

# RICA: A Reliable and Image Configurable Arena for Cyborg Bumblebee Based on Can Bus

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**Abstract**—In this paper, we designed a reliable and image configurable flight arena, RICA, for developing cyborg bumblebees. To meet the spatial and temporal requirements of bumblebees, the Controller Area Network (CAN) bus is adopted to interconnect the LED display modules to ensure the reliability and real-time performance of the arena system. Easily-configurable interfaces on a desktop computer implemented by python scripts are provided to transmit the visual patterns to the LED distributor online and configure RICA dynamically. The new arena system will be a power tool to investigate the quantitative relationship between the visual inputs and induced flight behaviors and also will be helpful to the visual-motor research in other related fields.

## I. INTRODUCTION

Because of the unmatched flight performance of insects, more and more researchers are attracted to developing cyborg insects to compete with the man-made UAVs (unmanned aerial vehicles). It is undoubtedly that how to precisely control the flight of insects is an important challenge should be solved firstly. Recently various approaches have been used to control the flight of insects. For example, H. Sato *et al.* employed neural-muscular stimulator to module flight behavior of cyborg beetles [1]. S. Budick *et al.* investigated the role of visual and mechanosensory cues in structuring forward flight in *Drosophila melanogaster* [2]. A cyborg cockroach could follow the predefined lines smoothly also using the electrical stimulation on its antennae [3]. Inspired from the visual information processing mechanisms [4, 5], there were possible approaches to induce the flight behavior of insects by presenting controlled visual inputs to the subjects [6].

For their outstanding payload capability and visual cognitive functionality, bumblebees are selected as the biological platform in our research. To develop cyborg bumblebees by visual stimulation, the first challenge is to design a parameter-configurable arena to generate visual patterns to the retina of bumblebees, and investigate the quantitative relationship between the input visual patterns and flight behaviors of the subjects. These arenas also contribute much to the research on the neurobiology of the insect visual systems. There are three kinds of arenas developed. R. Wolf and M. Heisenberg designed a mechanical drum to present

visual stimuli [5]. S. Zhang and M. Srinivasan employed white and black strip tunnel to provide visual cues to honeybees [3, 4]. Cathode ray tube (CRT) [6] and liquid crystal displays (LCD) [7] may be the simplest way to provide visual stimuli in flight arenas. Another widely used version developed by M. Reiser and M. Dickinson in 2008. Researchers find it powerful to investigate the neural sensation mechanism and behavior fly of *Drosophila melanogaster* [10].

TABLE I. COMPARISON OF MAINSTREAM INSECT ARENA SOLUTIONS

<i>Item</i>	<i>Mechanical drum</i>	<i>CRT /LCD</i>	<i>LED (12C)</i>	<i>LED (CAN)</i>
<b>Refresh rate(Hz)</b>	-	<b>60-200</b>	<b>380</b>	<b>&lt;=5000</b>
<b>Image configurable</b>	No	Yes	Yes	Yes
<b>Direction</b>	<b>Left and right depend on motor</b>	<b>All directions &lt;200</b>	<b>All directions &lt;380</b>	<b>All directions &lt;5000</b>
<b>Speed(Hz)</b>	<b>depend on ambient</b>	<b>configurable</b>	<b>configurable</b>	<b>configurable</b>

The principle of these arenas are significantly different. The overall performance metrics are listed in Table 1 to show the advantages can be achieved by the new solution using CAN bus and LED modules. First, it is more convenient to build an image configurable flight arena using LED arrays. Second, there still exists an improving space, characteristic of image configurable, refresh rate and real-time. The new generation of visual arenas should present visual pattern reliably and flexibly to induce desired behaviors for the bumblebees.

To meet these requirements, in this paper, we adopted the Controller Area Network (CAN) bus to build a reliable and image configurable arena (RICA), especially for cyborg bumblebee research. CAN is a high-speed serial communication protocol that was proposed by Robert Bosch GmbH in the mid-1980s, and become an industrial standard in 1993 [9]. Its reliability and real-time performance make it a suitable technique to interconnect the LED display module in the visual arena. We believe RICA can provide an engineering solution for new flight arena and also is much helpful to be used in other visual neurobiological experiments.

The remainder of this paper is organized as follows. The requirements and the architecture of RICA are presented in section II. Then section III discusses detailed implementation and configurable interfaces. Finally, section IV concludes this paper.

