ChronoPilot – Modulating Time Perception

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***Abstract*—Although time can be measured objectively, human time perception is remarkably subjective and influenced by cognitive states, individual motivations, and social factors. This malleability of perceived time can be evidenced, for instance, in stressful situations where one might experience a lack of time, while one might lose track of time in more relaxing circumstances. Based on fundamental knowledge from psychology and cognitive science, the ChronoPilot project aims at developing a prototype technology driven by artificial intelligence to extend or compress human subjective time adaptively and whenever required. Mediated-reality approaches, such as virtual and augmented reality, have enormous potential for presenting the users with visual, auditory, and haptic stimulation patterns that directly or indirectly influence their subjective time and which are difficult to reproduce in the real world. Going beyond individual settings, ChronoPilot will also investigate how to coordinate time plasticity in collaborative environments where one group member's actions may affect other members' perception. Different scenarios, where humans alone or humans and robots have to collaborate in realistic and virtual environments, will validate the planned research. In this paper, we present the fundamental concepts of our project ChronoPilot, which is a work in progress.**

***Index Terms*—user-centered design, artificial intelligence, distributed system, sensor system, intelligent actuator, virtual reality, augmented reality, collaboration, cognitive science**

I. INTRODUCTION

The human perception of time involves complex interactions between neural systems, perceptual systems, information systems, and social systems. However, time perception is a highly subjective experience. Time may feel compressed in high workload situations, while, in other cases, where attention is not in great demand, time might feel stretched. This subjective experience may impact a wide spectrum of human actions and decisions, starting from motor actions up to strategic decisions. The *ChronoPilot* project aims to exploit this malleability of timing for our advantage at any given moment by delivering stimuli via mediated-reality technology into the human senses of vision, audition, and haptics (see Fig. 1). The purpose is to extend or compress time adaptively whenever required.

ChronoPilot's projected technical breakthrough for manipulating subjective time purposely relies on a series of cognitive techniques to tune time experience. These approaches will allow us to model key variables known to modulate timing as a function of multisensory stimulation and integration. We will translate these models in adaptive Virtual Reality (VR) and Augmented Reality (AR) environments and ultimately integrate a set of body-worn technologies in a 'ChronoPilot device' that autonomously stimulates the appropriate sensory modalities when required by its wearer. The ideal adaptation will be determined by a number of behavioral and physiological indicators of the user's mental workload, stress, and

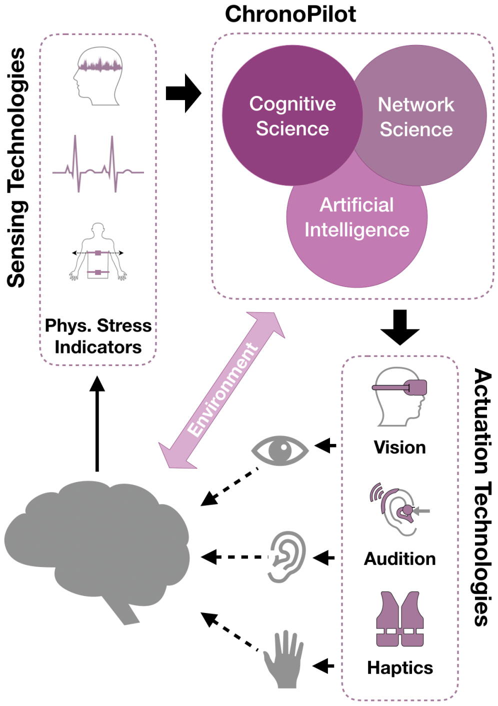

Fig. 1. ChronoPilot's system overview.

flow, as well as the context (e.g., environment, task, goals). Instead of requesting explicit user input about the currently desired time perception, we plan to have the ChronoPilot device measuring, for example, physiological stress indicators that, in turn, allow for automatically deriving the required time modulation. To achieve a high degree of autonomy and reliability, we will develop and study intelligent signal processing supported by machine learning and statistical methods.

