**Developing an affect enhanced "Turrellian" RGB LED lamp designed to improve mood: towards multimodal affect-sensitive computing and devices.**

**EXECUTIVE SUMMARY**

**INTRODUCTION**

**Context**

No aspect of mankind’s mental life has more pertinence to the quality and meaning of our very existence than emotions. Quite simply, emotions make our life worth living and sometimes worth ending. With the advent of computers, it became inevitable that systems and devices would be increasingly used to recognise, process, simulate and interpret human affects.

Coupled with the exponential increase in transistors on silicon integrated circuits (microchips), Moore’s Law has promulgated exuberant innovation in computing technology. Resulting in computing technologies that will increasingly embed themselves into the fabric of our everyday living spaces, project the human user into the foreground. Indeed, these user-centric and intelligent computer systems will seamlessly serve the needs of the user with software operating automatically in the background.

These advances in computing power, wearable computer devices and interaction modalities promises a new dawn for computer systems and applications. Indeed, since Rosalind Picard’s, notable paper and book on affective computing in 1995 – much research has been established towards developing affective computers, systems, interfaces and robots.

Additionally, in more recent times, prominent human computer interaction researchers Pantic et al. have encouraged the development of affect-sensitive multimodal human computer interaction (MHCI or HCI2) – specifically computing which can understand and respond to natural and autonomic modes of human communication such as emotion automatically via analysing a range of human modalities. These devices or interfaces should transcend the traditional keyboard and mouse, succinctly understanding and adapting to human behaviour and signals.

In this vision of the future, often referred to as “ambient intelligence” humans will be surrounded by intelligent yet invisible multimodal computer devices that can anticipate all our daily needs. For instance, cars will automatically pull over if a driver becomes drowsy, our favourite music will be played by speakers when we come home weary after a long day at work and smart watches may prompt us with notifications to remind us to meditate when we are feeling stressed or agitated.

There are significant advantages to these increasingly empathetic and multimodal computers, interfaces and machines. Evidence from multimodal human computer interaction (MHCI) research finds that they are more human-like, usable, efficient and effective. Not only this, but these multimodal affect-sensitive computers and devices certainly have the capacity to significantly improve users’ day-to-day moods, emotions, routines and overall quality of life.

Spectrums of coloured lighting diffused by an internet of things (IoT) lamp has been chosen as the most appropriate natural medium to explore enhancing the mood of users. This is because different spectrums of lighting have been proven to have a non-invasive range of health and emotional benefits from improving concentration and sleep to even alleviating depression and migraines.

Additionally, there are an increasingly popular variety of IoT lighting devices designed to treat specific health disorders or on-command calibrate specific suitable environmental ambiences for their users. Therefore, there is undoubtedly value in adding more to this IoT lighting market by providing a device which acts automatically enriches users’ affective state, mood and experience.

**James Turrell**

As the device-namesake James Turrell’s artwork has been a dominant influence in this research. Turrell emerged as one of the foremost artists associated with the Light and Space movement of the 1960s. His art encourages a state of reflexive vision that he calls “see yourself seeing” wherein we become aware of our own senses, emotions and of light as a tangible substance.

Particularly, Turrell’s work explores the immateriality of light – building on the sensorial and emotional experience of space and colour. His oeuvre, phenomenological *lightscapes* feature technically advanced LEDs, which are configured by computer programming. Collectively these innovative and photographic techniques enable light and its spectrum of colour to have a physical presence and fully immerse the space.

These expositions and spaces engage viewers – capturing the limits and wonders of human perception prompting an incredibly transcendental and emotional experience. As Turrell aptly notes, “my material is light, and it is responsive to your seeing”. This physical engagement with light and colour strongly inspires the aesthetic design of the Turrellian LED lamp.

In this sense, Turrell’s work particularly his expositions focusing on the Ganzfeld effect hones visitors’ senses by deliberately removing elements of perception and enabling colour to fully inhabit and immerse the space. The colour itself provides an emotional experience for viewers and the Turrellian LED lamp is keen to capture a similar emotional response for positive purposes through immersive coloured lighting.

