ZenG: AR Neurofeedback For Meditative Mixed Reality

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C&C '19, June 23–26, 2019, San Diego, CA, USA
ACM 978-1-4503-5917-7/19/06.
https://doi.org/10.1145/3325480.3326584

Abstract
In this paper we present ZenG, a neurofeedback AR application concept based on Zen Gardening to foster creativity, self-awareness, and relaxation through embodied interactions in a mixed reality environment. We developed an initial prototype which combined physiological sensing through EEG with AR visualisation on the Magic Leap Display. We evaluated the prototype through preliminary user testing with 12 adults. Results suggest users found the experience to be enjoyable and relaxing, however the application could be improved by including more features and functionality. ZenG shows the potential for AR to provide immersive and interactive environments that could promote creativity and relaxation, providing solid grounds for further research.

CCS Concepts
•**Human-centered computing** → *Mixed / augmented reality;*

Author Keywords
Neurofeedback, Mixed Reality, Mindfulness Technology

Introduction
The development of interactive systems integrated with biofeedback for creative and meditative purposes have received increasing interest in the field of HCI over the past

few years. However, a lot of these designs focus on static activities and practices, such as guided meditation, to increase levels of relaxation and mindfulness. In addition, augmented reality (AR) applications are being developed at an increasing rate, and as head-mounted displays become increasingly affordable and commercially available, we believe there is a unique opportunity to create embodied interactions through more kinetic meditative practices to achieve a creative, relaxed, and immersive state.

The main research interests of the project involve a multi-faceted approach incorporating elements of interactive kinetic meditation, tools for creative self expression and, subtle neurofeedback cues to support reflection of ones evolving cognitive state. We aim to foster self-awareness and creative exploration of ones environment through embodied interactions resulting in a gradual transformation of their immediate environment, using mindfully-designed tools, into a personal zen garden.

We present the exploration and design of *ZenG* a neurofeedback-driven AR application concept that combines a series of expressive virtual tools within the context of gardening, such as a watering can, rake, and seeds, with intuitive interaction techniques derived from kinetic meditation activities. From analyzing a user's brain activity and measuring active engagement with the meditative tools, we can provide neurofeedback by adapting the environment through overlaying virtual content such as plants, trees and animals. To this end, *ZenG* aims to transform mundane environments into a creative and playful spaces and encourage self-reflection by bringing one into the present moment through engaging and meditative interactions.

Kinetic Meditation

Meditation can be static or kinetic, and research suggests that both forms are effective for promoting relaxation and creativity [7][9][2]. Static meditation refers to a practice of present moment attention and non-judgmental awareness that is cultivated while remaining physically still [7][10]. A meditative state is achieved through focusing on a sensation such as the breath, a sound, or a mantra. Kinetic meditation uses prescribed body movements to reach a similar mindset of non-judgmental, present moment awareness and attention [10]. Examples of kinetic meditation include mindful colouring, gardening, or walking. Many static meditation applications exist for smartphones or web-based delivery [15][14]. AR presents a unique opportunity to support kinetic meditation, as it allows users to engage in guided meditative activities while maintaining awareness of their environment.

Neurofeedback

Neurofeedback via electroencephalography (EEG) is a tool used for treatment of a spectrum of psychological and neurological conditions [1]. EEG non-invasively measures the electrical activity of the brain from the surface of the scalp, which correlates with the mental processes occurring underneath. This complex bio-signal comprises of a number of frequency bands that are usually associated with specific mental states. Within the meditation literature, Alpha (8 - 13Hz) and theta (4 - 8Hz) activity have most commonly been identified as neural correlate of the mental activity although some studies have reported changes in beta (13-30Hz) and gamma (30Hz) frequencies bands [4][12]. A consensus is yet to be reached regarding the EEG correlates of meditation and thus the research into the efficacy of neurofeedback methods in meditation is still in its infancy. Nonetheless, the technique has successfully been shown to be effective in other areas and promises a vast opportunity for a variety of artistic, therapeutic or clinical applications.

The aims of ZenG

The overall aim for this body of work was to investigate the concept of *ZenG* and the feasibility of real-time biofeedback, specifically neurofeedback, in a mixed reality environment using an AR head-mounted display (HMD) to track and improve users levels of relaxation and self-awareness. Previous work has investigated the feasibility of BCI (brain-computer-interface) AR applications [11][13]. We aim to contribute to the field through these discrete objectives:

1. Investigate AR as a viable alternate reality environment for kinetic meditation.
2. Proof-of-concept of an AR environment to achieve a sense of escapism and create a positive association between the user and their environment, which could increase relaxation and creativity.
3. Experimentation with a novel method of visual biofeedback, instead of the conventional method of presenting graphs of EEG activity over time.

