Altering the Speed of Reality? Exploring Visual Slow-Motion to Amplify Human Perception using Augmented Reality

Pascal Knierim[1], Thomas Kosch[1], Gabrielle LaBorwit[2], Albrecht Schmidt[1]
[1]LMU Munich, Munich, Germany, {firstname.lastname}@ifi.lmu.de
[2]Bucknell University, Pennsylvania, United States, gll007@bucknell.edu

Figure 1: Altering the speed of reality allows us to observe fast events in great detail. With amplified vision, the take-off of the seagull is visible in slow-motion. The relative speed of slow-motion is first low and then accelerating to catch up with reality.

ABSTRACT

Many events happen so fast that we cannot observe them well with our naked eye. The temporal and spatial limitations of visual perception are well known and determine what we can actually see. Over the last years, sensors and camera systems became available that have surpassed the limitations of human perception. In this paper, we investigate how we can use augmented reality to create a system that allows altering the speed in which we perceive the world around us. We contribute an experimental exploration of how we can implement visual slow-motion to amplify human perception. We outline the research challenges and describe a conceptual architecture for manipulating the temporal perception. Using augmented reality glasses, we created a proof-of-concept implementation and conducted a study of which we report qualitative and quantitative results. We show how providing visual information from the environment at different speeds has benefits for the user. We also highlight the required new approaches to design interfaces that deal with decoupling the perception of the real would.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing**; **Mixed/Augmented reality**; *Interaction design theory, concepts and paradigms.*

KEYWORDS

Human Augmentation, Perceptual Amplification, Mixed Reality, Augmented Reality, Proof of Concept.

ACM Reference Format:
Pascal Knierim[1], Thomas Kosch[1], Gabrielle LaBorwit[2], Albrecht Schmidt[1]. 2020. Altering the Speed of Reality? Exploring Visual Slow-Motion to Amplify Human Perception using Augmented Reality. In *AHs '20: Augmented Humans International Conference (AHs '20), March 16–17, 2020, Kaiserslautern, Germany*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3384657.3384659

1 INTRODUCTION

Sight is a crucial sense for humans to understand and interact with the environment around them. The visual system has well-known temporal, spatial, and spectral limitations, and this defines what individuals can and cannot perceive with the naked eye. Historically advances in tools for enhancing visual perception have led to significant scientific progress. The invention of the microscope and telescope have literally changed how we observe and what we know about the world. The spatial properties of the visual system limit the field of view (FoV) and the perceived resolution. Temporal properties constrain what we can see when objects are in motion

---

AHs '20, March 16–17, 2020, Kaiserslautern, Germany

https://doi.org/10.1145/3384657.3384659

or events happen rapidly. The detailed observation of fast-paced objects becomes challenging to perceive through natural limitations. Thus, the temporal resolution also defines the minimum number of frames that are required to perceive a series of images of a moving object as smooth and continuous [2]. By now, digital sensing technologies are available that outperform human perception. High-speed cameras provide a much higher temporal resolution than the human eye. Lenses and high-resolution sensors provide more substantial spatial resolution [8, 10], and thermal imaging allows humans to glance beyond their spectral limitations [1, 6]. In this paper, we investigate how to use Augmented Reality (AR) to overcome the temporal limitations of human visual perception in real-time and as a natural extension of the human sense. We experimentally investigate how we can implement glasses that allow us to change the speed with which we observe the environment. Our contribution is: (1) a description of the concept for slow-motion AR glass and a discussion of the related challenges, (2) a proof of concept implementation of a system that allows to alter and in particular slow down the speed of how we visually perceive our environment, and (3) a discussion of user feedback gathered from participants experiencing AR slow-motion technology.

2 BACKGROUND

This work is embedded in the broader context of human perceptual augmentation and amplification. Here, we provide a brief background on the temporal aspects of human perception.

Recently, technologies have been researched that amplify the human body and mind [13]. With the availability of wearables, human senses can be augmented to achieve efficient perceptions of information [12]. There are AR glasses that provide build-in cameras with video sampling rates that exceed the temporal limitations of the human eye. Such ubiquitous recording capabilities enable in-situ recordings of situations that can be replayed in slow-motion for in detail investigations.

