CHAPTER 44

Optical Wireless Communication and V2LC with Ad hoc Technologies

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ABSTRACT

The Optical Wireless Communication (OWC) technology envisages a variety of application scenarios ranging from chip-to-chip communication to inter-satellite communication links. The OWC technology plays an important role in massive device connectivity of Iota networks in terms of sensing, monitoring, and data resource sharing. The Visible light communication (VLC) is an emerging technology that is intended to enable high-speed data transmission. The visible light communication (VLCs) is a subset of OWC that utilizes electromagnetic waves in visible band (390 nm-700 nm) and uses an LED or LD as a transmitter. The OWC technologies are classified into visible light communication (VLC), light fidelity (Life), optical camera communication (OCC), and free space optics (FSO), are considered to be enabling technologies to meet the demands of 5G/6G and Iota networks for their advanced features. The OCC uses LED array as a transmitter and a CCD camera or image sensor as a receiver. OCC normally uses VL or IR as the communication medium. However, ultraviolet (UV) spectrum can also be used as the communication medium. The FSO technology uses LD and PD as the transmitter and the receiver, respectively. A two different setups are used for intelligent reflecting surfaces in the context of VLC systems, namely, intelligent met surface reflector (IMR) and intelligent mirror array (IMA). The vehicular services are offered by different OWC technologies in indoor, outdoor, and space communications.

Keywords: *visible light communication, FSO technology, intelligent reflecting surfaces etc.*

INTRODUCTION

OWC TECHNOLOGIES FOR THE 5G/6G AND IOT SYSTEMS:

(A) NEED FOR OPTICAL WIRELESS COMMUNICATION:

The RF band ranges from 3 kHz to 300 GHz of the electromagnetic spectrum. However, the range (3 kHz, 10 GHz) is widely used by the existing wireless technologies because of favorable communication

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properties in this range. This band is almost exhausted and insufficient in providing the high demands of the 5G/6G and Iot networks. It is also strictly regulated by the local and international authorities.

RF is currently widely used for different wireless connectivity. RF-based wireless communication faces several limitations, such as limited spectrum, great interference effect, and strict regulation. Only RF-based wireless communication technologies are insufficient in meeting the demand of 5GB and IoT networks. Therefore, researchers are working hard to determine a new spectrum that would fulfill the exponentially growing demands. A very large optical band is considered to be a promising solution

for the development of 5GB and IoT networks with high-density and capacity. In comparison to RF-based networks, OWC-based network technologies offer unique advantages, such as high data rate, low latency, high security, and low-energy consumption. Communication distances ranging from a few nanometers to more than 10,000 km are possible through the deployment of different OWC systems The other key features of the OWC include high unregulated bandwidth, high level of security, low-power consumption, low infrastructure and device cost, no interference with RF devices and networks, high achievable SNR, and easy integration into existing lighting infrastructures [V1].

OWC Spectrum Range: OWC points to wireless communications that use infrared (IR), visible light, or ultraviolet (UV) as transmission medium. It is a promising complementary technology for traditional wireless communications operating over RF bands. OWC systems operating in the visible band are commonly referred to as VLC[V50].

The optical wireless communication (OWC) is a promising candidate to high-speed wireless communications. Due to the advantage of the license-free operation over a significantly wider spectrum, many technological advances have proliferated in OWCs. OWCs utilize three different regions of the electromagnetic spectrum: ultraviolet (UV), visible light, and infrared (IR). As shown in Figure 1, visible light communications (VLCs) are a branch of OWCs that involve electromagnetic waves in the visible spectrum to communicate.

In recent years, optical wireless communication (OWC) technologies have attracted extensive research interest because of some of their excellent features. Wireless connectivity based on the optical spectrum is termed “OWC”. OWC has become a favorable complementary technology to radio frequency (RF)-based wireless technologies for future communication networks, including fifth- and sixth-generation (5G and 6G, respectively) communication systems. OWC technologies possess a number of prominent features such as wide spectrum, high-data-rate, low latency, high security, low cost, and low energy consumption, addressing the highly demanding requirements of 5G-and-beyond (5GB) (e.g., 5G and 6G) communications. Aside from this, the Internet of Things (IoT) network is becoming increasingly important.