We chose to explore the concept of *ZenG* as an AR application for multiple reasons. Firstly, we wanted to explore the concept of ambiguous technologies and so-called ’apparent behaviour’ [6]. As a novel mode of interaction with subtle neurofeedback queues and access to creative tools, we allow users to creatively augment to their personal physical space. Doing so enables users to construct new narratives about their surrounding environment they cannot establish through real life gardening. Urban green areas provide a sense of refuge, nature and solidarity for stress relief [5], which can be brought indoors via *ZenG*. Gardening within AR extends our target user base to those with limited available space or limited mobility to nurture a physical garden. Such users may include hospitalized patients or people living in extremely crowded urban areas. Additionally, AR is preferred over VR not only due to the idea of transformative spaces, but also for safety reasons. AR enables users to engage in kinetic mediation whilst maintaining awareness of their surroundings to avoid injury and trip hazards.

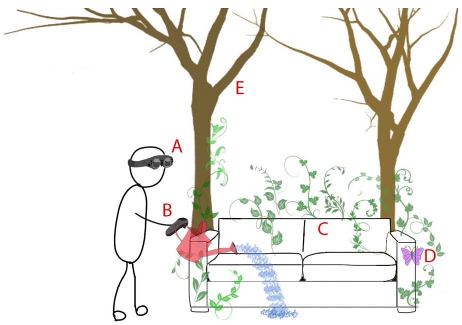
An AR prototype application was created for the MagicLeap One HMD to investigate some of the conceptual underpinnings of *ZenG*. We implemented one of the tools, the watering can, as well as a neurofeedback system through adaptive plant colors based on alpha wave activity. We conducted an informal user study to collect qualitative feedback on the concept of *ZenG* and the initial prototype.

Design of *ZenG*

Inspired by real-world Zen gardens, we explored a number of design concepts for *ZenG* which can be categorized into virtual tool concepts, based on tools and objects used in real zen gardens, and environmental neurofeedback, related to the behaviour of the natural world. Through these designs we aimed to develop a novel AR application that would create a dynamic feedback loop between the user, the physical environment and the virtual content.

The 3 interactive objects we designed were a *watering can*, *rake*, and *seeds*. *Seeds* can be placed by the user through out their real environment, such as on furniture, aided by the AR controller. Once the user has placed a seed, it can then be watered with the *watering can* to allow plants to grow. Using literature around color theory, we explored how color can be manipulated to represent different cognitive states. Related work around the concept of affective color has shown that hue and saturation can be used to express emotions, such as calmness or relaxation, which would correlate to colors of low saturation and high lightness [3].

Figure 1: Initial sketch of *ZenG* design. A) The Magic Leap HMD, B) The controller with the *watering can* tool superimposed, C) Plants growing in the user's personal space which are reactive to the 3D mesh of the room, D) A butterfly to represent prolonged engagement and relaxed cognitive state, E) Wilted trees to convey previous disengagement or anxious cognitive state from the user.



The *rake* tool is used to create patterns in the users environment, as one would rake patterns into sand, which is part of the kinetic meditation the user can engage with.

The levels of engagement with the kinetic meditation, planting seeds, watering plants and raking patterns, are tracked and considered with a users brain activity. Plants will then either flourish and grow or wilt and die depending on these parameters. Additionally, this information can be relayed to the user through the ambient sounds using spatialized audio as well as small animals/insects appearing in the space after engaging with the meditative activities for an extended session. Figure 1 shows an initial design sketch of how a user's environment may adapt.

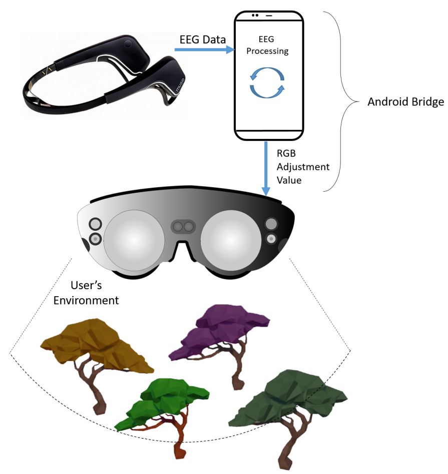
Prototype Implementation

To create the application, we followed a series of steps involving a scientific literature search, storyboarding, prototyping, development, and user testing. Firstly, we conducted a scientific literature search covering kinetic meditation exercises and EEG activity during meditation. This literature informed the design of our meditative activity and the EEG signals used to reflect the level and state of brain activity. Next, we created a storyboard where we designed how the user interacts with their environment based on their behavioral and EEG data. Through this process, we drafted the modes of interaction, necessary props and criteria for transitioning between meditative environments, as evident in the previous sections.

The environment was then created within the Unity game engine using MagicLeap One SDK, sourcing the visual and auditory components from available databases. We focused on the interaction that we considered most relevant and interactive with the 6 degrees of freedom controller hardware: watering plants. The MR environment consisted of several loci where flat rocks were placed around an occasional bush. There were seeds hidden beneath some of the rocks and when they were watered, a tree emerged from the ground.

