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Disco Lamp: An Interactive Robot Lamp

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Abstract—**When watching a Pixar movie, we are always amused by the cute and sprightly lamp hopping up and down to replace the letter "I" of the word "PIXAR" before the movie starts. A simple movement, but a touching one. Here, motivated by wondering what other functionality a lamp can have, we report on the design and development of an interactive robotic lamp. It can sense hand gestures, thus either providing appropriate lighting to the area where the hand resides, or changing its mode between lighting and music. The movable and reactive lighting permits the operator to work freely in front of a bench with a large area which needs intensive lighting. When the lamp is in music mode, it becomes a robot dancer which follows the rhythm of the music and provides disco-style dynamic lighting.**

I. Introduction

Humans are attracted to objects which move, especially when the motion interacts with them. Over the past few years, researchers have worked hard in the field of "interactive robotics" [1-6], spreading out in several application fields such as entertainment, education, and therapy. Entertainment robots are usually built to catch and react to the rhythm of music in the environment. For example, *Keepon* [7-9] is a 4 degree of freedom snowman-like robot. It has a microphone installed inside the nose as the sensory source for detecting sounds from the environment, so it can shake its body in time with the music. *Miuro* [10, 11], a relatively simple vehicle-like robot, is equipped with an MP3 player interface and a set of loudspeakers. When the music plays, it moves back and forth with the tempo. Travis [12, 13], a case study for the "dumb robot, smart phone" paradigm, is a robotic speaker dock and music listening companion. It generates segment-specific and beat-synchronized gestures based on the song's genre. Disco Robo [14] is a cute music-responsive robot that busts all the best dance moves. Not only does it feel and move to the beat, it expresses lively emotion through its animated face. OU [15] is a cartoon-designed robot which has used movement controlled robotics technology and music analysis technology. Depending on the rhythm of music, OU can display various movements and express the music's emotion through head rotation, up and down movement at different speeds, 16 LED mouth lights flashing, etc.

Here, instead of making a robot which provides interactive functionality for a human, we report on the development of an interactive robot "lamp" as shown in Fig. 1, which tries to extend the functionality of widely existing and daily-use objects. Because of the lamp's ready existence in our daily life, it is more comfortable for a person to interact with. Hereafter the lamp is referred to as "Disco Lamp." We have implemented two functions in the lamp. The first function is hand tracking. When the operator moves a hand over the desktop, the lamp automatically tracks the hand and provides lighting to that specific area. This function is particularly useful when large spot lighting is required but which a single traditional desktop lamp cannot provide. Thus, the interactive lamp avoids the need for multiple desktop lamps, saving both space and energy. The idea of an automatically movable desk lamp has been developed before [16, 17], but a special sensor must be worn on the hand. Owing to recent developments in motion capture technology, in our work the hand needs no sensor. The second function is lamp "dancing." When music plays, the lamp moves in time to the music. At the same time, the lamp colorfully spotlights the ceiling which creates an entertaining atmosphere. The reported interactive lamp breaks the stereotype of an ordinary desktop lamp and creates interesting possibilities.

Fig. 1. Photo of Disco Lamp.

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The rest of the article is organized as follows. Section II introduces the design concept. Section III describes the hardware, including the mechanism and the mechatronic system. Section IV presents the program, and Section V provides the performance evaluation of Disco Lamp. Section VI concludes the work.

II. Design Concept

The design philosophy behind Disco Lamp is different from a completely new interactive robot, because a lamp has geometry and functionality constraints. The shape of the disco lamp should generally follow that of an ordinary lamp, or the user will not treat it as a familiar object. The functionality of the disco lamp should be based on the original functionality of the desktop lamp and extend it. In our case, the spotlight is the core. The added functionality requires hardware which takes up space. The space constraints should be considered as well.

After investigation, Disco Lamp is set to have two functions, tracking and entertaining. To achieve these functions, new hardware is implemented. The passive joints of the lamp arm are now driven by servo motors. The light bulb is replaced with high-brightness LEDs with four different colors: red, blue, green, and white. The Leap Motion Controller is used to acquire position and orientation of the hand. A small laptop serves as the computation source, and the Arduino Uno is utilized to drive the motors.

In tracking mode, Disco Lamp will follow where the hand is under its workspace. Instead of making "eye-contact" [18], which is the most used function in human-robot interaction, we tried to let the lamp follow where the hand is to have a different interaction. We believe that if the lamp can always follow where hand while writing, it can help save energy. The Leap Motion Controller is used to get the palm position of the hand when it enters the workspace. The coordinates of the palm with respect to the Leap Motion Controller are then changed to that with respect to Disco Lamp. After that, inverse kinematics calculate Disco Lamp's joint angles for tracking the hand. As a result, Disco Lamp can always track the hand during work and provide a spotlight on and around the area where the hand resides. This function is particularly useful when the workspace is large: the operator no longer needs to move the spotlight when working. Disco Lamp is an effective and energy-saving solution.

