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Communication with Ambient Light using Digital Micromirror Devices

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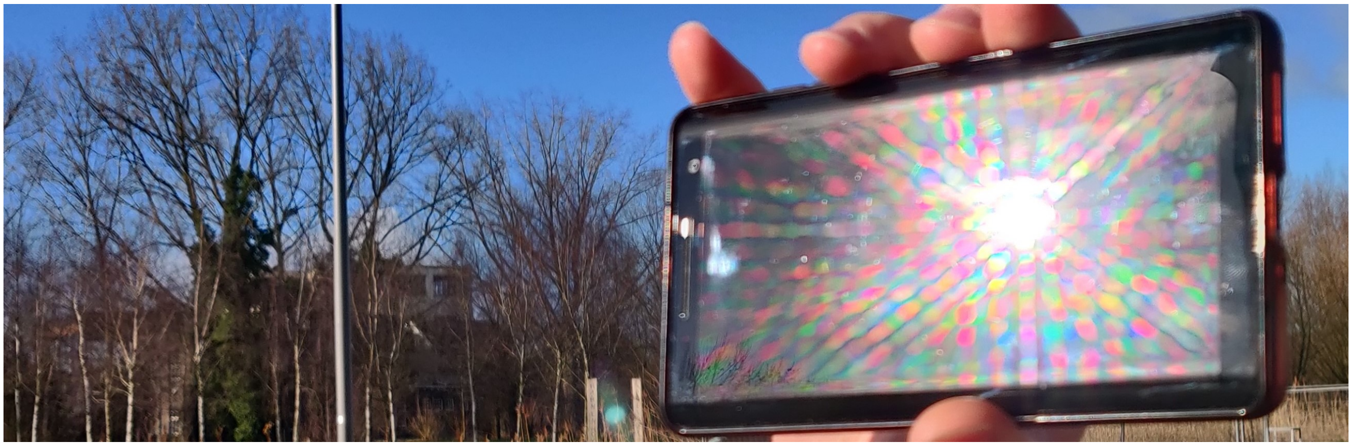

Figure 1: Phone reflecting light as a mirror. This symbolises the main idea of our research. We utilize micro mirrors to transmit information via sunlight reflections and use the smartphone's camera as a receiver to decode those reflections.

ABSTRACT

Passive visible light communication (VLC) takes advantage of the pervasive nature of ambient light in our environment for wireless transmissions. The design of transmitters in passive VLC predominately uses liquid crystal displays (LCDs). While LCDs are an economical choice with low power consumption, they lack some key properties that are desirable for passive VLC. For example, LCDs absorb more than half of the incident light, leaving only a small portion to be used for communication. In addition, since the direction of ambient can change over time, the relative positions of the LCDs and receivers have to be changed constantly to maintain the correct alignment.

To overcome these shortcomings, we propose the use of a novel transmitter with integrated optical fibres and digital micro-mirror devices (DMDs). DMDs are able to reflect up to 97% of the incident light, while the accompanying optical fibres aim to capture ambient light from various angles and guide them to the DMDs in a fixed direction. This design is a first step towards the goal of decoupling the direction of ambient light from the direction of the optical link, while achieving the same communication characteristics as LCDs with a much smaller device. We also design an App to allow users to easily interact with the system and our evaluation shows that the link can achieve a data rate of 1bps at a distance of 30cm.

CCS CONCEPTS

• **Hardware** → **Wireless devices**; • **Computer systems organization** → *Embedded systems*.

KEYWORDS

Visible Light Communication, Passive Communication, Digital Micromirror Device (DMD)

1 INTRODUCTION

Visible Light Communication (VLC) is an emerging technology for wireless communication that has gained traction from both academia and industry in recent years. Compared to traditional radio frequency wireless communication, VLC has several advantages such as an unregulated wide bandwidth and high security. VLC can be further divided into two main areas: active and passive. In both areas, the intensity of the light is modulated at a speed that is invisible to the human eye, but can be received and decoded by optical receivers. In active VLC, the driver circuitry is modified to modulate message signals by varying the driving currents of an LED. In passive VLC, an external surface is used to modulate message signals by changing the characteristics of the light passing through or reflecting from the surface. Compared to active VLC, passive VLC has the advantage of exploiting the ambient light in our environment, without having the need to directly control the light source.