EEG was measured with Muse 2014 headset (Interaxon, CA). Activity is recorded at four channels, Fp1, Fp2, TP7 and TP9 at 220Hz sampling rate. Internal digital signal processing module computes Fast Fourier Transform (FFT) on the raw signal using a Hamming window of 256 samples. The window slides across the next 22 samples (10Hz sampling rate) resulting in 90% overlap between two consecutive windows. After down-sampling the alpha band power to 0.25Hz, it was normalised to a value on a scale between the minimum and maximum alpha band powers for the session. If values fell outside of the range, the minimum or maximum was updated accordingly. The R parameter of the RGB colour of the trees were changed as a function of

Figure 2: The system architecture for the neurofeedback prototype. Data is provided by the Muse headset and then relayed via an android bridge to the Magic Leap HMD. Within the Unity application, the tree’s texture color is directly adjusted based on the relative alpha band value.



the normalised alpha value.

We conducted informal user testing involving 12 adult members of the public completing a brief demonstration and filling in a survey. The survey collected qualitative data on strengths and weaknesses of the application, and intent to recommend the application to a friend.

Initial Findings

Strengths

Participants reported liking the overall relaxing effect of the application. Participants 2, 5, 10 and 12 noted the ambient music and sounds as particularly ’relaxing’. Participants 5, 7, 8 and 11 ’liked the concept’, with 7 specifying ’EEG and AR integration’. Participants 2, 3, 6, 8, 9, and 10 liked the specific objects in the garden such as ’the butterfly’, ’the scale of the trees’ and ’the flow of water’ when interacting with the watering can.

Possible improvements

Participants felt the application could be improved in a number of ways. Participants 1, 6, 7 and 9 wanted an increased number of objects and to improve the ease of interaction. Participants 5 and 11 wanted an increased ’diversity of plants and animals’ in the environment. Participants 4, 9, 10 and 11 thought the graphics were a limitation, needing ’improved modelling’ and more detail. Participant 8 noted the ’hardware limitations’ of the EEG and AR HMD being difficult to set up. Participant 2 noted that the presentation of the user’s mental state was not always obvious, particularly in the way that mental state ’transitions’ are executed.

Intent to recommend

Most respondents would recommend the application to a friend. Reasons for recommending the application were that it was interesting, enjoyable, and could be helpful for stress relief. One participant responded maybe. Two respondents reported they would need tracking limitations to be fixed and for the garden to have more realistic graphics with a greater diversity of nature before recommending it to a friend.

Discussion and Future Work

Preliminary findings indicate that the application was enjoyable and created a relaxing environment for the user. It is worth noting that users wanted more features and functionality in the future. While many would recommend the app to others, a portion of the users indicated that improved graphics or additional features are crucial before the application was recommendation worthy. In sum, the feedback indicates the possibility of creating an immersive, interactive and relaxing environment within AR which establishes a solid foundation for further research and development of *ZenG*.

A limitation of this study was that the user experiences were very brief and the evaluation was informal. As a result, it was not possible to evaluate the effects of the technology with prolonged use. It was not feasible to evaluate the application's possible stress-relieving properties over time. Long-term experimentation would also be required to evaluate whether the application promotes a positive relationship between an individual and their environment, and whether an ubiquitous, environment-embedded visual feedback is more effective than graphical bio-feedback. Additionally, the application was constrained by the limited graphical content and the small array of interactions supported through the Magic Leap controller.

Our future research directions could include validation of the current approach. Firstly, sensorimotor and vestibular side-effects of sustained operation within AR systems should be investigated to further strengthen the rationale behind choosing AR over VR. Effects on the user should be compared to similar research done on VR [8]. Also, whether AR assisted meditation can provide over and beyond what is already available for mental health needs to be explored. This line of research should involve a systematic comparison with other conditions such as real life gardening, gardening within VR or non-meditative activity within AR. Exploring the clinical effectiveness of the current AR gardening method will be critical to successfully launch development of *ZenG* as a real life application. Lastly, the bio-feedback system requires more rigorous research. Kinetic meditations are rarely studied in the literature and EEG signals associated with the meditative practice is yet to be clearly defined. Moreover, research into incorporating other physiological signals can improve our understanding of complex interplay of physiology and mental activity and provide guidance in how to leverage such signals to create a more effective assistance during meditations.

ZenG as a neurofeedback technology has the capacity to make internal processes of a user more tangible. The integration of tangible artifacts and haptic feedback would present an opportunity for further creative self-expression through instinctive yet ambiguous embodied interactions. Such ambiguity would enable a user to interpret their data uninhibited and non-judgmentally. The inclusion of tangible artifacts supplementary to the interactive tools, for instance object proxies, would enhance the preexisting feedback loop between user, physical space and virtual content. By enabling a user to leverage the affordances of physical objects in their environment we allow for more intuitive and embodied interactions. Furthermore, haptic technologies present an interesting opportunity for tailored, personal and ambiguous neurofeedback. For instance, vibrotactile, electrotactile, thermal or force feedback as a means of conveying brain activity or other physiological data would enable neurofeedback through interaction with the system.

Acknowledgements
We wish to thank Mark Billinghurst, Aaron Quigley, Deb Polson, and the Empathic Computing Laboratory at University of Auckland's Bioengineering Institute for their support during the 2019 Augmented Reality Summer School. We would also like to thank MagicLeap for providing access to the devices.

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