Most interactive robots today feature an entertainment function, usually a response to music. To be different, Disco Lamp not only shakes with the rhythm of the music but also provides a colorful and pulsing spotlight to the environment, which enhances the functionality of the ordinary lamp. The frequency spectrum of the music is characterized and divided into four sections, each driving one color LED and one servo motor. In that way, Disco Lamp can vary its spotlight condition and swing the lamp arm according to the rhythm of the music. Because the spectrum of the music varies significantly, the corresponding arm motions and spotlight also have dramatically different patterns, which create a lively "party atmosphere."

Switching between tracking and entertainment modes is achieved by configuring a specific hand gesture at a specific location within the working space. When the operator points at the preset "invisible cubic bottom" for several seconds, the Leap Motion Controller senses the gesture and the mode change initiates. Thus, no extra sensor is required for mode switching.

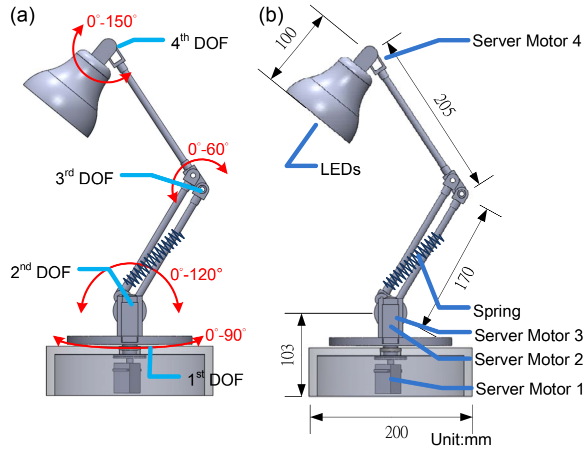

Fig. 2. Mechanism and dimensions of Disco Lamp.

III. Hardware

Disco Lamp has four degrees-of-freedom (DOFs) as shown in Fig. 2(a). The first three DOFs are in charge of generating the translational motion. The arrangement of these three DOFs is like that of the PUMA arm [19], where the first one is for rotation with respect to the vertical axis, and the second and third ones reside in the vertical plane for creating displacement between the end effector and the base. The fourth DOF of Disco Lamp is for pitch motion of the lamp shade, which can be regarded as the end effector of the ordinary robot arm. Normally there are three rotational DOFs at the wrist of the robot arm, so arbitrary positioning and orientation of the end effector with respect to the base can be achieved. Here, because the rotational DOF with respect to the direction of the spotlight out of the lamp shade has no effect (i.e., the spotlight is axisymmetric), at most two rotational DOFs are required. These two DOFs can be regarded as pan-and-tilt at the "neck" of Disco Lamp if the lamp shade is regarded as the head of the lamp. The joint arrangement of an ordinary desktop lamp mostly follows this structure. Here, in Disco Lamp the tilt (pitch) DOF is kept and the pan DOF is discarded to reduce neck complexity. The latter has no significant effect on overall spotlight condition. In this "humanized" equivalency, motion of the tilt DOF is like nodding of the head. The motion of the first three DOFs are like human body motion.

The four DOFs of Disco Lamp are driven by RC servo motors as shown in Fig. 2(b). The first, second and fourth DOF are directly driven by the first, second and fourth servo motors, respectively. The third DOF is driven by a servo motor via a planar and parallel four-bar linkage mechanism, thus keeping the structure of the lamp arm neat. In addition, two springs are mounted on the linkages for gravity compensation, thus reducing the load of the servo motors.

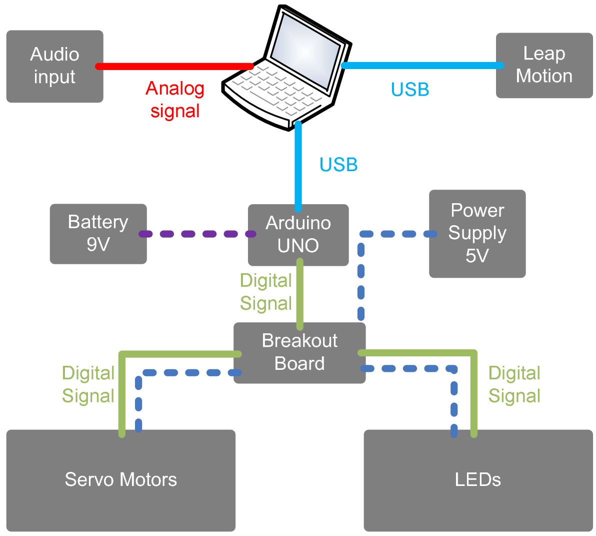

Fig. 3. Mechatronic system of Disco Lamp.