Single and collaborating ChronoPilot devices will adaptively improve an individual's interactions with their environment, but also collectively when interacting with other humans and/or novel artificial intelligent systems (e.g., robots). Inspired by research on joint attention, emotional contagion in humans, and collective systems, we will investigate how networked ChronoPilots can coordinate and synchronize time modulation strategies between all group members collectively. We will explicitly include the future outlook of hybrid groups, where humans will interact with technological counterparts such as robots and other intelligent agents.

ChronoPilot's goals will be demonstrated in two real-world scenarios. A precision farming scenario that will involve an individual user coordinating a group of drones to perform a set of farming tasks and an industrial production scenario ('Industry 4.0'), where we will have a multi-person experimental setup of heterogeneous human groups. ChronoPilots will communicate with one another to carefully balance requirements across groups in a form of "shared timing".

ChronoPilot's realization necessitates a close collaboration between diverse disciplines and perspectives. This collaboration aims to: 1) Model the dynamics of human subjective time in terms of key psychological variables. 2) Modulate time perception through multisensory stimulation that is 3) auto-triggered by the ChronoPilot device as an intelligent agent implementing methods of machine learning that measure, monitor, and classify physiological and behavioral signals of users; 4) coordinate time perception in human and hybrid collectives; 5) evaluate whether timing can be utilized to improve well-being and productivity in hybrid and human collaboration.

II. THE CHRONOPILOT PERSPECTIVES

A. Modeling the dynamics of human subjective time as a function of key psychological variables

The ability to process temporal information accurately is critical for a natural organism's survival and its goal-driven interaction with the environment. Yet, under strenuous conditions, the ability to accurately perceive physical time is not necessarily beneficial for our behavior. In such scenarios, subjective time expansion (or compression) may be crucial in avoiding or postponing dangerous situations or catastrophic events [1], [2]. Perceived time expansion (or compression) may, therefore, serve as a tool to enhance perceptual processing, boost cognitive performance, guide attention to issues critical for survival, and facilitate motor functioning [1], [3]. Thus, in ChronoPilot, we focus on how we can promote expansion (or compression) of perceived time to optimize the individual's sensory, cognitive, and motor processing.

Current research has shown that we can experimentally expand and compress the apparent duration of stimuli or events by manipulating the critical factors driving perceived time estimates. Time expansion can be attained, for example, by providing the organism with salient, arousing, novel, or emotional stimuli (e.g., [4]). Attending to specific stimulus features can enhance one's temporal resolution, boosting the decision-making processes and modifying actions so as to delay or even avoid the critical event. Critically, it has also been suggested that slowing down the perceived time can be learned through experience and training [2]. Hence, exposing an individual to a simulated yet surprising and critical situation may benefit their behavior the next time they may find themselves on this trajectory towards a strenuous event.

In ChronoPilot, therefore, we collect state-of-the-art knowledge and produce new knowledge that will allow for the modeling of the factors (in isolation or combination) that dynamically modulate the human time percept in both the individual or the collective setups. This effort to consolidate and dynamically apply this knowledge in mediated reality among individuals or groups (human or otherwise) has never been attempted before.

B. Modulating time perception via multisensory stimulation

In ChronoPilot, we envision a body-worn companion device (set of wearables) that outputs appropriate multisensory stimuli to expand or compress the human subjective time experience. The device will stimulate visual, haptic, and/or auditory channels when needed (see Fig. 1). ChronoPilot will identify the most effective sensory channels in a particular situation; for example, some channels that are less relevant to the performance in a specific task, while others are particularly suitable to manipulate the most relevant cognitive factors.

Visual and auditory channels will be utilized given that visual stimulation is simultaneously perceived over a spatially distributed area with relatively high precision. In contrast, auditory input does not necessarily require directing the sensor organs to the stimulus, but the acoustic output can be synthesized, delayed, and mapped to a specific location with spatial audio techniques, both speaker- and headphone-based. Audiovisual stimuli can be accurately generated through head-mounted displays (HMDs), AR glasses, and other external devices employed in stationary or mobile/nomadic VR/AR systems. Research in cognitive science described a number of auditory and visual time-modulating effects that can be utilized for time manipulation, such as chronostasis effects from visual flickering stimuli or specific sound sequences and novelty effects of audiovisual environments [5], [6].