The visual sense and the perception of time are strongly coupled [4]. Eagleman [3] found that repetitive events result in a *repetition suppression*. Such suppression results in a skewed perception of repetitive events, like the movement of the pointer of a clock. In faster intervals, the more repetitions are perceived. Fast-paced events that happen frequently are hence harder to process on a visuospatial level. Rose and Summers [11] investigated how different stimuli durations were perceived. They find that the duration of visual events that occur for a short period are overestimated by about 50%. Hence, past research investigated how the boundaries of human vision can be circumvented. Rekimoto [9] presented a prototype that observes the spatial features of the environment to make information visible. Small unreadable text can be detected and magnified on devices that can track the environment using conventional optical sensors. Zhao et al. [14, 15] presented the use of head-mounted displays (HMDs) to monitor the user's surroundings for further augmentations. They find that low-vision users benefit from magnification features that enable them to see objects that were more difficult to perceive. Kasahara and Rekimoto [5] go even further and research how intellectual capabilities can be boosted by sharing the perceived vision with other persons using virtual reality.

3 RESEARCH CHALLENGES

The core of our vision is a technological solution that allows us to change a person's perception of how fast the world around them is progressing. This change creates a discrepancy between what we perceive and what is happening in the present world. In particular, we are interested in the following research challenges:

RC1 How to technically alter the temporal properties of what we visually perceive with AR technology?

RC2 How to overcome the speed decoupling of the perceived decelerated situation and the real process happening?

RC3 How to create a convincing and positive experience allowing to change temporal properties of the visual perception.

In this paper, we do not claim to solve these challenges. We rather take the first experimental steps towards understanding the challenges and map out individual solutions.

4 SLOW MOTION PERCEPTION

When interacting with the real world around us, we take the speed with which things happen as given by nature, as something we cannot change. A bird moves its wings while passing by, a wheel on a car turning, an apple falling from a tree. We are used to NOT being able to see certain things. Either it is too fast, or we miss the moment when it happens. In contrast with recorded media, we have gotten used to being able to manipulate the playback-speed. Consider watching a recording of a football game. While watching the video, you can pause it at any time and look at a scene as a still image. You can slow down scenes and watch them in slow-motion or speed them up and see them in fast-forward. You can also replay a situation multiple times. Decelerating the real events in our environment is typically not feasible due to laws of physics (e.g., the speed of the falling apple is determined by gravity), and altering our perception is not possible from a physiological and biological perspective.

4.1 Vision

In our vision, we bring the experience we know from interacting with recorded media to real-life events in our physical environments using augmented reality. Our vision is as follows:

> ***Using a head-worn camera display system, users can alter the speed in a seamless way with which they perceive the current physical environment they are in. This is implemented in a way that users do not experience a disconnect of the perceived environment and the real physical environment. The temporal alteration is primarily on the visual channel, but it should additionally include further modalities (e.g., auditory, tactile).***

Realizing this vision includes challenges in recording the environment, presenting the recorded environment, and also in keeping the user from interacting with an environment that is potentially not in sync with their perception.

5 ALTERING THE SPEED OF REALITY

For a compelling experience of visual slow-motion in an AR environment, several hardware and software components need to intertwine. First, we illustrate all components involved in an ideal

AR experience. Based on this conceptual architecture, we then describe our prototypical realization covering a subset of the ideal slow-motion implementation.

5.1 Conceptual Architecture

Three main aspects need to be addressed to develop a convincing and persuasive AR slow-motion system: Hardware, software, and interaction concept. The schematic of our conceptual architecture is illustrated in Figure 2. The hardware components can be divided into sensing and displaying technology. The straightforward solution comprises a generic imager attached to a HMD. The quality of the slow-motion is highly based on the temporal and spatial resolution of the sensor. Due to its simplicity, this setup implies certain limitations. The fixed arrangement of wearable display and camera does not allow to compensate for head movement and rotation of the user while experiencing the decelerated stream. A 360° camera is required to overcome this limitation. Fusing imager and inertial measurement unit (IMU) data allows to decouple head movement from the camera stream and enables the user to freely (three degree-of-freedom (DOF)) look around within the slowed-down environment. For an overarching experience of a decelerated environment and support to navigate this environment, image-based 3D reconstruction [7] or volumetric video capture devices are required. These devices allow for full temporal reproduction of the environment; however, they currently require the sophisticated instrumentation of the environment. Independent of temporal and spatial resolution, as well as the format (2D, 3D, 360° stream), the sensor data is forwarded to the processing unit. Here, the video stream is slowed down based on the users' input. Depending on the hardware setup, additional processing like decoupling the users' movement or interpolation of frames to enhance further the experience is done. At the beginning and end of the decelerated stream, transitions (ease-in/ease-out) are suggested for a smooth transition and to indicate the change in presentation speeds. The processed stream is presented to the user through a HMD on-demand. User input is either discrete for a fixed decelerated stream or continuous for flexible control of the playback speed. In advanced implementations of slow-motion for AR, the activation of the deceleration could be automated based on context, gaze, or brain activity using electroencephalography.