Indeed, Museum of Fine Arts Houston curator De Lima Greene notes that, Turrell’s “pieces enact not just an emotional response to colour but a sharpening of all of your perceptual faculties. After you have spent some time looking at Turrell, you walk out and pay attention to how even an ordinary lightbulb casts light upon the wall”.

**Turrellian LED lamp**

This thesis describes the development and testing of a new IoT RGB LED lamp, the Turrellian lamp, which inspired by the phenomenological works of Turrell and research initially outlined above – utilises light, colour and affect-sensitive MHCI to improve user’s mood and quality of life.

Particularly, the Turrellian LED lamp offers an enhanced sensory experience to benefit users mental-wellness, cognition and emotion – few realise the importance of appropriate lighting and the subconscious effect of coloured lighting on mood. The lamp aims to subtly expose users to appropriate colours and hue profiles of lighting to enrich their present mood and cognition based on detailed research from colour psychologists Valdez et al.

Conventionally, individuals have accustomed to the importance of music for their cognition and quality of life – people everyday use radios, phones or even music streaming platforms to play their favourite songs and playlists. Surprisingly, in stark contrast, ambient environmental lighting has been broadly overlooked by society due to its imperceptible nature and perceived unimportance. However, like music, ambient environmental lighting holds significant importance for individual’s mood, health and general cognition.

With this realisation, more recently, there has been growing demand for smart IoT light devices, lamps and lighting systems. Generally, these devices fit into two key categories. In the first category, the light devices are designed to be manually calibrated by users to provide ambient lighting on-command. In the second category, the light devices are designed to provide “health” functionality to treat specific disorders and syndromes such as seasonal affective disorder (SAD), sleep disorders and even dementia.

In contrast to these categories, the Turrellian LED is the first IoT lighting device to use insights from affect-sensitive computing to work synonymously with its users’ affective state (both conscious and subconscious) and offer mood enhancement through coloured lighting. Furthermore, the Turrellian LED has the capacity to operate automatically and autonomously. The goal of utilising insights from disparate fields such as ambience research, psychology and affective computing in the form of the Turrellian LED is threefold for users:

* To positively impact user’s cognition, affective state and mood through non-invasive coloured lighting.
* To encourage users to become committed to self-reflection and journaling practices – amplifying their daily routine with appropriate lighting and fostering emotional stability.
* To provide a low-demand and novel computer architecture for IoT devices, which is sensitive to users affect and offers multimodal human computer interaction.

Researchers within MHCI and affective computing have focused on the delivery of a wide variety of devices and applications such as more usable operating systems, driverless car design, healthcare, education, marketing or advertising research, video games, robots and even mirrors. However, as of yet no research paper has sought to utilise affective computing for building an ambient coloured LED lamp. This is despite much having been written and established regarding the influence of lighting and colour on users’ moods and emotions.

As a contribution in a new area of research, this thesis aims to support further work in this area by using open source and accessible prototyping platforms, providing an accessible GitHub repository for the codebase and by documenting developments and shortcomings to fully support further research or collaboration.

***Engineering design process and user experience testing***

Due to the pioneering nature of the LED lamp and the importance of users’ personal affective experience with the lamp. I decided to employ an engineering design process in which I would develop a beta ‘demo’ prototype for extensive experimentation and user-experience testing with candidates.

This collaboration with eventual potential users would help provide useful data and research concerning the devices effectiveness and ease of use. Equally it would enable necessary adjustments and improvements to be successfully made to the interface and Turrellian LED product.

Testing on ? was conducted to provide feedback, experience and expertise for the device. Due to the constraints of the Coronavirus pandemic and consequent issue of test subjects safely. Instead of engaging in a high number of test candidates, I adopted Sun Microsystems researcher, Nielsen’s model which encourages small usability tests for development.

I worked with test subjects observing their relationship with the device, usability of the interface, conducted interviews and think-aloud studies for focusing on their responses to the Turrellian LED. A control lamp was employed with test participants for direct comparison to determine the effectiveness of the Turrellian LED.