The haptic channel will also be exploited in our design, given that stimuli transmitted through the skin are harder to be perceived by others in proximity, guaranteeing privacy, and can be presented on a large stimulation area that is often task-irrelevant. Stimuli will be delivered by a set of actuators (vibrators, thermoelements) positioned in a matrix in a vest or gauntlet. Different stimulation patterns across the body will modulate experienced time via, for example, learned associations or inducing arousal [2], [7], [8]. ChronoPilot will finally benefit from the effects of multisensory enhancement through the parallel presentation of stimuli over different sensory channels. Multisensory effects are often more intensive than the mere addition of its unisensory components; thus, we will utilize multisensory illusions and attentional effects [9]–[11] for modulating timing.

C. Autonomously triggered stimuli for time modulation

We plan the ChronoPilot device as an intelligent, autonomous agent that measures and monitors all relevant physiological and perceptual variables of its user, then employs this to decide which stimuli configuration to apply. These decisions are sent to the multisensory generator devices described in the previous section. Hence, ChronoPilot exploits a decision model that is not only capable of estimating the current subjective time but also of harnessing the user's perceptual input to select stimuli and predict the aggregated effect of candidate stimuli on the user's experience.

Besides the link with perceptual content, there is increasing evidence that our time perception is not only the result of raw sensory input but that sensations are modulated by emotions and bodily states [12]. Neuroscientific computational accounts such as predictive coding, therefore, provide a good starting point [13], where the human brain is cast as constantly trying to update its internal generative model of the world to explain its sensory input. Using recent advances in deep learning, generative models have recently been scaled up to processing high-dimensional sensor input [14].

Therefore, generative models provide a good starting point for our research since they learn an environmental model directly from sensory input and allow to sample hypothetical scenarios that enable optimal planning of stimuli generation. Moreover, they have been used to model psychological and cognitive factors in time perception, like valence [15] and short-term memory [16]. Lastly, the planning capacity may also be helpful in multi-person situations, in which one ChronoPilot could use its own model to simulate the likely time perception of another agent.

D. Collective time perception and coordination

Modulating an individual's subjective time perception in a useful and efficient fashion is an enough challenging task. Yet, we plan to consider interacting human groups that need to coordinate (e.g., in a work environment) and may profit from a coordinated subjective time percept. In the collective context, additional challenges may arise, such as the individual vs. group profit, the group coordination, the dynamic change in the group size and individuals, etc. Our overall goal is to maximize the number of participants who are in the flow state.

Our research will consider both groups where individuals' time perceptions are aligned, as well as groups in which the individual time perceptions are largely different. We anticipate the second type of group to be more challenging to achieve a group state of flow. Consider, e.g., a group of highly experienced workers who easily get bored by regularly done tasks, while the same tasks may be perceived as challenging by an inexperienced group of workers who are new to the job.

We will inherit methods from intelligent agents, multi-agent systems, and swarm systems [17] to design group coordination and interaction [18], [19]. We plan to focus on developing efficient strategies for collective decisions [20] made by groups of interacting ChronoPilots. Such decisions may be the outcome of a negotiation process to harmonize time perception across the group individuals. We aim to develop a set of methods to coordinate ChronoPilot's devices to cope with contradicting user requirements in terms of their subjective time perception [21], especially in diverse groups. We will investigate different approaches to detect such conflicts and to resolve them [22], [23].

As we cannot exclude the possibility that, due to external or internal sudden changes, users may require different or even opposite time perception within a short time, we will also study methods of collective change detection [24]–[26]. This requires applying change and step detection methods from statistics to our distributed system based on signal processing of measured features (e.g., indicators of stress). We plan a hybrid approach that analyzes data individually by each ChronoPilot and in a distributed way by matching detected changes with other group members. Furthermore, we plan to exploit various interaction models to investigate their impact on the coherence and the efficiency of the Chronopilot's collective output. Given the diversity in a human group, we will also need to develop approaches to detect qualitative changes in the induced social network, such as the dynamic splitting of the group into contradicting time perception requirements.