Figure 1. OWC technologies for the 5G/6G and IoT systems

The main technologies of OWC networks include visible light communication (VLC) , light fidelity (LiFi), optical camera communication (OCC), and free space optics (FSO) communication. The Comparison of the performance metrics in various OWC technologies is shown in Table 2.

OWC and IoT : A large number of end-user devices or sensors are connected in IoT. Moreover, tactile internet will be the essential feature of the future IoT. It will enable real-time communicating systems with a range of societal, industrial, and business use cases. To envision the idea of IoT, the number of end-user physical devices connected to the internet is exponentially growing. Therefore, the IoT generates a large volume of data. The OWC technologies can play an important role of sensing, monitoring, and resource sharing in massive device connectivity of IoT networks. Moreover, the OWC can also meet the low-power consumption and high security requirements of the IoT[V15].

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(B) OWC TRANSMITTER AND SENSORS:

In OWC, LED or laser diode (LD) is applied to convert an electrical signal to an optical signal at the transmitter and the receiver uses a photodiode (PD) to convert the optical signal into electrical current. The information is conveyed by modulating the intensity of optical pulse simply through widely-used scheme such as on-off keying or pulse-position modulation, as well as advanced multi-carrier schemes such as OFDM to get higher transmission rate. To support multiple users in a single optical access point, OWC can apply not only typical electrical multiplexing technologies such as time-division, frequency-division, and code-division multi-access, but also optical multiplexing such as wavelength division multi-access. [A50]

The optical system applying image sensors to detect the optical pulse also called optical camera system. The imaging sensor can convert the optical signal into the electrical signal [A50].

Optical MIMO technology is also implemented in OWC, where multiple LEDs and multiple PDs are applied, in contrast to the multiple antennas in a typical MIMO system operating in the RF band. [A50]

There are many applications that are incorporating a human appearance and intending to simulate human dialog, but in most of the cases the knowledge of the conversational bot is stored in a database created by a human expert. However, very few researches have investigated the idea of creating a chat-bot with an artificial character and personality starting from web pages or plain text about ascertain person. This Project describes an approach to the idea of identifying the most important facts in texts describing the life(including the personality) of an historical figure for building a conversational agent that could be used in middle-school CSCLs cenarios. Although numerous agent frameworks have been proposed in the vast body of literature, none of these available frameworks proved to be simple enough to be used by first-year students of computer science. Hence, the authors set out to create a novel framework that would be suitable for the aims of the course, for the level of computing skills of the intended group of students, and for the size of this group of students. The content of the introductory AI course in question is a set of assignments that requires the students to use intelligent agents and other AI techniques to monitor, filter, and retrieve relevant information from the World Wide Web. It represents, therefore, a synthesis of the traditional objectivist approach and a real-world-oriented, constructivist approach to teaching programming to novices. The main aim of implementing such a pedagogy was to engage the students in learning to which they personally relate while attaining intellectual rigor.

II. VLC as Enabling Technology of OWC:

(A) Visible Light Communications: VLC works in the frequency range of 400 THz to 800 THz. Differing from the RF technologies in lower THz range that use antennas, VLC relies on illumination sources – especially light-emitting diodes (LEDs) – and image-sensor or photodiode arrays to implement the transceivers. With these transceivers, a high bandwidth can be easily achieved with low power consumption (100 mW for 10 Mbps to 100 Mbps) without generating electromagnetic or radio interference [A50].

Interactive Visible Light Communications Key advantages of LEDs are their flexibility and controlability. The speed of how they are LED are controlled defines different application areas, as depicted in Fig. 3. We assume here the use of white RGB LEDs. Slow control speeds, with intensity/color changes in LEDs taking place in a temporal scale from minutes to hours, define smart lighting applicaations, see Fig. 3 (left). The other extreme, Fig. 3 (right), with very high control speeds, defines what we understand by VLC. LEDs are controlled, in this case data modulated, with speeds that can go to hundreds Mbps and beyond. There is however an intermediate operating mode, when LEDs are controlled in a scale of seconds, see Fig. 3 (middle).

