Unpacking Visible Light Communication as a Material for Design

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ABSTRACT
Communication through visible light (VLC) is gaining ground as an alternative to traditional radio communication in many settings. Effectively using VLC in creative design processes may however be difficult as the material properties of VLC can be hard to grasp and therefore to use. This paper presents a design exploration where a set of artifacts was created to enable designers to play around with VLC and better understand its properties and their potential use for design. Each artifact was designed to illustrate a particular property of light communication ranging from inner workings of transmission protocols to properties of light in itself. The set was used in two small scale workshops where users played around with the artifacts and afterward were interviewed about their experiences. Interviews and observations from the workshops suggest that users gained insights into the material properties of light communication and were also inspired to think of creative uses for VLC based on those insights

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Visual Light Communication; materiality; interaction design.

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H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
The rapidly increasing number of wirelessly connected devices has led to a "Spectrum Crisis" due to the growing need for more bandwidth [10]. Recently communication using Light Emitting Diodes (LED) has emerged as an alternative to digital Radio Frequency Communication (RFC) particularly in contexts where communication can piggyback on existing LEDs used for illumination.

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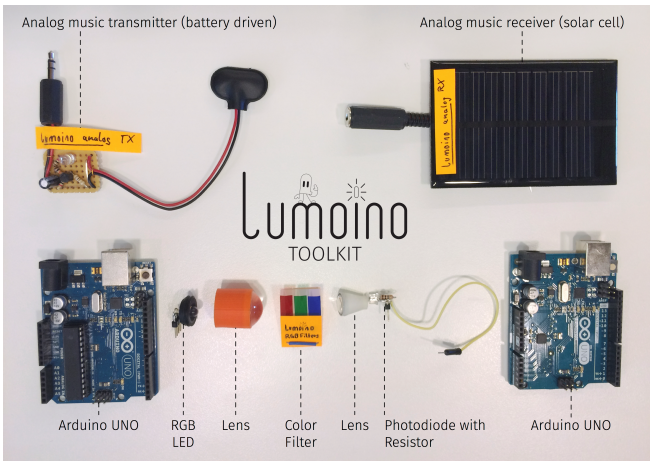

Figure 1. The artefacts of the "Lumoino" toolkit.

While technical gains and advantages of Visual Light Communication (VLC) are apparent [9], it may be hard to apply in the designer's process because of it technical complexity. Hence it can be challenging for designers to find the "…harmonious intersections between what is possible, acceptable, needed, and desired" [7] that they strive for.

This paper reports on a design exploration attempting to shed light on VLC as a design material through an Inspirational Bits approach [17]. The approach revolves around exploring materiality through artefacts that allow playful tinkering with technological properties of the material. An example of such an artefact from Sundström et al. is "RadioSound" which turns the received signal strength (RSS) of Bluetooth transmissions into sound to demonstrate how the signal strength is influenced by the environment [16]. Through such explorations designers engage in a conversation with the material and learn about its properties and how they may come into play in their design work [14]. Through the examples provided by the artefacts designers also gain insight into the necessary skills needed to successfully work with the material. Without such skills the material stays inert, presenting itself as matter rather than a material [1, 5].

In our design process seven artefacts exploring VLC in different ways were assembled into a toolkit (see Figure 1) with the intent of making black-boxed [17] properties of VLC available for playful material explorations.