**Map of project paper**

The thesis is clearly divided into four parts:

* **Literature review**: In this section I define affect sensitive MHCI, critically taxonomize recent contributions to the field. Before juxtaposing the research with recent relevant insights from affective science.
* **Design approach and prototyping:** Here I discuss the context for the Turrellian LED, colour psychology and the groundwork for successful delivery of a beta prototype.
* **User experience testing:**
* **Outcomes**

**Project aims and objectives**

The project core aims are twofold. Firstly, developing a prototype product and application which enriches the current IoT smart-lighting market. Secondly, to contribute to burgeoning academic research and discourse within affect sensitive MHCI via providing criticism of current approaches, contributing a novel solution and offering pathways for future research.

In order to achieve these aims the six objectives of the project are as follows:

1. Present a thorough and critical taxonomy of existing affect sensitive MHCI systems and literature.
2. Critique current multimodal approaches and offer insights from neuroscience – particularly embodied emotion and its contribution to affective computing design.
3. Explain the design approach and research foundations of the Turrellian LED and evaluate competitor devices.
4. Develop a fully functioning beta prototype – equipped with integrated hardware, physiological sensors, LEDs and a graphical user interface (GUI) controller.
5. User experience test the functioning beta prototype and collect initial results versus a control lamp.
6. Analyse results and offer clear pathways for future research – so as to continue development towards affect-sensitive multimodal computer devices.

**Affect-sensitive MHCI**

**Chapter introduction**

In this chapter, I firstly clearly define and signify affect sensitive MHCI and its specific position within the broader research area of affective computing. Afterwards, I secondly and specifically contextualise with a taxonomy of modalities and approaches of prominent MHCI researchers. Lastly, I thirdly critically evaluate, compare and contrast the differing approaches with respect to the Turrellian LED’s own system architecture.

**Definition**

Affective computing is the study and development of systems and devices that can recognise, interpret, process and simulate human affects. Originating with philosophical enquiries of the mind, this modern branch of computer science was properly defined under Picard’s 1995 paper. However, the focus of this research paper is affect-sensitive MHCI – a smaller subset of affective computing.

Affect-sensitive MHCI originated more recently under a paper written by prominent researchers Pantic and Rothankrantz in 2008. MHCI focuses on specifically next-generation HCI designs, which are capable of recognising users affective state – to become more human-like, usable and effective. Therefore affect-sensitive MHCI differs from broader affective computing because it is specifically focused on interpreting and processing the emotional state of users and thus improving man-machine interaction.

To ensure systems are multimodal, affect-sensitive MHCI designs monitor multiple non-communicative cues or modalities. For instance, facial expressions, body movements, vocal and physiological reactions to automatically determine the affective state of the user. This ability to immediately empathise forms a cornerstone of human-to-human communication. Indeed, in face-to-face communication and interaction human beings socially process affective behavioural signals with little effort. Affect-sensitive MHCI thus envisages understanding their users affective state in a similar and automatic way.

**Taxonomy of approaches and significance of field**

As alluded to in the chapter introduction, there has been tremendous divergence in the approaches, modalities and methodologies employed by MHCI researchers designing affect-sensitive computer systems. Consequently, all human interactive modalities (sight, sound and touch) and non-verbal interactive signals (facial expressions, vocal expressions, body gestures and physiological reactions) have not been researched equally.

Currently most MHCI research has been preferentially invested into facial expression recognition and auditory speech analysis. These modalities are logically most desirable due to their non-invasive nature. Indeed, a camera or microphone can succinctly use to automatically document any users changes in vocal or facial changes and immediately deduce the underlying change in a user’s affective state.

Additionally, the two modalities of facial and vocal expression most neatly mimic natural forms of human social and emotional communication, which depends on auditory and visual facial signals. For example, we view mouth expressions to interpret if another party is smiling denoting happiness or the sound of guttural sobbing will usually preclude another party’s sadness.

Contrastingly, physiological reactions and bodily gestures require the use of intimate physical sensors for tactile processing of users changes in affective state. Often experiment participants have labelled these physical sensors as uncomfortable and mildly irritating. Resulting in less preference for physiological based architectures and gestural-based research and platforms.

Despite the different modalities used by MHCI for designing affect-sensitive computer systems and devices. There is broad consensus that a fusion of the above approaches will lead to the most sensitive and functional system. A system which utilises and processes all modalities automatically – enabling the machine to have a comprehensive apprehension of its user and their current affective state immediately.