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In such case, we can exploit meaningful visual interaction with users by creating visual signalling aimed at informing, enhancing social interaction, orchestration of situations, guiding and other activities. Light is highly intuitive and conveys directly and quickly information to users. These three operating modes can be combined to create what we define as interactive visible light communications, iVLC [19]. [v17].

LIGHT-BASED INTERNET OF THINGS

The concept of Internet of Things (IoT) is slowly but surely connecting the world way beyond people, vehicles and machines. It aims at connecting virtually anything. In the

future, trillions of objects could be, among others, identified, controlled and localized remotely. One of the challenges of IoT is that nodes need energy to operate, and while this is not a big issue in many cases (vehicles, home/office appliances, etc.), it is a key restriction in many objects, as internal batteries need to used. The concept of light-based IoT (LIoT) exploits light in multiple ways, namely, to harvest the energy needed to operate, and to transmit and receive wirelessly information [21]. In this way, the node is energy autonomous. This approach is also called Expose and Connect, as nodes are connected to internet whenever they are exposed to light.

Even though LIoT can be implemented with discrete/integrated component technologies, this concept becomes highly attractive when implemented with printed

electronics (PE). Indeed, PE makes possible to implement the whole system on a substrate like paper or film, with potentially very low cost and negligible environmental impact. Fig. 5 illustrates the concept of LIoT, where a node is connected exploiting light for powering up the system and creating a wireless link.

Note that radio can also be used here. Even though PE is not a fully mature technology, key components and technologies needed to implement LIoT are readily available today, such as printed solar cells, printed optical components (photodiodes, LEDs, lenses), printed displays, etc. The LIoT concept can be extended to consider not only small surfaces but also large areas, such as those of ceilings, floors, walls, furniture and others. This results in the concept of Living Surfaces (LS) [21]. A surface is an opportunity to scavenge energy from the immediate environment and to integrate functionalities on board such as connectivity, signal processing, sensors, displays, actuators and others, all using PE technologies. In case of large surfaces, the harvested energy could be significant, although energy efficiency of printed solar cells considerably lags the efficiency of conventional solar cells. LS can have integrated specific functionalities to fulfil certain requirements associated with an application and scenario, or, on the other hand, they could integrate generic functionalities that could be used and reconfigured opportunistically. Functionality diversity or redundancy, e.g., repetition of functions implemented all over a large surface, together with reconfigurable/scalable architectures would make LS a truly powerful and ubiquitous solution in the future. Any surface could become a display, a data processing center, a sensing area, a wireless connectivity platform, etc. Glimpses of possible applications of LS are shown in a recent 6G vision video [22]. [v17].

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Visible light communication (VLC) is a data communication method using a light source. The idea lies in turning a light source on/off and use it to transmit data. Visible light communications are considered to be another form of data transmission using existing infrastructure by modulating light, typically the transmitter is a light emitting diode (LED) and the receiver is a photodiode or image sensors. The use of visible light for communication is motivated by recent developments in LED technology that are leading the way toward their full adoption as a replacement for incandescent and fluorescent lighting.

The Visible Light Communications Consortium (VLCC) was started in Japan in November 2003 to fulfill the aim of developing VLC technologies leading to VLC standards. VLC technology was also evaluated in Europe in the Home Gigabit Access project (OMEGA) started in January 2008, designed to deliver 1 Gigabit/second (Gaps) of internet data by utilizing indoor lighting.

For a given bandwidth, bandwidth efficient modulation schemes can be also used to increase the achievable data rate for example pulse amplitude modulation (PAM) or orthogonal frequency division multiplexing, those efficient modulation schemes can be of a great interest in the VLC channel. The signal to noise ratio (SNR) in the VLC channel is typically in excess of 60 dB electrical which allows the receiver to detect multiple amplitude levels in a signal [V2]

VLC TRANSMITTERS AND SENSORS:

CAMERA COMMUNICATIONS (CAMCOMM):

Optical camera communication (OCC), is another promising OWC technology, which is mainly used for positioning and navigation in indoor environments. An OCC receiver consists of embedded cameras or image sensors, while transmitter is a typical commercial LED. Moreover, OCC spectrum spans between the infrared and ultraviolet bands, with wavelength in the range of 10,000 nm. Due to the wide spread of smartphone devices with sophisticated embedded cameras, OCC can be easily implemented in these smart devices, rendering it as the practical version of VLC [A34].

