Digital Desk[22], and Rekimoto’s Augmented Surfaces[15]. In these papers the physical elements and the digital ones coexist on the table.

There are new explorations of mixed reality desktops [5], virtual element placement [26] and mixing augmented reality and virtual reality [16]. While research pushes the technological limits, the replication and industrialization of such results faces many challenges.

Most commercial interactive tables inspired by the former surface by Microsoft are provide reliable user input[24]. They usually use computer vision, or RFID tags like the Tangisense[9]. HP proposed a hybrid computer - interactive projection in late 2014[6]. Current commercial system propose 2D projection (rectangular) and interaction on this projected screen [21] [14] [19] [20] [18].

The system we propose is “the next step” to these systems and inspired by research: the projection is in context with the physical objects. It is a different approach where the physical activities is at the center of the application.

1.1 Challenges of AR

The demos we propose are at the intersection of research activities and product presentation. The possibilities explored by research laboratories generally take years or decades before being available for professionals or the general public. In this project research laboratories (Inria & ENAC) directly collaborate with professionals (RealityTech).

Augmented Reality is a growing field of research, and it is at the intersection of computer vision, computer graphics, and human computer interaction. The following are challenges of this field.

1.1.1 Rendering. The rendering possibilities extend every year with projector manufacturers that add pixels, contrast and luminosity to new devices. The computer graphics community also extends the rendering possibilities. The fundamentals of rendering SAR are summed up in Bimber and Raskar’s book. [2]. Recently, the quality of rendering SAR with projectors was pushed by Siegl et al.[17] to achieve very high fidelity rendering on objects. The coming research challenges explores perception illusions[11] as well as redering. This is especially difficult when real-world ambient illumination and many different physical materials are present.

1.1.2 Tracking and registration. Object detection and recognition has known many plateau, from marker tracking[7] to image features [12]. Nowadays the possibilities are getting larger with deep neural networks for image recognition [8] and pose estimation[25] [3].

However, the mess of real life is a challenge for computer vision algorithms. Choosing the most suited algorithm, and training it (for deep learning) remains a big challenge. Moreover, the transfer from

research prototypes to robust applications is in itself an additional difficulty.

1.2 Exhibition overview

We propose three different SAR exhibitions with the same underlying technology. Every demonstration was created by different development teams.

The first exhibition is about light and color models. Different cards represent colors, and users (adults or children) can combine the cards to get a better understanding of light and colors.

The second exhibition is an outcome of the VISTE research project¹ which has the goal to improve learning of spatial information by visually impaired people (VIP). This application is designed to be used for orientation and mobility classes in which VIP learn how to navigate autonomously. Visually impaired people can explore a tactile map and obtain audio information about points of interests on the map by touching these points. We extend this project to contexts beyond maps (e.g. exploration of tactile images of flowers).

The last exhibition enables visitors to create Artificial Neural Network (ANN) with tangible interfaces and train the ANN to recognize images. It is intended as a scientific outreach tool for museums or students. The goal is to make machine learning approachable for the general public by letting them create and train their own networks using tangible interfaces.

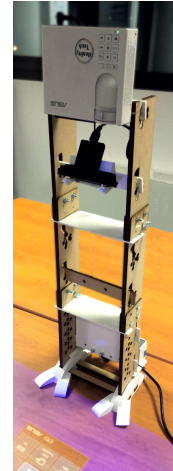


Figure 2:
RealityTech’s
fablab prototype.

1.3 Spatial augmented reality system

Every exhibition has its own controls in the form of cards, raised-line maps, or laser-cut neurons. These controls can be made of many different materials such as paper, plastic, wool, wood and cardboard. They are made interactive thanks to our SAR system.

The system consists of a depth camera, a short throw projector, and a PC, assembled in a column placed on a table. This hardware system is built and sold by RealityTech as their “fab lab prototype” as seen in figure 2. This setup is small and can be taken into small parts to make it easy to transport.