Providing machines with empathy and emotional intelligence is crucial for improving existing computer systems, devices and architectures. Furthermore, it has a wide variety of application in multiple fields. Machines capable of sensing and responding to users’ affective feedback are likely to be more persuasive, natural and trustworthy. Therefore, these systems have useful application within a plethora of fields for instance:

* Elderly care
* Medical fields and diagnosis
* Marketing and advertising research
* Education
* Monitoring for inattention

Certainly,

**Chapter conclusions**

**Affective science**

**Chapter introduction**

The core ideas and concepts of affective computing can be traced back to insights from affective science, neuroscience, psychology and philosophy. Currently there is no scientific consensus on a definition of emotion. Subsequently in recent years emotions have become divisively and vigorously researched and debated.

In this chapter, I critically discuss insights from affective science most pertinent for developing the Turrellian LED system architecture and future affect sensitive multimodal IoT devices. Notably, little academic literature has sought to deliberately synthesise disparate fields of study with developing multimodal IoT devices.

However, research findings with developing computer technology Indeed disparate fields of study can improve our understanding of

**Chapter introduction**

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Furthermore consumers have readily purchased

Due to the sensorial works of artist James Turrell, the growing demand for ‘health’ orientated IoT light devices, significant findings from ambience research, neuroscience and psychology.

Furthermore, current market lighting devices are all manually calibrated by their users or medical practitioners to provide a comfortable ambience or treat a specific health condition and there is no concrete evidence of either categories effect on improving user’s mood. Consequently, at present there is no lighting device or application calibrated to improve overall mood, engender positive emotion, and work synonymously with its users’ affective state automatically. This is despite much having been written and established regarding the influence of lighting and coloured lighting on uses’ moods and emotion.

Disparate fields of study / Light as a medium for health and mood

Lighting, ambience research, artist James Turrell has conclusively found multiple health and emotional benefits coherent with

There are significant advantages to multimodal affect-sensitive computer devices and systems.

Devices capable of understanding users intimately – achieve mood improvement, be easier to use etc.

Multimodal human computer interaction (MHCI) researchers have processed different natural human modalities to extract user’s emotions with prominent techniques including facial expressions, vocal intonations, textual analysis and physiological reactions. In particular, facial expression, vocal intonations and physiological reactions enable MHCI researchers to achieve automatic processing of users emotion.

Rather facial expressions utilising both machine learning and AI has become dominant and most central to providing automatic affective feedback recognition for computer systems. In contrast, body gestures or physiological signals, textual sentiment analysis and auditory analysis have to a greater extent represented a more secondary role in multimodal computing technologies affect-sensing research.

However, this research supports the contention that a broad fusion of approaches is most desirable to creating affect

***Overview of research paper***

Product release cycle

***Research output***

**Part 1 – LITERATURE REVIEW**

***Chapter – Affective computing***

***Chapter – Light, emotion and IoT light devices***

***Chapter – Embodied, scaffolded emotion and multimodal affect-sensitive computer architectures***

**Part 2 – PROTOTYPING, TESTING AND DEVELOPMENT**

***Chapter – Prototyping and hardware development***

***Chapter – Physiological affect-sensors***

***Chapter – Software and web application integration***

**Chapter Introduction**

In this section I exhibit initial sketches, prototyping and development of the project. The focus of this project was on aesthetic outcomes, interaction and early delivery of the lamp. Additionally, the lack of commercial devices utilising affect-sensitive platforms or LED coloured lighting to improve mood meant that a clear empirical and user-centric approach to research seemed most appropriate. Throughout alpha and beta development of the Turrellian RGB LED lamp – I incorporated an agile development cycle resulting in the development of several projects and incorporation of user-feedback for continual improvement whenever possible. Only here due to the consequences of the Coronavirus pandemic and pioneering nature of the project– I proceeded informally and opportunistically, utilising friends, family and colleagues whenever possible.

As discussed in the previous section, prototyping was carried out in MAX/MSP - a high-level music development environment, which allows fast development of musical and interaction ideas. To work in this way I first had to develop a library which allowed simulation and control of Matsuoka’s Neural Oscillator(MNO) nodes in MAX/MSP.

**Part 3 – BETA PROTOTYPE AND UX TESTING**

**Part 4 – OUTCOMES AND FUTURE WORK**