Camera Communications (Capcom), is defined as the usage of the cameras for communications, where the camera image sensor is used for data reception. Camera communications utilizes a commonly used visible light sensor which is the mobile phone camera. The transmitter in a camera communication system could be an LED or an LED display which is modulated to transmit information.

There are two types of camera image scanning, A global shutter camera is a camera that captures the scene details all at the same time. A rolling shutter camera is an imaging receiver which time sequentially expose each row of pixels per frame. For example, “QR Code” is one form of line of sight marketing were the targeted users are few cm’s away from the QR code pattern. The range of the targeted users by the line of sight marketing can be extended using CamCom. The data transmitted on a CamCom system similar to the same data embedded in QR Code pattern, for example product website and product sale locations. To control the LEDs the system should allow dimming, which can be performed using pulse width modulation.

CamCom is also utilized for vehicular communications, the success rate of locating the transmitter is found to be 96% by utilizing a high speed camera as a receiver. The receiver finding algorithm that relies on differences between the current frame and previous frames to locate the transmitter in the image.

A rolling shutter camera was utilized to subsample the image, where the transmission frequency of the source is 120 Hz for logic zero and 105 Hz for logic one so that every bit duration is 1{15 seconds i.e. every bit is represented by two samples using iPhone 4 camera at 30 fps. A modulation method namely under sampled Frequency shift ON-OFF Keying (UFSOOK) modulation is defined .

A data rate of 10 Mbps is claimed by utilizing special CMOS image sensor with hardware accelerators fabricated specifically for optical communication as a receiver and 1010 LED achieving average packet arrival rate of 91% over 5 second transmission in an experimental vehicle with a maximum speed of 25 km/h, where a successful packet is being received when the receiver is able to detect the preamble and the postamble (end of transmission) [V2].

VEHICULAR COMMUNICATIONS-V2LC [V18]

V2LC can support applications that require communication among a limited number of vehicles, all in LOS. Regarding the group structure requirement, VVLC can support applications that require both long term (i.e., persistent) and short term (i.e., non-persistent) relationship between vehicles.

This illustration shows, from left to right, the sender including signal processing (encoding, modulation), the LED driver logic, and the optical transmitter front-end; the channel which is influenced by interference from other light sources, weather effects, and reflections; and the receiver, including optical front-end, and the signal processing (demodulation, decoding).[V18]

(A) VEHICULAR COMMUNICATIONS: are foreseen to play a key role to increase road safety and realize autonomous driving. In addition to the radio frequency (RF)-based dedicated short range communication (DSRC) and long-term evolution (LTE) communication technologies, vehicular visible light communication (V2LC) is proposed as a complementary solution, utilizing readily deployed vehicle light emitting diode (LED) lights as transmitter with image sensors such as photodetector (PD) and camera as the receivers. V2LC fundamentals including transmitter and receiver characteristics with dimming capabilities are reviewed in this chapter. Depending on the field measurements using off-the-shelf automotive LED light, communication constraints are demonstrated. Moreover, considering the line-of-sight (LoS) characteristics, security aspects of V2LC is compared with the DSRC for a practical vehicle-to-vehicle (V2V) communication scenario.

Modern vehicles are also equipped with image sensors such as PDs and cameras. PDs are utilized to detect ambient light levels and rain to automatically activate headlights or wiper blades, while the cameras are used for driver assistance systems such as lane keeping assistant, traffic sign recognition, pedestrian detection, and forward collision warning. Hence, usage of the existing vehicle LED lights and image sensors is foreseen to allow low vehicular visible light communication (V2LC) system implementation costs.