The software behind this is called PapARt and stands for “Paper Augmented Reality Toolkit”². The name comes from the first scientific publication[10]. Here are its uses to create the demonstrations:

- It handles hardware configuration and integrates drivers for cameras, and depth cameras.
- It creates intrinsic and extrinsic calibrations for camera projector systems.

¹<http://visteproject.eu/>

²<https://github.com/poqudrof/Papart>

Nectar: Multi-user Spatial Augmented Reality for everyone.

- It integrates existing and original computer vision algorithms. The pre-existing ones are marker and feature tracking from ARtoolKitPlus, and OpenCV. We added to it color and touch detection and tracking.
- It enables ways to create mini-applications in tracked sheets of paper.
- It provides AR rendering for Processing³.
- It will provide AR rendering for Unity3D⁴ in 2018.

The PapARt is an open-source software created at Bordeaux University, Inria and RealityTech. The source code of all the exhibitions is either distributed as open-source projects or the sources can be provided on demand for the interfaces for visually impaired people.

2 EXPLORATION OF COLOR MODELS.

Light is a complicated physical concept, in this exhibition we focus on the exploration of color. Visitors can combine colors by moving cards. When a card is placed on the table, a colored circle is projected next to it can be added or subtracted to projected colors.

A short questionnaire guides users' exploration of the interactive system. Here are some examples of the questions:

- (1) What is the color white ?
- (2) What are the color yellow and magenta ?
- (3) Why do you see white when you combine, red, green and blue ?

The answers to the questions can be found by mixing the primary colors. The mixing can be additive (like projection) or subtractive (like printing).

During the experimentation phase, we propose to use only three cards at first: red, green and blue. Later on, users can get the cyan, yellow, and magenta cards. The whole experience is made for autonomous exploration.

An example of exploration is shown in figure 3. A user does color additions: blue + cyan = cyan, and cyan + yellow = white. He or she can deduce:

- cyan is composed of blue and other colors.
- yellow and cyan combined contain all the colors.

2.1 Showcased features

The main feature for this application is the use of direct physical manipulation for interactive multi-user applications. Anyone can take cards and manipulate them on the table. Consequently, the number of users is limited by the space around the table, rather than the software.

The scenario is not constrained by the application, but by the printed instructions. It can be followed or ignored, and all the cards can be used at the same time without restriction. The freedom we propose is suitable for educational system where the student explores the answer through physical manipulations.

This application is shipped with the examples of PapARt: the code is short and the application design is minimalist. We want to show that SAR for education and entertainment does not require a large amount of software development. However, it requires design and creation of physical elements to make the application complete.

³Processing a language that enables the creation interactive visual applications. See <http://processing.org> for more information.

⁴Unity3D is a popular video game creation framework.

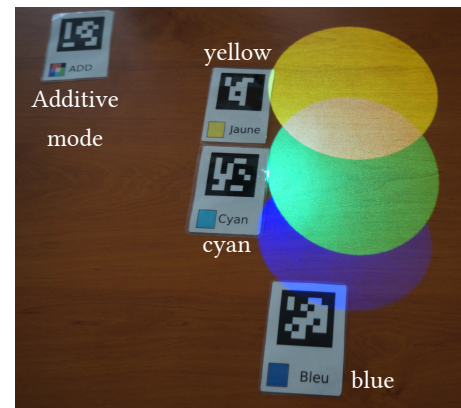


Figure 3: Color combination in additive mode.

The guides and questions will be available in French for Laval Virtual, and in English for international events.

3 MAPS FOR VISUALLY IMPAIRED PEOPLE.

Throughout the world, 253 million people live with vision impairments, and 36 million of them are blind [23]. Those people face important challenges related to orientation and mobility (O&M) which might even prevent them from travelling. It is also difficult for them to acquire knowledge about spaces before travelling, as most maps are visual. In special education schools, visually impaired children receive O&M training. Raised-line paper maps with braille text have mainly been used for teaching spatial thinking to VIP. These maps possess significant limitations, as for instance only a limited amount of information can be presented on those maps, and as they are only accessible to the VIP who are able to read braille. Recent technological progress has enabled the design of accessible interactive maps, e.g. audio-tactile maps, which overcome these limitations [4]. In the VISTE project, such an audio-tactile map has been developed based on the PapARt technology [1].

