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Optimization lighting layout based on gene density improved genetic algorithm for indoor visible light communications

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ABSTRACT

For indoor visible light communication system, the layout of LED lamps affects the uniformity of the received power on communication plane. In order to find an optimized lighting layout that meets both the lighting needs and communication needs, a gene density genetic algorithm (GDGA) is proposed. In GDGA, a gene indicates a pair of abscissa and ordinate of a LED, and an individual represents a LED layout in the room. The segmented crossover operation and gene mutation strategy based on gene density are put forward to make the received power on communication plane more uniform and increase the population's diversity. A weighted differences function between individuals is designed as the fitness function of GDGA for reserving the population having the useful LED layout genetic information and ensuring the global convergence of GDGA. Comparing square layout and circular layout, with the optimized layout achieved by the GDGA, the power uniformity increases by 83.3%, 83.1% and 55.4%, respectively. Furthermore, the convergence of GDGA is verified compared with evolutionary algorithm (EA). Experimental results show that GDGA can quickly find an approximation of optimal layout.

1. Introduction

VLC (Visible light communication) technology has the potential of delivering greater data rate densities (Mb/s/m^2) compared to radio-based systems [1,2], so VLC becomes one of the next hot candidates for short-range wireless communication technology due to its confidentiality, rich spectrum resources and harmless to human body. Rapid development of solid-state lighting has expanded the function of white Light Emitting Diode (LED) for VLC system. In VLC system, lighting source composed of several plural white LEDs is not only illuminating devices, but also a part of the communication system.

In the indoor VLC systems, users are randomly distributed in different indoor position. How to ensure that these in different positions of the users get the same quality of communication, the specific performance of how to ensure that the received signal-to-noise ratio (SNR) uniform distribution has influence on the quality of communication for indoor VLC. Location and number of lamps are the two key factors affecting the received SNR [3,4]. SNR distribution on communication plane may become uniform by placing some lamps in the middle of ceiling when designing lamp layout [5,6]. In [6], Azian et al. concluded that the SNR performance is proportional with the position and number of LED lights, which experimented in an office area with 5 m×5 m×2.2 m (length×width×height). The receiving power is an important factor that affects the consistency of communication quality and capacity of VLC system. And the distribution of received power in a room varies with the different layout of lightings. The optimal layout of the LED spherical array is studied to optimize the indoor communication performance by changing the parameters of angle, the ball radius, and the power of different LED [7,8].

It is important for the communication plane to have a uniform power distribution in order to guarantee the quality of visible light communication systems [9,10]. In [11], Zhang et al. proposed a method to minimize the PARR of receiving power to make all receivers more uniform. Some researchers [12] pointed out that by adjusting layout of lamps can also obtain consistency covering of power. But this algorithm can only be used in particular circumstance. Recent years, researchers [13] proposed an evolutionary algorithm (EA) to address the problem. Their algorithm is capable of reducing the volatility of received power by modifying the light intensity of transmitter on the ceiling. In [14], the ant colony algorithm is used to make the receiving light power and illumination intensity more uniform by adjusting the power adjustment factor of 4×4LED array transmitter. But dynamic adjustment factors in the algorithm are difficult to implement. Square layout and circular layout were compared from the perspective of illumination and communication characteristic in investigation [15]. It is concluded that a hollow circular design provides better illumination.

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The study indicates that lamp arrangement has a tremendous impact on the performance of a VLC system [16]. Three different circular lamp layouts, that are the hybrid corner lighting layout, the hybrid wall lighting layout (HWLL) and the hybrid edge lighting layout, were proposed according to the geometric characteristics of ceiling plane in [16]. In [16], HWLL circular layout is the best layout to implement the VLC system. However, authors did not point out how to achieve these layouts.

From the above analysis, we can draw the conclusion that obtaining an optimal lamp layout that satisfies both the LED lighting and communication needs is a complex problem. In order to solve the problem and optimize the LED placement for receiving the uniform power, we propose a gene density genetic algorithm (GDGA). In the proposed GDGA, the lamp coordinates are used to construct genes. The variance of optical signal power on the communication plane is used to build the fitness function. The optimal lamp layout can be achieved through operator of selection, mutation and crossover.

The rest of this paper is organized as follows. In Section 2, we give an overview of indoor VLC systems model and mathematical optimization model of lighting layout. Details of GDGA are elaborated in Section 3, including chromosome structure, fitness function, selection operator, mutation operator and crossover operator. In Section 4 the experimental results are demonstrated and discussed. Finally, we draw the conclusions in Section 5.

2. System model of indoor visible light communications

The system environment deployed in this work is an empty room with dimensions $L \times W \times H$ shown in Fig. 1. The reflectivity of ceiling, walls and floor are 0.8, 0.5 and 0.2, respectively [13,17]. The communication plane where the VLC receivers are deployed is about h meter high above the floor in a horizontal plane containing the user's optical receiver [12,13,17]. We assume that LED arrays are placed in the same plane and have a Lambertian radiation pattern minimum required illuminance for reading is 400 lx according to the European lighting standard [18]. Each LED is biased at the recommended bias point in the datasheet (i.e. 350 mA) and has an optical output power, in terms of 189 mW.