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## II. METHODS

### A. Requirements analysis of the system

To meet the panoramic visual of bumblebee and avoid the ambient light, the physical structure of RICA is designed as cylindrical platform (Figure 1(a)). Three main design factors are considered: the temporal resolution, the spatial resolution and color vision of the bumblebee's compound eye.

Firstly, it has been reported that bumblebees has the temporal resolution of 130Hz [14]. RICA must have a refresh rate above the 130Hz. To fulfil this requirement, LED arrays are the suitable solution due to their switch characteristic and high switching speed. They can satisfy the temporal resolution requirement and the image configurability.

Secondly the spatial resolution of the bumblebee's compound eye should be taken into account. Despite the spatial resolution affected by ambient factors, such as light levels and speed of movement [11], it mainly depend on two factors: interommatidial angles  $\Delta\phi$  and the acceptance angle of the ommatidium  $\Delta\rho$ . Theoretically, the value of  $\Delta\rho$  is proportional to the extent to which the image of the world is blurred and the value of  $\Delta\phi$  is inversely proportional to the capacity of sampling the detail in the image [13]. It was confirmed that the interommatidial angle is  $2.5^\circ$  to  $6.5^\circ$  and the vertical and horizontal ommatidial accept angle respectively are  $3.92^\circ \pm 0.76$  and  $3.76^\circ \pm 1.1$  [14]. J. Spaethe and L. Chittka also demonstrated that larger bumblebee workers possess much better visual resolution than honeybees (minimum visual angle of  $3.5^\circ$  vs  $5^\circ$ ) [15]. According to Johannes Spaethe and Lars Chittka's work [15], we can achieve the triangle in Figure 1(b) and

$$\tan\left(\frac{\Delta\rho}{2}\right) = \frac{D}{2L} \quad (1)$$

where D is the upper cut-off size of the target that bumblebees cannot detected, and L is regarded as the optimal distance between the target and the facet of compound eye. According to Eqn(1) D is the size of a single LED (Figure 1(a)), and L (Figure 1(a)) is the radius of RICA.

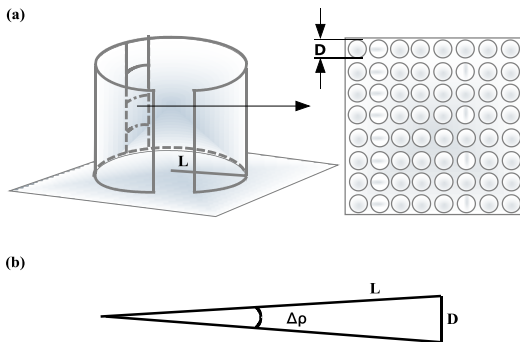


Figure 1. Physical structure of RICA: (a) shape and size of RICA, where L represents the radius of the cylindrical arena, and D is the target will be present to the bumblebees compound eyes.; (b) the geometrical relationship between the ommatidial angles  $\Delta\rho$ , L and D.

Thirdly, it has been known that there are three distinct classes of photoreceptors in bumblebees' compound eyes: ultraviolet, blue, and green photoreceptors. Among these photoreceptors, most of them have a peak response in green [14]. It also has been demonstrated that green photoreceptors possess the highest processing speed and heavily affect

motion detection [15]. Therefore, we choose  $8 * 8$  green LED array ( $32 * 32 * 19\text{mm}$ ) as the display module.

Based on the above three factors, D is a constant since the LED array has been selected. We choose  $2.5^\circ$ , the smallest acceptance angle of the ommatidium  $\Delta\rho$ , to ensure that RICA presents a continuous image pattern to the bumblebees. Then, according to the formula of regular polygon circumference, the number of LED display module will easily be calculated. The calculation is that RICA needs 18 column of LED display module. So the pixel resolution of RICA is  $32 * 144$ . Considering that others equipment, such as cameras, micro operators, will be installed for experiments requirements, we leave a column of two LED display module space for that purpose.

### B. Architecture of the system

As shown in Figure 2, the system consists of a personal computer (PC), a LED display distributor (LDD) and 16 LED display modules (LDMs).

PC: (Figure 2(a)) PC is responsible for flexibly and easily generating a new binary image or converting an existing image to a wanted binary image. Furthermore, PC can also transmit the researcher's specific configurations to the LED display distributor, such as refresh rate, pixel speed etc.