It may sound surprising to use projection in order to design accessible content for blind people. One point is to keep an inclusive perspective, and so paradoxically to make the documents which are accessible for VIP (i.e. tactile documents) also accessible for sighted people (e.g. sighted teachers or parents). One other point is to make PapARt technically flexible enough to be articulated with various other technologies, including assistive technologies. The PapARt demonstrator is not only about visual projection. Indeed, the detection features are usable on any surface and document.

3.1 Interactive Map Exploration

In this application, we combined the PapARt toolkit with tactile tools that are already used in O&M classes (e.g. raised-line maps and magnet boards), and added audio output using a text-to-speech synthesis (TTS).

The prototype enables visually impaired students to explore existing raised-line maps as displayed in figure 1(b). Users explore the tactile map with both hands as they are accustomed to. Complementary visual information is projected on the raised-line map for the the students with residual vision. VIP can obtain an audio

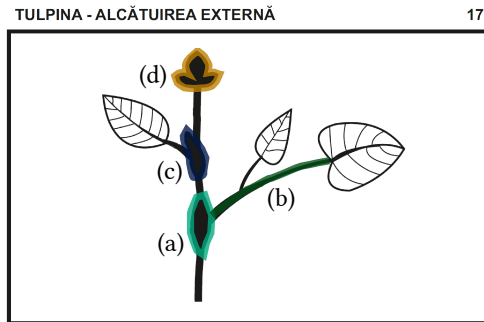


Figure 4: Raised-line image of a tulip with interactive content. Each part (a), (b), (c), and (d) contain a text that is read with Text-to-speech program.

description by simply pointing to a tactile element with one finger and pressing a key on the keyboard. This prototype has been evaluated in a user study, as presented in [1].

3.2 Interactive Botanical Atlas

An augmented diagram can make a support accessible which has not been accessible until now. We are able to extend this from the application of maps to other contexts in education and learning (e.g. schema used in biology, see Figure 4). Moreover, with the interactive technology, we can go beyond the features provided by paper document. For instance, some game-play can enhance an existing tactile document with augmented interactive features : a quiz for learning, discovering all the interactive zones, giving feedback to the blind users that all the zones have been already explored or not, guiding the user to a target (by sound or vibration).

The Interactive Botanical Atlas demonstration addresses typical interactive challenges (and benefits) in interaction. First, PapART keeps the visual support for sighted and partially sighted people and tactile support for visually impaired people. It also makes it fully accessible for the partially sighted and blind people by adding complementary audio, as illustrated in figure 4. Finally, the application is usable for several users with different capabilities.

This makes it possible for a sighted teacher to check the mapping between the visual content and the non-visual content by superimposing the digital augmented content over the physical existing content.

Second, PapART helps to create an interactive area over any support, while the projection allows to match the raised area with the actual interactive area. This way, a botanical atlas can be explored by VIP : text-to-speech description of the manually explored elements, indication about not yet explored elements. Moreover, interactivity and gameplay are added: a quiz in which users have to locate elements, collaborative interaction and indications about new elements on the interactive area.

3.3 Showcased features

In this demonstration, we show two different scenarios. First, we present a raised-line map of the Bordeaux train station which has been augmented with audio feedback and projection. Second, we present a botanical quiz, which combines tactile graphics with audio

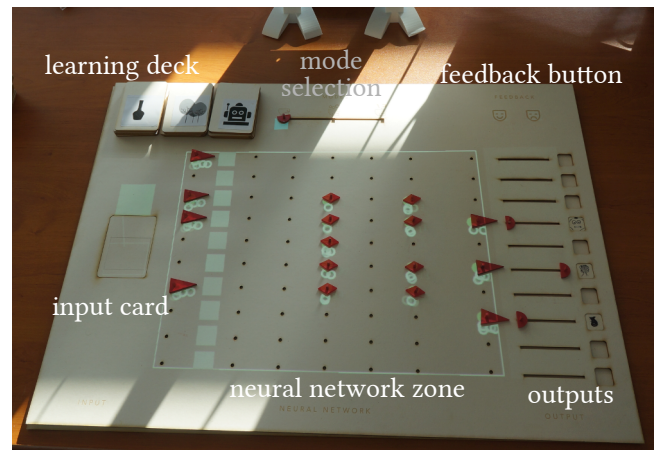


Figure 5: Neural network physical interface: construction phase.