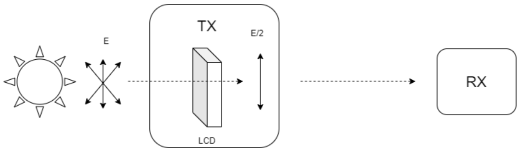

Figure 2: Light energy lost using an LCD: 50%

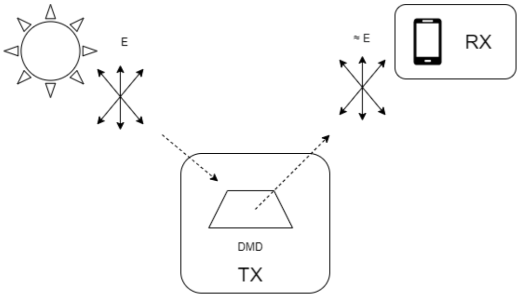

Figure 3: Light energy lost using a DMD: 3%

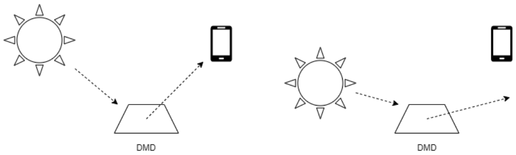

Figure 4: The sun moves during the day, therefore the reflected light changes direction

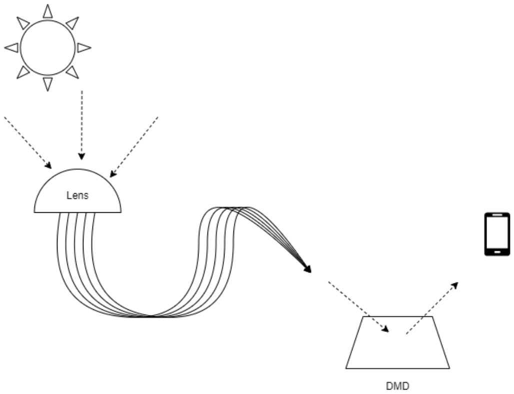

Figure 5: By using a lens to capture light, the movement of the sun doesn't influence the direction of the reflection

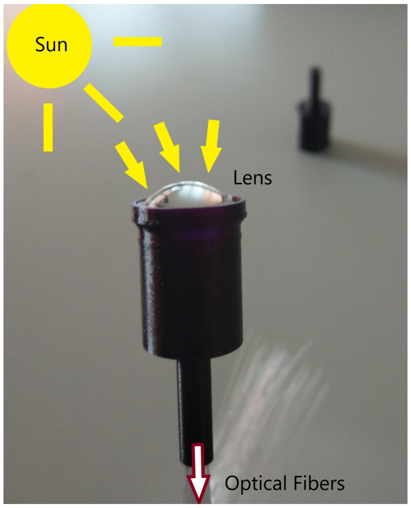

Figure 6: 3D printed light collector

The majority of passive VLC systems proposed in the literature rely on the use of liquid crystal displays (LCDs) to modulate light [2][6][7][8][9][10], as shown in Figure 2. A LCD modulates the incoming light on its surface with two states: in the opaque state, the LCD surface absorbs the incident light (logic zero), and in the clear state, the LCD surface allows the incident light to pass through (logic one). However, as LCDs are only able to realize these two states in combination with polarizers, less than half of the incident light can typically pass through the surface in the clear state due to polarization mismatch. One device that is able to overcome this disadvantage is the digital micromirror device (DMD). A DMD is a small chip containing thousands of small mirrors with the size of less than 10 microns. DMDs are widely used in video projection technology (beamers), where every mirror represents a pixel. The mirrors can be switched to two fixed angles with respect to the surface normal, allowing two binary states to be sent by reflecting light (or not) towards the intended receiver.

In our work, we are trying to implement a communication link between a DMD and a smartphone. Smartphones have been used before as VLC receivers but mainly using active lights sources as transmitters (LEDs) [1][3][4][5]. In our design, the DMD reflects the modulated *ambient light* towards the camera of a smartphone, which is then decoded by an App and displayed on the screen.

2 OPTICAL AND MECHANICAL STRUCTURE

As the reflection off a DMD is primarily specular, the light source and the receiver have to be precisely aligned to establish an operational link. When sunlight is used as the light source in passive VLC, as the position of the sun changes in the sky throughout the day, its direction with respect to the DMD also changes. This causes the reflected light to be misaligned to the receiver, as shown in Figure 4, where the signal-to-noise ratio (SNR) can significantly deteriorate. To overcome this problem, we propose the integration of optical fibers and lenses into a passive VLC system, as shown in Figure 5. The sunlight is "collected" using a convex plano lens connected to multiple optical fibers. In this manner, the collected light is guided through the optical fibers and emitted directly onto the DMD. This allows the incident angle of the light on the DMD to remain the same regardless of the location of the sun. The design is shown in Figure 6, and the other end of the optical fibers, illuminating the DMD at a fixed angle, is shown in Figure 7.