5.2 Prototype Implementation

Given the previously outlined architecture of a slow-motion AR system, we developed a subset for our prototype based on the HoloLens mixed reality headset. This device has the advantage that it is wearable, self-contained, and comprises already all required hardware components for the exploration of decelerated environments. The displayed stream was decelerated when the user presses the button on the HoloLens remote. The built-in camera of the HoloLens supports video streaming at 30 frames per second (fps) at a resolution of 1408x792 pixel. When the slow-motion is initiated, each frame of the stream is presented three times, causing the sensation of a decelerated environment. The decelerated stream was displayed until the user presses the remote button again. Then a fast-forwarded is presented to the user displaying all captured frames as condensed time-lapse. This fast-forward results in blending of the past and current video buffer without necessarily losing context. Currently, our prototype is based on the built-in components of the HoloLens. Hence, our implementation does not compensate for head rotation but is light-weight, tangle-free, and portable.

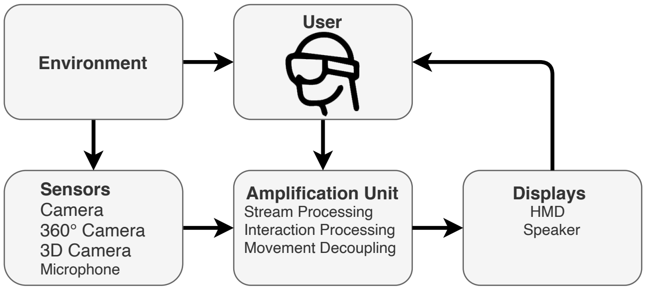

Figure 2: Schematic of the conceptual architecture.

6 PRELIMINARY EVALUATION

Our apparatus enables users to decelerate the visual stimulus on demand. The goal of our preliminary evaluation is to deeper understand the effects of visually slowing events down. We explore the users' attitudes towards the new possibilities as well as the overall user experience of our apparatus. We encouraged participants to use our wearable apparatus for a visual diagnose task. Throughout the study, we collected quantitative and qualitative data to investigate the unique aspects of a slowed down vision.

We invited 10 participants (5 female, 5 male) aged from 22 to 39 (mean=27.5, SD=5.0) from the computer science complex. All had normal or corrected to normal vision and received sweets for their participation. After welcoming the participants, we informed them about the course of the study and asked to provide written consent. We then collected demographic data, explained our prototype, and afterward started with the study.

During the study, participants had to estimate the jump height of the experimenter. Once with the support of changing the temporal resolution using our prototype and once without. For both conditions, the experimenter jumped once with low, medium, and high force in front of a wall that was prepared with large and clearly visible measuring tape. The experimenter verbally announced each jump. The setup of the jumping task is illustrated in Figure 3. We video-recorded the jumps and participants' estimations for offline analysis. We collected the height estimates of the participants during all three jumps for both conditions. This results in six height estimates per participant. The experimenter counterbalanced the jump force and the availability of slow-motion per participant. The participants were allowed to initiate the slow-motion at any time. Afterward, participants filled in a final questionnaire, and we conducted semi-structured interviews.

7 FINDINGS

We statistically analyzed the height estimates provided by the participants and derived three themes regarding the experience of slow-motion based on the semi-structured interviews and questionnaire.

Regarding the jumping task, we calculated the relative error based on the video recordings and participants estimations for

Figure 3: During the jumping task, participants had to estimate the jump height of the experimenter.

the slow-motion (M=4.15cm, SD=6.26) and without slow-motion (M=5.72cm, SD=5.32) condition. Applying a Shapiro-Wilk test did not result in a deviation from normality ($p > .05$). Hence, we submitted the relative error to a t-test which does not reveal a statistical difference ($t(26) = 1.48$, $p = .076$) between both conditions.