output and projection. This demonstration has been developed as part of a research project in close collaboration with a special education school (IRSA in Carbon Blanc, France). It makes use of the PapART touch detection capacities, as well as projection and audio output.

Unlike most computing systems, the size units used is millimeter and not pixels. This enables an easy the integration of physical elements that are pre-existing such as the raised-line maps or models that were used during the exploration phase.

4 MACHINE LEARNING WITH ANN.

Machine learning (ML) has recently gotten very popular in research and industry. At the same time it gets a negative publicity regarding the possible danger of creating an Artificial Intelligence (AI) that gets too smart and incontrollable. While this danger is possible, the new possibilities offered by advanced ML algorithms are far from science fiction and get published every year in the best conferences and integrated at scale in large companies.

In our demo, we propose a scientific outreach scenario. The visitors will be able to create an Artificial Neural Network (ANN) and teach it how to categorize images. All of the interactions are presented on the table, in SAR.

4.1 Visitor scenario

After a brief introduction to machine learning, we propose to create an ANN. The neurons are incarnated in diamond shaped red tokens and the visitors can place them in columns. The first column represents the image input, the next five columns are the “hidden layers” of the ANN, and the last one is the output. This is illustrated in figure 5.

Once the ANN is set, the weights (connections) between the neurons are created randomly and projected between the neurons as seen in figure 1(c). They can train the ANN to recognize objects by placing a card in the input space, and press the positive feedback button. During the learning the weights are adjusting: visitors can see the light intensity going lighter or darker.

After the learning phase, they can switch to prediction mode. In this mode the visitors can check if the learning process was

Nectar: Multi-user Spatial Augmented Reality for everyone.

successful or not. They can show a card that the ANN never saw, and get the values of the output neurons.

The visitors will experience the difficulties of machine learning on their own: getting a good input data set, training the network with enough diversity, creating an ANN not too simple or too complex so that it encodes data in a proper way.

4.2 Showcased features

This demo has a variety of user input modalities, each are different but transparent for the user. The neuron inputs are pixels. To create these pixels, we capture a 5cm by 5cm image from the camera, and sub-scale it to 8x8 pixels. Some of these pixels are used in the ANN input. With our system it is simple to select a zone (possibly moving) and get an image from it.

The neurons are 25mm by 15mm diamond shaped objects. They are treated as red objects and found and tracked using our color tracking algorithm. When it is detected for a certain amount of frames a neuron is created. The output sliders used for the training phase also use the red object tracking.

The mode selection contains software buttons that can be activated with red objects. In the same way, the feedback buttons can be activated by touching them with the fingers. We chose to use objects for mode switching because the mode stays activated after its selection, so the object stays there. Conversely, the feedback activation is done one step at a time and requires an action each time.

Finally, these spaces are treated as separate in the code and they communicate via shared variables. Consequently, the developer and the code can track only what is needed at a given place. Each space can be considered like a small program with its own inputs and outputs. In this application the spaces are:

- **Mode Selection:** small zone with three buttons that are activated by red objects.
- **Feedback zone:** small zone with two buttons that are activated by touch.
- **Input Image:** capture a squared image and extracts pixels for the ANN.
- **Neural Network:** capture red objects during the creation phase, and draws the neurons connections in other modes.
- **Outputs:** Set of sliders that use red objects to choose the output of the ANN during the learning phase.