Although the group sizes that we will investigate in reality will remain small, we will study scalable decentralized methods that would allow us to use the ChronoPilot approach on large scales. We plan to achieve a high degree of scalability by relying on known techniques from swarm robotics [27] as well as scalable methods of consensus finding with contrarians from opinion dynamics [28]. Especially to test large-scale systems, we will develop mediated-reality (simulation) environments using common tools (e.g., Unity) to study and evaluate our approaches.

III. CONCLUSION AND OUTLOOK

ChronoPilot will be realized through the interdisciplinary work of many different areas of science, transforming timing into a dynamically adjustable notion for both human individuals and groups. This is now feasible with the essential technologies becoming readily available, and we can begin combining them in new ways to harness the full potential of artificial intelligence techniques in mediated reality.

ChronoPilot's novel methodology of time modulation will pave the way for innovative applications and products, improving efficiency, well-being, productivity, creativity, and safety. The improved understanding of the psychology of time perception and the complementing technological means to modulate timing can profoundly impact both technology and society. Time will no longer constitute a passive, constant, and immutable factor, but, instead, it will be a novel focal point around which future socio-technical approaches related to human-human and human-machine interaction revolve.

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REFERENCES

[1] V. Arstila, "Time slows down during accidents," *Frontiers in Psychology*, vol. 3, p. 196, 2012.

[2] R. Buckley, "Slow time perception can be learned," *Frontiers in Psychology*, vol. 5, p. 209, 2014.

[3] W. Matthews and W. Meck, "Temporal cognition: Connecting subjective time to perception, attention, and memory," *Psychological Bulletin*, vol. 142(8), pp. 865–907, 2016.

[4] P. Tse, Intriligator, J., J. Rivest, and P. Cavanagh, "Attention and the subjective expansion of time," *Perception and Psychophysics*, vol. 66, pp. 1171–1189, 2004.

[5] K. Yarrow, H. P, R. Heal, P. Brown, and et al., "Illusory perceptions of space and time preserve cross-saccadic perceptual continuity," *Nature*, vol. 414, pp. 302–305, 2001.

[6] I. Hodinott-Hill, K. Thilo, A. Cowey, and V. Walsh, "Auditory chronostasis: hanging on the telephone," *Current Biology*, vol. 12, pp. 1779–1781, 2002.

[7] S. Novich and D. Eagleman, "Using space and time to encode vibrotactile information: toward an estimate of the skin's achievable throughput," *Experimental Brain Research*, vol. 233, pp. 2777–2788, 2015.

[8] H. Seifi, C. Anthonypillai, and K. MacLean, "End-user customization of affective tactile messages: A qualitative examination of tool parameters," in *2014 IEEE Haptics Symposium*, vol. 12. IEEE, 2014, pp. 251–256.

[9] M. Ernst and H. Bülthoff, "Merging the senses into a robust percept," *Trends in Cognitive Sciences*, vol. 8, pp. 162–169, 2004.

[10] V. Santangelo and C. Spence, "Multisensory cues capture spatial attention regardless of perceptual load," *Journal of Experimental Psychology: Human Perception and Performance*, vol. 33, pp. 1311–13 211, 2007.

[11] L. Shams and A. Seitz, "Benefits of multisensory learning," *Trends in Cognitive Sciences*, vol. 12, pp. 411–417, 2017.

[12] H. Merchant and K. Yarrow, "How the motor system both encodes and influences our sense of time," *Current Opinion in Behavioral Sciences*, vol. 8, pp. 22–27, 2016.

[21] T. D. Seeley, "Consensus building during nest-site selection in honey bee swarms: the expiration of dissent," *Behavioral Ecology and Sociobiology*, vol. 53, no. 6, pp. 417–424, 2003.