(B) V2LC TRANSMITTERS:

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LEDs are used in vehicle headlights, turn signals, taillights, and stop lights. LED arrays with high power form the headlights, fog lights, stop lights, and taillights, whereas single low- or mid-power LED usage is preferred for turn-signals. High-power automotive LEDs draw upto 700 mA current with a typical luminous flux of 200 lm. Low/mid-power off-the-shelf vehicle LEDs turn on with the currents between 60 and 300 mA. Higher current requirements are known to limit the switching capability of LEDs. Furthermore, white LEDs used in the vehicle lighting are usually phosphor-based and have a 3-dB modulation bandwidth in the order of a few megahertz. Phosphor-based white LEDs consist of a blue LED component coated by a phosphor layer. Even though the blue component of LEDs provides upto 20 MHz modulation bandwidth, slow phosphor relaxation time is known as another limitation for the modulation bandwidth of the vehicle LEDs. Thus, higher modulation frequencies of LEDs for V2LC are not considered to be feasible.

Wavelength division multiple access (WDMA) techniques in VLC systems to support multiple users. It has been a subject of interest in many studies in OWC systems to support multiple users by sharing wavelengths among users. A multiplexer is used at the transmitter to aggregate wavelengths into a single optical beam. The receiver uses a de-multiplexer to separate the wavelengths. Two different light sources are utilized in OWC systems, namely RGB LEDs and RYGB LDs and both can support WDMA.

(C) V2LC-TRANSMITTER CHARACTERISTICS

The LED is an optoelectronic device that transduces electrical energy to optical energy by emitting incoherent light when driven under forward current. Electrical and optical properties (e.g., current-voltage (I-V) characteristic, capacitance, color) of the LEDs can directly impact communication performance.

There are two conventional techniques to produce white light using LEDs. One technique requires the proper combination of two or more LEDs of different color in a single chip.

The most common implementation of this technique is the combination of red, green, and blue LEDs to obtain a trichromatic White LED (WLED). From the communication perspective, the presence of multiple LEDs in a single chip is advantageous as it allows the use of modulation techniques that can modulate each of the individual LEDs, hence provide higher data rates.

The other technique for producing WLEDs uses phosphor coating with one or more monochromatic or ultraviolet LEDs. The most popular implementation of phosphorcoated WLED is the coating of a blue LED with yellow phosphor layer. In this configuration, some of the blue photons emitted by the LED are converted to yellow photons as they interact with the phosphor layer, whereas other photons escape

unaltered. The mix of blue and yellow photons results in white light. The thickness of the phosphor coating determines the color temperature of the resulting white light: the thicker the yellow phosphor, the warmer the color temperature. Vehicle headlamps typically have a cold color temperature between 4000–6000 K.

D. LED-BASED EXTERIOR AUTOMOTIVE LIGHTING

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Traditionally, exterior lighting systems in vehicles facilitate active safety by providing proper forward illumination and signaling. The former helps for seeing, while the latter for being seen. The signaling functionality also conveys information to the traffic regarding the presence, dimensions, as well as the current maneuver of the vehicle (e.g., turning, breaking, stopping, reversing). Advanced applications like glarefree high beam, Adaptive Front-Lighting System (AFS), and, most recently, matrix LED-based AFS, have been further developed to improve the signaling and illumination Functions.

E. HEAD AND TAIL LAMPS AS V2LC TRANSMITTERS

Repurposing of existing vehicle head lamps and tail lamps for communication is technically possible, however, their use as V2LC transmitters must not hinder the primary function of illumination. There are many architectural and system-level features of automotive lighting modules that can positively or negatively impact the communication aspect. For instance, even simple manufacturing technicalities, like series or parallel connection of the LEDs have an impact.

Another system-level feature of vehicle lighting modules that largely impacts the communication aspect is the function carried out by the optical elements within the lighting module:

A complex optical system (consisting of, e.g., projection module, reflectors, cover lens) controls the shape of the emitted light beam, intrinsically performing spatial beam shaping, to ensure that the emitted light pattern complies with the road safety regulations (to minimize glare of oncoming traffic, and backward reflections to the driver). Considering that in a V2LC system the lighting module is the antenna, any modification of the antenna pattern naturally impacts the communication performance.

Additionally, as headlamps and tail lamps are important styling elements of a vehicle's overall appearance, their design varies depending on vehicle type and model. Such design differences result in slightly different radiation patterns, which, in turn, can have nontrivial impact on the V2LC performance.