In the following we present and discuss the three themes we obtained from the qualitative data, namely *perception*, *confidence* and *technology*.

***Perception*.** The participants in our study considered the prototype as an extension and amplification of their visual sense. The possibility of changing the temporal resolution allowed them to observe fast events in greater detail:

> *"[...] it gives me the chance to catch some insights." (P4)*

Besides, participants noted the discrepancy between visual and auditory stimuli during visual observation task. While hearing the immediate takeoff and landing of the experimenter, the visual stimuli were not in sync.

> *"[...] it was kind of confusing that I've heard her hitting the ground again, but the visuals were not synced." (P2)*

***Confidence*.** Although the jump hight estimation error was not significantly improved, participants felt more confident using the slow-motion since they had more time to analyze the scene:

> *"Using the application for a task like this gives me higher confidence in my estimates." (P10)*

One participant raised higher self-esteem in their confidence when using slow-motion to assess their results compared to when not using the HoloLens:

> *"I can definitely tell that my guesses were more accurate or [...] at least my confidence about the guesses increased." (P5)*

***Technology*.** While most of the participants appreciated the possibility to slow down upcoming events, the technical limitations of our apparatus became prominent. Still, participants rated the overall ease of use with 4.6 on a five-point Likert scale. One participant stressed the importance of cameras that capture with high frame rates and low exposure to increase the quality of the displayed slow-motion:

> *"The decelerated versions didn't have many frames, however, so the slowed-down images seemed blurry." (P1)*

Adjusting the velocity of the displayed images during slow-motion was requested several times. Precisely, participants wished for more frames to be captured, which would enable finer adjustments between the deceleration levels.

8 DISCUSSION AND LIMITATIONS

We acknowledge that we employed a rather simple tasks. Still, it required focus to grasp a snap-shot of the motion. Hence, the evaluation revealed certain novel aspects of decelerated perception.

In the *technology* theme, participants preferred the possibility of manually adjusting the speed of the slow-motion. The fast-forward was negatively perceived as presented in the *perception* theme. During this process, our participants were afraid to miss information from the real-world or slow-motion until they rebounded to reality. Interestingly, the *confidence* theme reveals that participants had more trust in their answers when using our prototype. Although technical constraints affected the opinion of the participants, most of them were confident in their answers when using slow-motion.

The co-presence of slow-motion while keeping track of the real-world was challenging for most of the participants. This was observed for the slow-motion as well as for the fast-forward. Both functionalities are required to enable seamless integration. Further, the technical challenges regarding built-in cameras of current head-mounted displays remain. However, we assume that this limitation will be resolved with the upcoming advances in technology.

Finally, participants reported confusion regarding mismatches between visual and auditory stimuli of the slow-motion and the real-world. We believe that the combination of sound and vision is only one case that must be considered when employing temporal manipulation. Further research is required to investigate different aspects and the consequences caused by mismatches between slow-motion and the real-world.

9 CONCLUSION AND FUTURE WORK

In this paper, we explored the effect of visualizing slow-motion in Augmented Reality. We presented a conceptual architecture and a prototype that enables user-triggered slow-motion by displaying a decelerated real-time video capture.

Next, we plan to modify the prototype for a improved perception of slow-motion and reduced perceptive mismatch between sound and vision. Further extensions include a fine-grained adjustment of slow-motion and investigation of different rebound strategies in a human-centered design process.

The preliminary evaluation revealed more accurate estimations during a visual observation task when using slow-motion. Qualitative inquiries comprised implications for the future design of slow-motion for wearable devices. We believe that our research paves the way for future research in this domain and reveals three key challenges that should be considered by interface designers when creating interactive slow-motion functionalities.

First, (1) users should be provided with cues not to move, walk, or otherwise interact with the environment while the perception is out of sync between the perceived environment and the physical reality. Second, (2) mechanisms and visualizations are necessary to smoothly and seamlessly re-synchronize the perceived environment with physical reality. Third, (3) it is required to recognize and predict when the user wants to interact in the physical space – ensuring that by this point in time, perception and reality are in sync.

***ACKNOWLEDGMENTS*.** This research was supported by the European Union's Horizon 2020 Program under ERCEA grant no. 683008 AMPLIFY.