[13] K. Friston, J. Kilner, and L. Harrison, "A free energy principle for the brain," *Journal of physiology-Paris*, vol. 100, no. 1-3, pp. 70–87, 2006.

[14] A. Tschantz, M. Baltieri, A. K. Seth, and C. L. Buckley, "Scaling active inference," in *2020 International Joint Conference on Neural Networks (IJCNN)*. IEEE, 2020, pp. 1–8.

[15] C. Hesp, R. Smith, T. Parr, M. Allen, K. J. Friston, and M. J. Ramstead, "Deeply felt affect: The emergence of valence in deep active inference," *Neural computation*, vol. 33, no. 2, pp. 398–446, 2021.

[16] A. Zakharov, M. Crosby, and Z. Fountas, "Episodic memory for subjective-timescale models," in *ICML 2021 Workshop on Unsupervised Reinforcement Learning*, 2021.

[17] H. Hamann, *Swarm robotics: A formal approach*. Springer, 2018.

[18] I. Rausch, Y. Khaluf, and P. Simoens, "Collective decision-making on triadic graphs," in *Complex networks XI: proceedings of the 11th Conference on Complex Networks CompleNet 2020*. Springer, 2020, pp. 119–130.

[19] I. Rausch, A. Reina, P. Simoens, and Y. Khaluf, "Coherent collective behaviour emerging from decentralised balancing of social feedback and noise," *Swarm Intelligence*, vol. 13, no. 3, pp. 321–345, 2019.

[20] Y. Khaluf, P. Simoens, and H. Hamann, "The neglected pieces of designing collective decision-making processes," *Frontiers in Robotics and AI*, vol. 6, p. 16, 2019.

[22] H. J. LeBlanc, H. Zhang, X. Koutsoukos, and S. Sundaram, "Resilient asymptotic consensus in robust networks," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 4, pp. 766–781, 2013.

[23] H. J. LeBlanc, H. Zhang, S. Sundaram, and X. Koutsoukos, "Consensus of multi-agent networks in the presence of adversaries using only local information," in *Proceedings of the 1st International Conference on High Confidence Networked Systems*. New York, NY, USA: Association for Computing Machinery, 2012, p. 1–10.

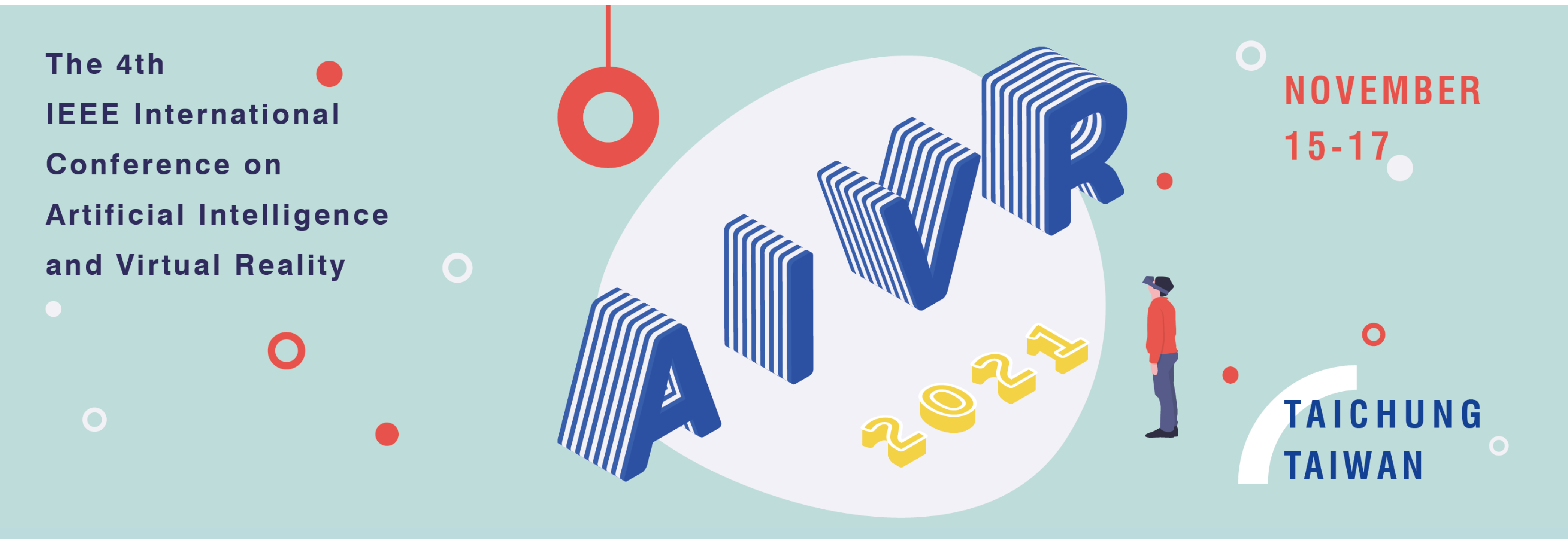
[24] M. Wahby, J. Petzold, C. Eschke, T. Schmickl, and H. Hamann, "Collective change detection adaptivity to dynamic swarm densities and light conditions in robot swarms," vol. ALIFE 2019: The 2019 Conference on Artificial Life, 07 2019, pp. 642–649.