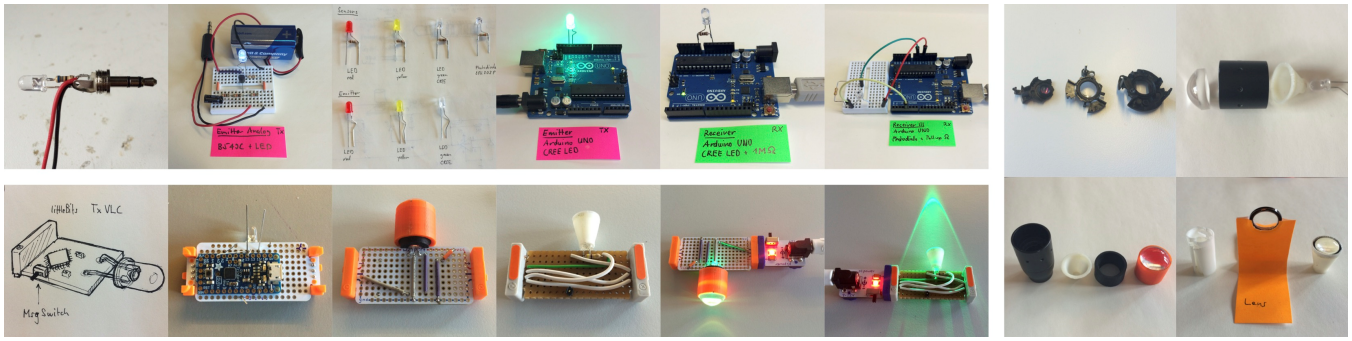

Figure 2. An excerpt from the design process. Top-left: Analog and digital prototypes. Bottom-left: "lumoBits " prototypes. Right: "Applitypes" prototypes.

BACKGROUND & RELATED WORK

There are several projects and products using VLC that have inspired our project. For instance, "Sound Modulated Light" [3] is an art installation that generates sound through light. Visitors listen to sounds by pointing a receiver with headphones at light sources each modulated by their own sound source. Moving the light receiver and pointing at several light sources at the same time changes the music composition in real-time. This enables the visitor to experience music in a more personal, spatial and bodily manner.

The "S T R A T I C" project [15] uses the “rolling shutter effect” to create visualizations from music. An audio synthesizer produces sound that directly modulates an integrated RGB LED. A camera with a CMOS image sensor captures the light and generates colourful line patterns due to the rolling shutter effect. The intention of this project is *"... to create a close sense between audio and video and [the] relation of synaesthetic experience..."*.

"Point-and-shoot data" [4], a smartphone case with an integrated control circuit, light source, lenses, filters and mirrors, makes use of the directionality and "physicality" of light. The optical components allow the user to manipulate the light communication channel directly which gives *"...the ability to engage in digital communications without needing to first obtain the senders' or recipients' digital IDs"*.

The "Internet of Toys" proposed by the Disney Research Institute focuses on applications in toys [2, 11-13]. Their implementations present a network of connected toys through VLC. The institute emphasizes the benefit that *"...Communication is independent from light effects or flickering that human eyes can perceive and data flow is visible and therefore steerable towards potential receivers." [13]* Children can play with the toys directly through light. This directs the child's attention to where the action is and creates a magical moment when a toy reacts to a user action with light. For example, pointing a magic wand with an integrated LED on a princess dress causes the dress to reveal different light patterns.

DESIGN EXPLORATION

Our work followed a constructive design research approach [8] where the toolkit iteratively took shape based on our explorations. We focused on hands-on activities where we explored ways of illustrating properties of VLC by building simple prototypes as well as tinkering with existing examples found online. Two Arduino projects[1,2] in particular provided a good foundation for a number of explorations. We were also inspired by previous work such as the "S T R A T I C" [15] and "Sound Modulated Light" [3] to explore the rolling shutter effect and use modulated light as a sound source. This helped us to gain insight into VLC from different perspectives.

Our approach was bottom-up in that we did not explore a predefined set of properties. Rather they emerged as we continuously explored VLC and created prototypes (Figure 2 shows an excerpt from the design process). We make no claims about the completeness of the set of properties we ended up exploring. Instead they represent the properties that in our work stood out as interesting from a design perspective. Once we had explored enough properties to share our insights we started condensing our work into a toolkit that could be used and experienced by others.

Design workshops

Two design workshops helped to ground our work. The workshops followed a simple format where participants 1) were introduced to and later 2) engaged in open tinkering and ideation with the artefacts, 3) and finally presented their ideas and provided feedback. To contextualize the ideation process participants used themes from an IxD course they were currently engaged in. Themes included: Fashion, Bodies & Health, Fitness & Sports, Nature & Animals, Homes, Cities & Transportation, Arts & Crafts, Kids & Play, and Audio-visual Media.

The workshops had five and six participants respectively. Participants were master’s students in interaction design or computer science without prior experience of VLC. All participants had at least basic computer programming skills.