In VLC systems, there are many links between transmitter and receiver including line of sight (LOS) links and non-LOS links. From Ref.[12], we know that the rate of reflected light to the received light is 95.16%, 3.57% and 1.27%, respectively. Therefore, the influence of the directed light is very large, which determines mainly the performance of the VLC system. For convenience of computer analysis, we only consider the directed light in this paper. So, optical signal power received by a VLC receiver can be calculated as follows:

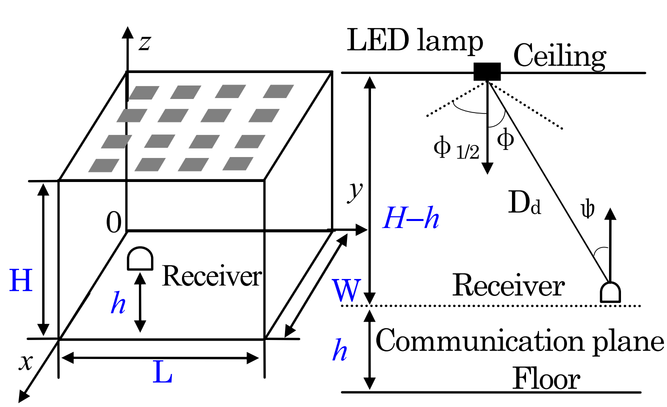

Fig. 1. Schematic view of indoor visible light communication system model using 16 lamps. Each black square represents a lamp that consists of 7×7 LEDs. The interval between LED is 0.01 m.

$$P_r = \sum_{LEDs} \left\{ P_t H_d(0) + \int_{walls} P_t dH_{ref}(0) \right\} \tag{1}$$

where P_t refers to transmission power of a lamp $H_d(0)$ is the direct current (DC) gain of the direct channel, $H_{ref}(0)$ is the DC gain of reflection channel. Respectively, they are discussed in details in [6,19,20].

In order to obtain the maximum value of received optical power on the communication plane, some parameters are stationary, such as optical to electrical (O/E) conversion efficiency, the refractive index of lens, FOV of the PD, physical area of receiver and transmitted optical power.

For an actual VLC system we should assume that every spot in the communication plane as shown in Fig. 1 is same important. This point is also validated in [13]. Users in a room should receive identical signal strength wherever they are. We call this power uniformity. We use variance of optical receive power on the communication plane to measure the uniformity of receive power. Apparently, the lower the power variance is, the higher the power uniformity would be. Thus, the optimization problem of variance of optical receive power can be given as:

$$\begin{aligned} &minimize\,\{D(P_r)\} \\ &s.\,t. \quad 0 \le x_1, x_2, \ldots, x_N \le L \\ &\qquad\;\; 0 \le y_1, y_2, \ldots, y_N \le W \end{aligned} \tag{2}$$

where N is the number of lamps, L and W represent the length and width of room, respectively. $D[P_r]$ is variance of received optical power on communication plane and its definition is in Eq. (5). Coordinate x and y denote horizontal and vertical coordinates of each lamp, respectively.

3. Gene density genetic algorithm

An improved genetic algorithm called GDGA is presented to optimize the layout of LED for VLC system in this paper. A gene indicates a pair of abscissa and ordinate of a LED, and a feasible individual represents a LED layout meeting the received power on communication plane in the room. The larger gene density means the more concentrated power distribution, and the smaller gene density implies the more distributed power distribution. The steps of the algorithm are provided below, and details of several steps are explained thereafter.

It is hard to predict when the LED optimal layout solution could be found, because the genetic algorithm is a stochastic search method [21,22]. As a matter of routine, we should design the terminated condition for the genetic algorithm after running certain iteration $iter_{max}$ in step 2 in Table 1. Moreover, if the best individual I_{best} remains unchanged for $iter_{unchg}$ generations, the optimal solution is also considered to be found and end the algorithm.

In step 1 of GDGA, to make the LED layout can be practically implemented, population generation is an important step. We define a gene library as follows:

$$\begin{aligned} &geneLibx = \{0, 1 \times \tfrac{L}{\xi}, 2 \times \tfrac{L}{\xi}, \ldots, \xi \times \tfrac{L}{\xi}\} \\ &geneLiby = \{0, 1 \times \tfrac{W}{\mu}, 2 \times \tfrac{W}{\mu}, \ldots, \mu \times \tfrac{W}{\mu}\} \end{aligned} \tag{3}$$

where ξ and μ are integer, they can guarantee that gene can only be generated in the specific point on ceiling, as a result they make engineering implementation feasible. In the population generation part of the algorithm, genes are randomly chosen from the gene library to construct chromosome.

One gene is a pair of abscissa and ordinate as shown in Eq. (4). The structure of chromosome can be written as:

$$Chromosome = ((x_1, y_1), (x_2, y_2), \ldots, (x_N, y_N)) \tag{4}$$

where $x_i \in geneLibx$, $y_i \in geneLiby$.