[25] A. G. Tartakovsky and V. V. Veeravalli, "Asymptotically optimal quickest change detection in distributed sensor systems," *Sequential Analysis*, vol. 27, no. 4, pp. 441–475, 2008.

[26] Y. Khaluf, I. Rausch, and P. Simoens, "The impact of interaction models on the coherence of collective decision-making: a case study with simulated locusts," in *International Conference on Swarm Intelligence*. Springer, 2018, pp. 252–263.

[27] G. Valentini, H. Hamann, and M. Dorigo, "Efficient decision-making in a self-organizing robot swarm: On the speed versus accuracy trade-off," in *Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems (AAMAS)*, 2015, pp. 1305–1314.

[28] S. Galam, "Contrarian deterministic effects on opinion dynamics:"the hung elections scenario"," *Physica A: Statistical Mechanics and its Applications*, vol. 333, pp. 453–460, 2004.



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News & Updates

A message from the IEEE AIVR general co-chairs

Unfortunately, the COVID situation is not resolving itself as soon as we hoped. Because the safety of our attendants is most important to us, it is likely that the majority of the conference will run virtually. We are still hopeful to complement it with at least a small on-location part in Taichung. Rest assured though that in any case, attendants and authors will not be expected to travel to Taiwan but can present their work and attend virtually.

Clarification

We are aware that there are multiple events that include 'AIVR' in the name. IEEE AIVR is an IEEE sponsored conference series started in 2018 (see history page). Please be advised that this conference is the only AIVR conference whose proceedings are published in IEEE Xplore and IEEE CSDL.

September 29, 2021: The link for conference registration is online. Author **must** upload their final camera ready paper and register before **Oct 20, 2021**.

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After three successful conferences in Asia, US and Netherland respectively, we were looking forward to bring IEEE AVIR back to Taiwan. Due to the COVID-19 situation, we plan to have a hybrid event. The 4th IEEE International Conference on Artificial Intelligence and Virtual Reality (IEEE AIVR 2021) in November 2021 will thus take place in a physical venue as well as online.

IEEE AIVR is a unique event, addressing researchers and industries from all areas of AI as well as Virtual, Augmented, and Mixed Reality. It provides an international forum for the exchange between those fields, to present advances in the state of the art, identify emerging research topics, and together define the future of these exciting research domains. We invite researchers from Virtual Reality (VR) as well as Augmented Reality (AR) and Mixed Reality (MR) to participate and submit their work to the program. Likewise, work on AI that has a relation to any of these fields or potential for the usage in any of them is welcome. Please refer to the different submission categories under "Call for Contributions" for further details.

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