[1] https://github.com/jpiat/arduino

[2] http://mchr3k.github.io/arduino-libs-manchester/

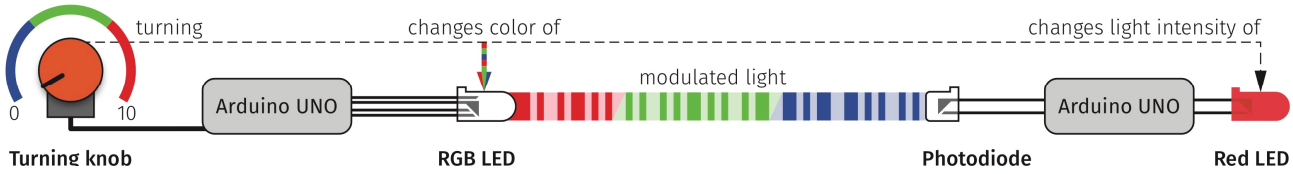

Figure 3. A diagram illustrating the functionality of the "Remoter" artefact.

THE LUMOINO TOOLKIT

The toolkit is targeting designers, hobbyists and students and aims to provide a basic understanding of visible light communication. It is a starting point that covers the fundamentals of the technology while more advanced aspects of state-of-the-art VLC as covered by e.g. openvlc [18] and technical aspects covered by [6] will be addressed in future work. The toolkit is open sourced on github[3].

In between workshops the "Remoter" artefact described below was added and the presentation of the artefacts was tweaked to create a more coherent narrative. The set of artefacts presented here is the current set used in the second workshop. Four artefacts were created using Arduino to illustrate properties of VLC, one provides an example of integrating VLC with existing devices to create new interactions, one explores other platforms that appeal to non-technical users, and the final one finds a new use for standard mobile phones in revealing properties of VLC.

Musicbeam

The "Musicbeam" is a music-through-light artefact. It consists of a set-up free analogue transmitter and receiver. The transmitter consists of a simple circuit with a modulated LED light into which any music player with a headphone jack, e.g. a mobile phone, can be plugged in. The receiver is a regular solar cell that connects to a pair of active loudspeakers via a headphone jack. Directing the transmitting LED toward the solar cell plays the music. A well-known side effect is that the solar cell receiver can also listen to any other light source. For example, a digitally modulated light source creates a distinctive square wave like sound. "Musicbeam" exemplifies the following properties of VLC:

Direction: Light illuminates an area thus VLC communication can be disturbed by objects and people and is restricted to the illuminated area. It also shows that light communication can be visually contained, unlike radio communication. Participants explored this feature by covering the light source with their hands in a rhythmic fashion.

Distance: The signal strength depends on the space between transmitter and receiver. An increase in distance results in a decrease in signal strength and thus, in this case, weaker audio output.

Lightpacer

The "Lightpacer" consists of two Arduino based devices: a transmitter with a modulated LED, and a receiver with a photodiode and an additional LED for indicating status. When the two devices are set up correctly, the transmitter sends a message to the receiver by using Manchester encoding. If the receiver successfully decodes the message, the indicator LED of the receiver blinks.

The Arduino program provides different transmission speeds that can be set in code. The lowest speed causes the light to flicker visibly but it can be increased until the human eye can't perceive flickering or the receiver can't detect a signal due to the transmission becoming unsynchronized. "Lightpacer" illustrates two properties:

Signal Quality: The relationship between transmission speed and the visual quality of the communication (flickering), and how the speed affects a successful transmission. The increase in transmission speed and distance between devices lowers the rate of a successfully received message.

Unisono: For devices to communicate with each other successfully, their transmission and reception speeds must be in sync like in RFC. Hence communicating devices are interdependent and need to be properly set-up for stable communication to take place. Users take synchronization for granted as devices take care of synchronization automatically when they establish a connection to each other.

Remoter

The "Remoter" is a result of ideas and feedback from the first design workshop. It uses the same setup as the "Lightpacer" artefact with some modifications. The transmitter has an RGB LED rather than an ordinary one and a potentiometer to change the LED colour. The transmitter encodes the potentiometer value into the light, independent of the color. The receiver in turn adjusts the light intensity of its LED per the received value (see Figure 3). The purpose is to show the possibility of layering information. The artefact exemplifies the following property:

Levels of disclosure: The colour of the LED is directly interpretable by the user. But what you see is not necessarily all you get, as the encoded message in the transmitting light may contain more information that is only accessible through a receiver.

Applitypes

The "Applitypes" are two optical extensions with lenses housed in 3D printed fixtures that are used to focus light from LEDs, to allow for a longer communication distance between transmitter and receiver. The focal length of the orange extension can be adjusted by twisting it, while the

[3] https://github.com/agentff6600/lumoino

white extension has a fixed focal length and is tailored to fit a photodiode (see Figure 2). The property illustrated is:

Reception quality: The communication distance can be increased but narrows the illumination area and may require precise aiming.