Figure 7: DMD reflecting light coming from optic fibers

Figure 8: DLP 2000 by Texas Instruments

3 TRANSMITTER

For a proof of concept design, we choose the DLP2000 DMD from Texas Instrument. The DLP2000 DMD has an aperture size of 4.84mm by 3.26mm, as shown in figure Figure 8. In our design, all pixels of the DMD have the same state, and the entire DMD device acts as a single pixel with on and off states. A simple pulse width modulation (PWM) was chosen to transmit the data. When a logic one is sent, the light is reflected into the receiver for a certain time period and then not reflected for the same amount of time. When a logic zero is sent, the time that the light is not reflected into the receiver is doubled. This modulation scheme allows ones and zeros to be easily distinguish, in the expense of unequal transmit times for different symbols. To demonstrate our design, ASCII texts are sent over the optical link. The non-extended ASCII table contains characters that are all 8-bit long and start with a zero. Because there isn't a character of all ones a preamble is chosen containing eight ones and then a zero. Note that using mostly ones in the preamble is faster because zeros require more transmission time. The preamble is sent multiple times to make sure the receiver will be able to see it. After the preambles, the ASCII characters are sent. There is no limit to the number of characters that can be sent. The format of the data frame is shown in Figure 9.

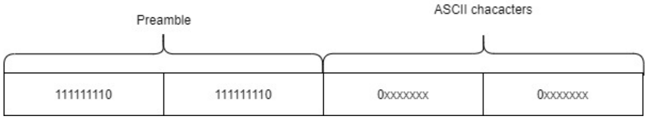

Figure 9: [Packet format

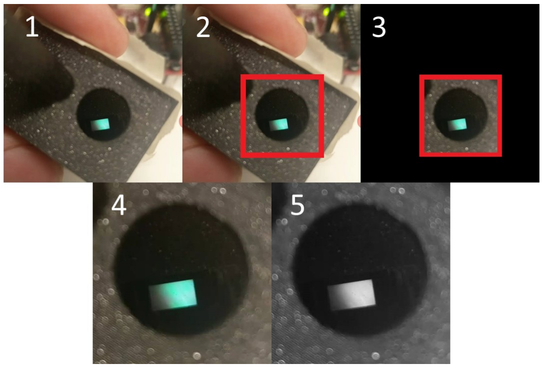

Figure 10: (1): Raw image. (2): Image tracking follows the DMD and draws a region of interest. (3): Only the ROI remains. (4): ROI is sent to image processing. (5): Image is converted to greyscale to determine the average pixel value.

4 RECEIVER

Images from the smartphone camera are captured and processed using an Android App. After selecting a region of interest, every captured frame is sent to an image processing pipeline, as shown in Figure 10. The region of interest makes the processing easier, as only a small part of the captured image needs to be used. An OpenCV tracker is used to track the DMD, so when the user moves the hand a little, the region of interest will still be on the DMD chip.

To describe the decoding process, let us denote $\mathcal{R}_i$ as the region of interest at time i (i.e. frame i). We calculate the average pixel value of each region of interest i, denoted as $\widehat{\mathcal{R}_i}$. During the preamble transmission, when the DMD is "on", the DMD will be reflecting light and the average reaches its maximum value $\hat{\mathcal{R}}_{max}$. When the DMD is "off", we obtain the lowest average value $\hat{\mathcal{R}}_{min}$. Later, when the ASCII characters are transmitted, if $|\hat{\mathcal{R}}_i - \hat{\mathcal{R}}_{max}| < |\hat{\mathcal{R}}_i - \hat{\mathcal{R}}_{min}|$, the DMD is decoded as "on", else as "off". Every time the state of the DMD changes, from "on" to "off" or vice-versa, we calculate the number of frames that the DMD spent in that state. If the "on" state has approximately the same length as the subsequent "off" state, a one is decoded, otherwise it is a zero. As soon as the bits are decoded, they are converted back to ASCII characters and displayed on the screen.

5 EVALUATION

Currently a bit rate of 1bps can be achieved. One of the main reasons for the low bit rate is the tracker used in the app. There is significant room for improvement. For example, putting the tracker in a different thread, so the rest of the program doesn't have to wait for the tracker to finish. A communication distance of up to 30cm is possible with our prototype. There are also some opportunities to increase the range. The image recognition step can be improved to look for smaller regions of interest. If we can capture *only* the DMD, the noise introduced by the surrounding areas will be eliminated and the range could increase significantly. At the moment the region of interest is set to a fixed size.

6 ACKNOWLEDGEMENTS

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