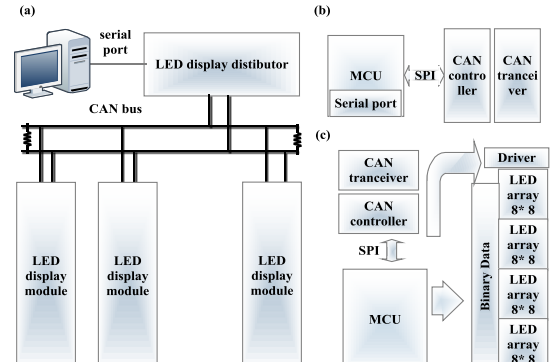


Figure 2. Architecture of the system: (a) three components of RICA and their connections (PC connects LDD via serial port, while LDD and LDM are all connected with CAN bus); (b) LED display distributor (LDD); (c) LED display module (LDM).

LDD: (Figure 2(b)) LDD takes charge of the distribution of binary images and the researcher's specific configurations between PC and LDMs. It can download binary images and the researcher's specific configurations from personal computer via serial port. Then those binary images and the researcher's specific configurations will be distributed to LDM through CAN bus. In addition, LDD should provide at least 16 connecting interfaces to LDM, ensuring the panoramic visual stimuli and leaving two spaces for other equipment installation.

LDM: (Figure 2(c)) each LDM has its own identifier that guarantees them to correspondingly receive binary images and the researcher's specific configurations from CAN bus. In this communication system, binary images are received by time-sharing means. That is to say LDM will timely receive CAN frames to update the predefined dynamic buffer, which will be read by LDM to control the four  $8 * 8$  LED arrays;

while the researcher's specific configurations will directly modify the predefined flags, to achieve wanted display effect.

### C. Software design

The software of RICA consists of two components: control module and display module.

**Control module:** Control module is responsible for the interaction between researchers and LDM. This module is implemented on PC and LDD. Based on two python packages, python image library (PIL) and pySerial, we developed our PC end tools, to control RICA. These tools have been packaged into RICA\_Configure, which can generate a new binary image or convert an existing image to binary images and receive the researcher's specific configurations. Then we employ a static buffer on LDD to store these binary images and the researcher's specific configurations. LDD will package these binary images and the researcher's specific configurations into standard CAN frames based on the identifier of each LDM. There are two kinds of CAN frames. One is employed to send binary images; the other is used to transmit the researcher's specific configurations. The former consists of 1 start bit, 11-bit identifier and 32-bit image data. The later consists of 1 start bit, 11-bit identifier and 64-bit configurations.

**Display module:** Display module is implemented on LDM. It can read the predefined dynamic buffers to control the LED arrays. As shown in Table 2, display module leaves five special configurations to researchers. *SELF* is used to determine which CAN frame will be received by LDM. *Refresh rate* is implemented by an on-chip timer of MCU, ensuring the requirement of temporal resolution. *Luminance* is responsible for modulating the luminance of the whole LEDs in RICA. Image configurability is achieved by *pixel speed* and *direction*. The mechanism of this dynamic buffer is we can update based on the direction, updating the first buffer for left, and vice versa. The direction of up and down is separately implemented by right and left shift.

TABLE 2. CONFIGURATIONS

Function	Flag	Value
Identifier	SELF	0x00 – 0x18
Refresh rate	refresh_rate	500-5000HZ
Direction	direction	right/left/up/down
Luminance	luminance	0-8
Pixel speed	speed	0-100HZ

### III. RESULTS

#### A. RICA

The complete system is shown in Figure 3. RICA is made up of 1 LDD (Figure 3(a)) and 16 LDMs (Figure 3(b)). In the design of LDD, a cylindrical connecting interface is provided to LDM and a MAX3232 (Texas Instrument, USA) is adopted to connect PC end and LDD for transmitting binary images and the researcher's special configurations.

Both LDD and LDM have their own MCUs and extended CAN controllers. MSP430F149 (Texas Instrument, USA) is a 16-bit RISC CPU, which has 48 I/O pin, two built-in 16-bit timers and two universal serial synchronous/asynchronous

communication interfaces. These features can make LDM support 32 \* 8 LED array. Therefore we utilize one MSP430F149 to control four 8 \* 8 green LED array KD12088BUG/W (Wuxi Compul Electronic Co. Ltd, China). We choose a PNP transistor (S8050) as the LED driver. Because the collector current of S8050 is 500mA, a S8050 can simultaneously light 32 LED, a column of a LDM.