While high-brightness LEDs, optics, and design variances can have unwanted side effects on V2LC, there are other features of exterior automotive lighting systems that can benefit it. As shown in Figure 4, the head (as well as tail) lighting modules consist of multiple lighting submodules. A typical headlamp has a daytime running lamp, a low beam (also known as dipped-beam lamp), and a high beam (also known as main-beam lamp). A typical tail lamp has, among others, a rear position lamp, a brake lamp, and a reverse lamp. Each of these lighting functions has different illumination characteristics, which can be exploited for best effort communication in a given scenario. For instance, due to the stronger and more directed radiation compared to a low beam, the high beam can be used for communication to farther distances.

Of course, to not disturb other traffic, the high beam cannot not be used at all times. This presents a trade-off in terms of practicality and communication for V2LC: It is implied that a lighting module needs to be turned on if it is to be used as a V2LC transmitter. In reality, however, this cannot be guaranteed in all situations, except for countries where daytime operation of selected lighting modules is mandatory. In such cases, it is safe to assume that a subset of lighting modules (i.e., daytime running lamp, low beam) will be on and, therefore, available for communication. If safety regulations do not permit the operation of a lighting submodule at all times (e.g., the high beam), modulation techniques with a very low duty cycle, such as the Dark Light concept where the frequency of the pulses is so low that the light is not visible to the human eye, can be used. Such a low duty cycle, however, comes at the expense of lower data rate.

One important advantage of exterior automotive lighting is that the lighting modules come in pairs. This enables the implementation of MIMO techniques, like transmit diversity or spatial multiplexing, for V2LC at no cost for additional antenna deployment. Initial simulative and empirical studies on this matter have demonstrated the feasibility of MIMO for V2LC. However, as shown by Turan et al. and Narmanlioglu et al., it is important to carefully choose the system parameters and transmitter combinations for such techniques to be beneficial for V2LC, else they can be counterproductive.

V2LC can also benefit from state of the art adaptive front lighting technologies used for forward illumination. These systems adjust the illumination characteristics of the headlamps for best visibility and comfort in different driving situations, based on sensory feedback (e.g., camera). Some features of AFS include automatic switch between low beam and high beam mode depending on oncoming traffic, weather conditions, and road curvature.

Most recent AFSs use matrix-LED technology, where a subgroup of LEDs from the LED matrix can be selectively turned on and off, for example, to avoid shining light on the windshield of oncoming traffic. Since individual LEDs have sharply separated radiation beams, it is possible to select subgroups of LEDs to communicate with multiple communication partners [v74]. As a result, spatial multiplexing can be implemented at a more granular level, i.e., groups of LEDs within a module, instead of whole modules. In some first work, Tebruegge et al. [v74] have shown that Space Division Multiple Access (SDMA) implemented using matrix LED-based Adaptive Front-Lighting System can effectively reduce multi user interference and help medium access for VVLC. Similarly, Segata et al. [v72] and Schettler et al. [v73] demonstrated its benefits for platooning. It is worth noting that advanced lighting technologies, like matrix LED-based AFS, are only implemented for headlamps, however, they would also be helpful for tail lamps (e.g., for tail to head communications as in the case of V2LC-based platooning [v73]). While architectural and system-level features of lighting modules can impact V2LC, it is also possible that V2LC impacts them. As stated initially, using exterior automotive lighting for communication must not affect their illumination function. However, the frequent switching of the LEDs can degrade the illumination quality and shorten their service life over time. The reason for this is junction temperature variation due to increased current density [119]–[121]. In the current literature there is no comprehensive research on the impact of V2LC on the deployed LEDs and/or on the overall exterior lighting performance.

CONCLUSION AND FUTURE SCOPE

The V2LC research domain is gaining the momentum continuously, both in the academic research group and in the next generation automotive industries. Evolving upon concept, methods, approaches and technologies known from indoor VLC applications to significant developments have been made on outdoor vehicular applications currently. Nevertheless, there are still many open questions that need to be investigated in order to reach the maturity in the V2LC technology.

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In this chapter, the state of the art in V2LC communication systems, transmitters & sensors/receivers, their standards, IRS and network applications are highlighted in Mechanics-systems point of view and open research domains to be perceived by the research community. This chapter work could be taken as a reference to get the peripheral knowledge with wider coverage as well as a guide for both researchers and beginners in this field.

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