REFERENCES

[1] Yomna Abdelrahman, Paweł W. Woundefinedniak, Pascal Knierim, Dominik Weber, Ken Pfeuffer, Niels Henze, Albrecht Schmidt, and Florian Alt. 2019. Exploring the Domestication of Thermal Imaging. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia (MUM '19)*. Association for Computing Machinery, New York, NY, USA, Article Article 9, 7 pages. https://doi.org/10.1145/3365610.3365648

[2] Michael F. Deering. 1998. The limits of human vision. In *2nd International Immersive Projection Technology Workshop*, Vol. 2.

[3] David M Eagleman. 2008. Human time perception and its illusions. *Current Opinion in Neurobiology* 18, 2 (2008), 131 – 136. https://doi.org/10.1016/j.conb.2008.06.002 Cognitive neuroscience.

[4] David M Eagleman, U Tse Peter, Dean Buonomano, Peter Janssen, Anna Christina Nobre, and Alex O Holcombe. 2005. Time and the brain: how subjective time relates to neural time. *Journal of Neuroscience* 25, 45 (2005), 10369–10371. https://doi.org/10.1523/JNEUROSCI.3487-05.2005

[5] Shunichi Kasahara and Jun Rekimoto. 2015. JackIn Head: Immersive Visual Telepresence System with Omnidirectional Wearable Camera for Remote Collaboration. In *Proceedings of the 21st ACM Symposium on Virtual Reality Software and Technology (VRST '15)*. Association for Computing Machinery, New York, NY, USA, 217–225. https://doi.org/10.1145/2821592.2821608

[6] P. Knierim, F. Kiss, and A. Schmidt. 2018. Look Inside: Understanding Thermal Flux Through Augmented Reality. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. 170–171. https://doi.org/10.1109/ISMAR-Adjunct.2018.00059

[7] David Lindlbauer and Andy D. Wilson. 2018. Remixed Reality: Manipulating Space and Time in Augmented Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, Article Paper 129, 13 pages. https://doi.org/10.1145/3173574.3173703

[8] Jun Rekimoto. 1995. Augmented Interaction: Interacting with the real world through a computer. In *Symbiosis of Human and Artifact*, Yuichiro Anzai, Katsuhiko Ogawa, and Hirohiko Mori (Eds.). Advances in Human Factors/Ergonomics, Vol. 20. Elsevier, 255 – 260. https://doi.org/10.1016/S0921-2647(06)80226-1

[9] Jun Rekimoto. 1997. NaviCam:A Magnifying Glass Approach to Augmented Reality. *Presence: Teleoperators and Virtual Environments* 6, 4 (1997), 399–412. https://doi.org/10.1162/pres.1997.6.4.399 arXiv:https://doi.org/10.1162/pres.1997.6.4.399

[10] Jun Rekimoto and Katashi Nagao. 1995. The World through the Computer: Computer Augmented Interaction with Real World Environments. In *Proceedings of the 8th Annual ACM Symposium on User Interface and Software Technology (UIST '95)*. Association for Computing Machinery, New York, NY, USA, 29–36. https://doi.org/10.1145/215585.215639

[11] David Rose and Joanna Summers. 1995. Duration Illusions in a Train of Visual Stimuli. *Perception* 24, 10 (1995), 1177–1187. https://doi.org/10.1068/p241177

[12] A. Schmidt. 2017. Augmenting Human Intellect and Amplifying Perception and Cognition. *IEEE Pervasive Computing* 16, 1 (Jan 2017), 6–10. https://doi.org/10.1109/MPRV.2017.8

[13] Albrecht Schmidt. 2017. Technologies to amplify the mind. *Computer* 50, 10 (2017), 102–106.

[14] Yuhang Zhao, Sarit Szpiro, and Shiri Azenkot. 2015. ForeSee: A Customizable Head-Mounted Vision Enhancement System for People with Low Vision. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '15)*. Association for Computing Machinery, New York, NY, USA, 239–249. https://doi.org/10.1145/2700648.2809865

[15] Yuhang Zhao, Sarit Szpiro, Lei Shi, and Shiri Azenkot. 2019. Designing and Evaluating a Customizable Head-Mounted Vision Enhancement System for People with Low Vision. *ACM Trans. Access. Comput.* 12, 4, Article Article 15 (Dec. 2019), 46 pages. https://doi.org/10.1145/3361866