MCP2510 (Microchip Technology Inc., USA) is a full CAN protocol controller implementing CAN specification V2.0 A/B. It includes three transmit buffers and two receive buffers and is also capable of acceptance filtering and message management, which reduces the amount of microcontroller management required.

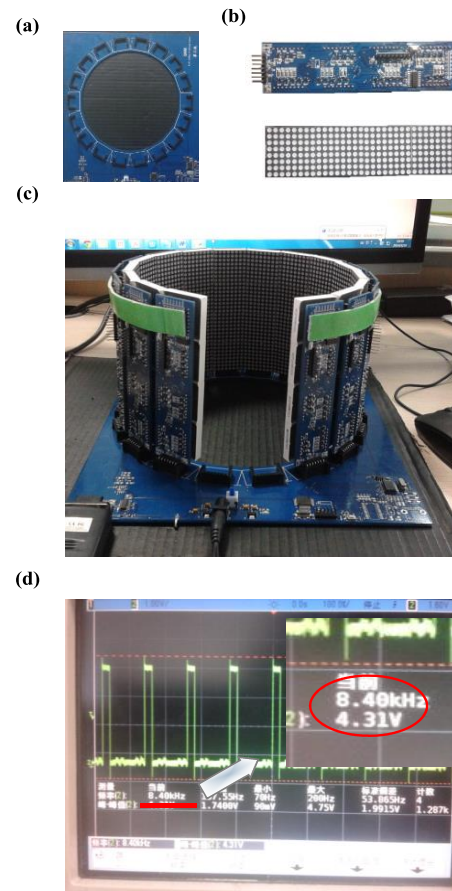


Figure 3. Components and the system of RICA: (a) LED display distributor (LDD); (b) LED display module (LDM); (c) the RICA arena (1 LDD and 16 LDMs), (d) the maximum refresh rate measured by Agilent 6000 DSO6032A (Agilent Technologies).

With this hardware configuration the maximum *refresh rate* can reach up to 8.40 KHz (Figure 3(d)). But in order to ensure the reliability and the speed of serial port we stipulate the *refresh rate* can be configured from 500Hz to 5000Hz. Others configurable interfaces are shown in Table 2. Researchers can utilize SELF to individually modulate LDM, such as luminance, direction, and pixel speed.

#### B. Show a "T" with RICA

The work flow is shown in Figure 4. There are three steps will be done to shown a "T" on RICA.

Step 1: Connect RICA components and power it on.

Step 2: Input the configurations, such as refresh rate, luminance, and convert the “T” picture to the form 32 \* 144 from python IDLE.

Step 3: Transmit binary image and the researcher’s configurations to LDD through send\_Command and download functions in RICA\_Configure. Then LDD will automatically distribute the binary image and researchers configurations to LDM.

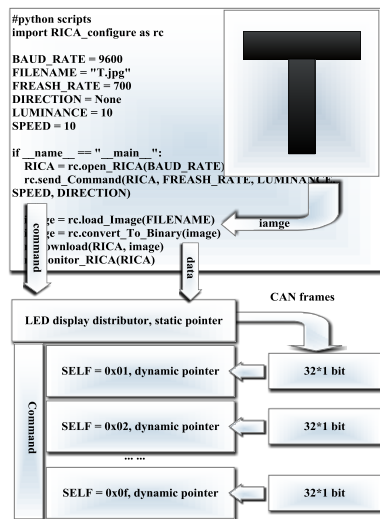


Figure 4. The work flow of RICA

When these steps are accomplished, RICA will enter a state shown in Figure 5. During the running time, we can monitor the status of RICA and update the binary image.



Figure 5. Displaying a “T”

### C. Reliability

The mean time between failures (MTBF) can be used to measure the reliability of the arena. Although we have not accumulated enough data for validating longer mean time over other solutions quantitatively, it is found that RICA can keep working four hours without any faults. The detailed reliability performance will be tested in the future research.

## IV. CONCLUSION AND DISCUSSIONS

The contribution of this paper is that we build a reliable and image configurable flight arena. It is also believed that this flight arena based on the CAN bus and easily-configurable interfaces can attribute positively to the

visual-motor research in neurobiological area. RICA presented in this paper meets the requirements of the spatial and temporal resolution of bumblebees well. Due to adopting the CAN bus communication and only 17 communication nodes, RICA features reliability and flexibility as its major advantages. What’s more, the python configurable interfaces make it easily to display various images for investigating the quantitative relationship between the stimulation patterns and the induced flight behaviors in experiments.

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