4.3 Notes about this exhibition

The creation of this exhibition started during a hackathon organized by the associations Mindlab⁵ and Ascoergo⁶. We would like to thank them for the organization of the event and the quality and involvement of the participants to the project: Lambert, Atlal, and Leo. We also would like to thank Pierre-Antoine Cinquin for the idea and discussions around this project.

5 CONCLUSIONS

These demonstrations present a new cutting-edge technology for SAR with applications not demonstrated yet. Besides the novelty,

the possibilities offered show that the gap between the digital and the physical worlds can be bridged.

5.1 Benefits for the professionals

Augmented Reality is an expanding field, every year new devices push the possibilities of what it is possible to create.

This year, we present our new device at is "fab lab prototype" state. It is fully functional and it is the first product of RealityTech. We want to create the best device for research and professional use, and we do so by confronting it to professionals and the general public all along the project.

During the event, the professional can spend time to discuss the uses, functionalities and find out how to provide the best SAR experience. The exhibitors will be developers and users of the technology.

Advanced feature showcase on demand. The three demonstrations show only part of what is possible to achieve with PapARt. On request we will show technical demonstrations of advanced uses such as holographic rendering and 3D mapping on physical objects.

5.2 Benefits for the general public

The general public is more receptive to applications than the pure technological innovation. The applications demonstrated show what we hope will be the future of multi-user SAR applications.

Each demonstration has value for the general public: the color combination application is in primary and middle school program. The augmented maps for VIP can bring awareness on the difficulty to access technology with no or low vision. Additionally, it shows that inclusive technologies means applications for all needs rather than for specific users.

The last demonstration shows how a computer can learn to distinguish between images using a simple neural network. This demonstration opens many discussions about computer vision, data creation and manipulation. The goal is to push the imagination of the visitors so that they can imagine a neural network capable of automatically drive a car and calculate how large it would be if we used physical diamond-shaped neurons.

5.3 New possibilities

The three demonstrations proposed are the preliminary of a future generation of applications that are both physical and digital. While these programs will not replace all digital applications, they enable creators to integrate existing physical objects into interactive applications. Consequently, the creation of this kind of programs requires fabrication skills which will be required in SAR development teams. During this exhibition, we will show the first commercially-available toolkit for spatial augmented reality.

ACKNOWLEDGMENTS

RealityTech is supported by Region Aquitaine, Pole Aquinetic and Unitec. The Interactive Map Application for Visually Impaired People is conducted with the support of the Erasmus+ Program of the European Union Pr. no 2016-1-EL01-KA201-023731.