Messenger – light based texting

"Messenger" is an example of integrating VLC with existing devices. The transmitter is similar to "Lightpacer" but also contains a text message that the user can change in the program code. The receiver acts as a regular USB keyboard. It receives the text message from the transmitter and forwards it like a regular keyboard to the connected computer via USB.

lumoBits

The "lumoBits" explore other platforms and form factors for packaging artefacts to make them accessible to non-technical users. They consist of a version of the "Remoter" packaged as littleBits[4], and are also compatible with the "Applitypes" optical extensions. "lumoBits" remove the setup process required by the Arduino version, yet they allow exploration of VLC properties such as "Concealed Information", "Direction", "Distance" and "Reception quality" as described above.

Rolling shutter visualization using smart phones

VLC is visible to the naked eye, but depending on factors such as transmission speed, it can be difficult to differentiate from regular light. Here the rolling shutter effect caused by properties of CMOS sensors used in e.g. most smartphones can be helpful. Viewing VLC through the smartphone camera creates characteristic line patterns that are a real-time chronological visualization of the communication that reveals details about e.g. modulation techniques and message structures. As such it was used as a tool for revealing hidden details of VLC. Figure 4 shows examples of an analog light source from the "Musicbeam" and a digital light source from the Remoter artefact. In the latter case the message structure of the communication becomes evident.

DISCUSSION

The toolkit has a simple design that exposes properties of the technologies involved in VLC. Our aim was to create a toolkit that allows designers to have a playful conversation with VLC by "un-blackboxing" the technology [17]. We believe this "un-blackboxing" reveals its properties in an honest way accounting for both strengths and weaknesses that can affect design. Lumoino uses affordable and familiar technologies such as Arduino and should appeal to a broad audience of researchers and practitioners.

The workshops were small in scale but indicated that the artefacts can stimulate ideation and lead to insights on how to use light as a communication medium. For instance, one participant developed an idea related to audience participation in concerts using VLC, based on the "Musicbeam" artefact. She envisioned parts of the musical performance to be communicated by the light show that is usually a part of concerts and the audience interacting with that in various ways, such as collectively acting as loudspeakers by holding up their VLC enabled devices towards the light.

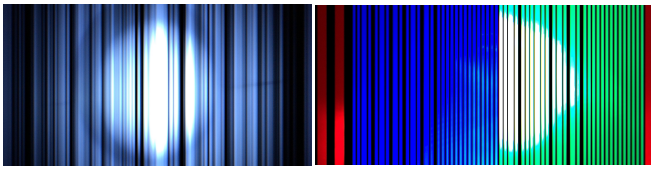

Figure 4. Rolling shutter visualizer: Left Visualisation: light modulated by an analog signal. Right Visualisation: light modulated by a digital signal. Each colour (red, blue or green) represents a message block.

Another idea, based on the Remoter artefact, was a fitness bracelet with a single LED interface. The LED shows the user's performance level by glowing green for good and red for bad performance. Additional information, such as heart rate, is embedded in the light and can be seen via a receiver such as a smartphone camera. Participants also came up with many ideas that were similar to the ones mentioned in the related work section although they were never introduced to them. Furthermore, the "Musicbeam" and "Rolling shutter visualizer" were frequently used to explore VLC properties. This made the participants realize that regular LCD displays, common light bulbs and smartphone LEDs are also usable for VLC.

During the approx. three hours that each workshop lasted, participants favored the setup-free artefacts such as "Musicbeam" and the "lumoBits" because interaction was quicker and required less effort. However, we expected our users who, although unfamiliar with VLC, all had programming skills to use the Arduino based artefacts more than they did. Feedback suggests that a guide would be beneficial in this respect and we are currently in the process of designing a booklet, which briefly explains each artefact, as a starting point for further exploration.

Finally, the Lumoino artefacts are inspirational bits in that they highlight properties of a digital material - VLC. However because it is a toolkit where the pieces fit together it also becomes possible to see how these properties can be combined in design work, as illustrated by for instance the fitness bracelet example above.

CONCLUSION

Through an Inspirational Bits approach we assembled a toolkit of artefacts that facilitates playful conversation with VLC as a design material, thereby "un-blackboxing" the technology. The toolkit is a starting point for further development that other researchers and practitioners can use to continue shedding light on VLC as a design material.

[4] http://www.littlebits.cc

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