⁵<https://mindlabdx.github.io/about/>

⁶<https://www.facebook.com/Ascoergo/>

REFERENCES

- [1] Jeremy Albuys-Perrois, Jeremy Laviolle, Carine Briant, and Anke Brock. 2018. Towards a Multisensory Augmented Reality Map for Blind and Low Vision People: a Participatory Design Approach. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA.
- [2] Oliver Bimber and Ramesh Raskar. 2005. *Spatial augmented reality: merging real and virtual worlds*. CRC press.
- [3] Alberto Crivellaro, Mahdi Rad, Yannick Verdie, Kwang Moo Yi, Pascal Fua, and Vincent Lepetit. 2017. Robust 3D Object Tracking from Monocular Images using Stable Parts. *IEEE Transactions on Pattern Analysis and Machine Intelligence* (2017).
- [4] Julie Ducasse, Anke Brock, and Christophe Jouffrais. 2018. Accessible Interactive Maps for Visually Impaired Users. In *Mobility in Visually Impaired People - Fundamentals and ICT Assistive Technologies*, Edwige Pissaloux and Ramiro Velasquez (Eds.). Springer.
- [5] Renaud Gervais, Joan Sol Roo, and Martin Hachet. 2016. Tangible viewports: Getting out of flatland in desktop environments. In *Proceedings of the TEI'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, 176–184.
- [6] HP. 2017. HP Sprout website. <http://store.hp.com/us/en/mdp/desktops/sprout-by-hp-204036-1>. (2017). [Online; accessed 1-December-2017].
- [7] Hirokazu Kato and Mark Billinghurst. 1999. Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *Augmented Reality, 1999. (IWAR'99) Proceedings. 2nd IEEE and ACM International Workshop on*. IEEE, 85–94.
- [8] Alex Krizhevsky, Ilya Sutskever, and Geoffrey E Hinton. 2012. Imagenet classification with deep convolutional neural networks. In *Advances in neural information processing systems*. 1097–1105.
- [9] Sébastien Kubicki, Sophie Lepreux, and Christophe Kolski. 2012. RFID-driven situation awareness on TangiSense, a table interacting with tangible objects. *Personal and Ubiquitous Computing* 16, 8 (2012), 1079–1094.
- [10] Jérémy Laviolle and Martin Hachet. 2012. PapART: interactive 3D graphics and multi-touch augmented paper for artistic creation. In *3D User Interfaces (3DUI), 2012 IEEE Symposium on*. IEEE, 3–6.
- [11] David Lindbauer, Jörg Mueller, and Marc Alexa. 2017. Changing the Appearance of Real-World Objects By Modifying Their Surroundings. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 3954–3965.
- [12] David G Lowe. 1999. Object recognition from local scale-invariant features. In *Computer vision, 1999. The proceedings of the seventh IEEE international conference on*, Vol. 2. Ieee, 1150–1157.
- [13] Paul Milgram and Fumio Kishino. 1994. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems* 77, 12 (1994), 1321–1329.
- [14] MotionMagix. 2017. MotionMagix interactive projection. <http://www.motionmagix.com/interactive-projection-system-software-price/>. (2017). [Online; accessed 1-December-2017].
- [15] Jun Rekimoto and Masanori Saitoh. 1999. Augmented surfaces: a spatially continuous work space for hybrid computing environments. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM, 378–385.
- [16] Joan Sol Roo and Martin Hachet. 2017. One Reality: Augmenting How the Physical World is Experienced by combining Multiple Mixed Reality Modalities. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology*. ACM, 787–795.
- [17] Christian Siegl, Matteo Colaianni, Lucas Thies, Justus Thies, Michael Zollhöfer, Shahram Izadi, Marc Stamminger, and Frank Bauer. 2015. Real-time pixel luminance optimization for dynamic multi-projection mapping. *ACM Transactions on Graphics (TOG)* 34, 6 (2015), 237.
- [18] Sony. 2017. Sony Xperia Touch website. <https://www.sonymobile.com/global/en/products/smart-products/xperia-touch/>. (2017). [Online; accessed 1-December-2017].
- [19] Vertigo systems. 2017. Vertigo living floor. <https://www.vertigo-systems.de/en/products/living-floor/>. (2017). [Online; accessed 1-December-2017].
- [20] You Tech. 2017. Interactive ground game. http://www.dltongyou.com/en/Home/Index/column/column_id/11.html. (2017). [Online; accessed 1-December-2017].
- [21] TouchMagix. 2017. TouchMagix interactive floor. <http://www.touchmagix.com/interactive-floor-interactive-wall>. (2017). [Online; accessed 1-December-2017].
- [22] Pierre Wellner. 1993. Interacting with paper on the DigitalDesk. *Commun. ACM* 36, 7 (1993), 87–96.
- [23] WHO. 2017. *Visual Impairment and blindness Fact Sheet Nr 282*. Technical Report. World Health Organization. <http://www.who.int/mediacentre/factsheets/fs282/en/>
- [24] Jacob O Wobbrock, Meredith Ringel Morris, and Andrew D Wilson. 2009. User-defined gestures for surface computing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1083–1092.
- [25] Paul Wohlhart and Vincent Lepetit. 2015. Learning descriptors for object recognition and 3d pose estimation. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. 3109–3118.
- [26] Robert Xiao, Scott Hudson, and Chris Harrison. 2016. DIRECT: Making Touch Tracking on Ordinary Surfaces Practical with Hybrid Depth-Infrared Sensing. In *Proceedings of the 2016 ACM on Interactive Surfaces and Spaces*. ACM, 85–94.