The main body of Disco Lamp is made of ABS and acrylic and is built via 3D printing technology and laser cutting. Linkages among the joints are made of aluminum rods. Detailed dimensions are in Fig. 2(b).

The mechatronic system of Disco Lamp is shown in Fig. 3. Computation power is provided by two devices: a laptop (Asus A43SM) which acquires data from the Leap Motion Controller via USB and audio signals via microphone input; and an Arduino Uno board which controls the motions of the servo motors and lighting of the LEDs. The data sheet of the four servos are shown in Table I. Thirteen LEDs are installed inside the lamp shade, composed of four different colors: four white, three red, three green, and three blue LEDs.

Table I. Specifications of the servo motors.

Servo index	4th	1st & 3rd	2nd
Brand	Futaba	Futaba	TowerPro
Model	S3114	S3003	MG995
I/O type	Analog	Analog	Analog
Torque (kg-cm)	1.51	3.17	10
Speed (sec/60)	0.1	0.23	0.2
Gear Type	Plastic	Plastic	Metal

IV. PROGRAMMING

The overall flow chart of the program is shown in Fig. 4. The program is written in LabVIEW for its friendly graphical interface. The main loop running at 250 Hz is in charge of determining which mode is in operation, and it is determined by the hand posture captured by the Leap Motion Controller. If the tracking mode is activated, the Leap Motion Controller is further utilized as the hand motion tracker, obtaining the

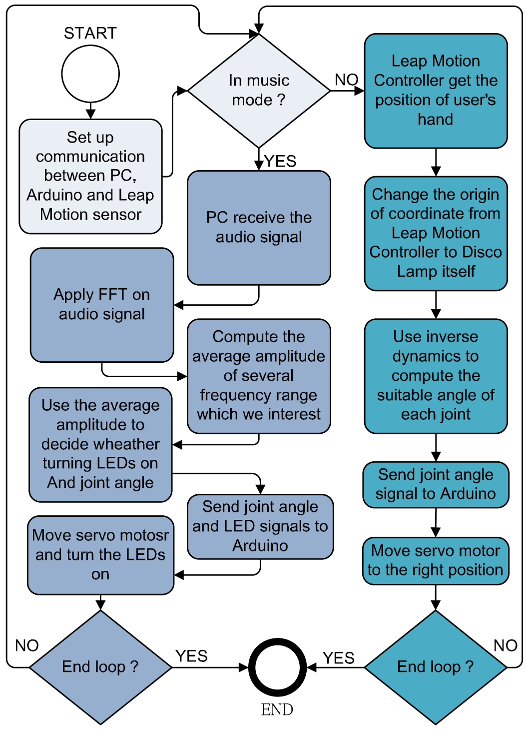

Fig. 4. Program flow chart of Disco Lamp.

position data of the hand in real-time. Next, the position data is represented in the coordinates of the Disco Lamp, and the configurations of all four joints are computed by the inverse kinematics of the Disco Lamp. Then the joint configurations are changed by driving the servo motors. If entertainment mode is activated, the laptop starts to record the audio signal and perform a Fast Fourier Transform. The obtained frequency response is linked to the motion and light conditions of the Disco Lamp. The above program was mainly written on the laptop, and only the real-time motor and LED control were written on the Arduino.

The tracking strategy for Disco Lamp is described as follows. The Leap Motion Controller provides the Cartesian coordinates *(X, Y, Z)* of the hand with the origin located at the center of the controller. With known relative configuration between the controller and the Disco Lamp, the coordinates can be represented in cylindrical coordinates (R, θ, Z) with the origin assigned at the base of the lamp. For ordinary video surveillance, a two-DOF pan-and-tilt camera is sufficient to position the target at the center of the camera view. In our case, because the distance between the hand and the lamp affects the light intensity, the distance should be kept the same for consistent light condition. According to the recommendations for eye health, the distance between the light source and the desktop should be set within 40 to 45 cm [20]. Thus, a 3-DOF lamp is required. In addition, light is usually desired from the top with some tilt. As a result, the 4th DOF is desired, which is used to set the pitch angle of the lampshade. In our case, 45 degrees is chosen as the nominal configuration. The other 3 DOFs are used to position the lamp with the right "light vector," which points 45 degrees downward (i.e., $\emptyset = 45°$) and has length $D = 40 - 45$ cm as shown in Fig. 5. The plane shown in Fig. 5 is the vertical plane located with orientation θ of the cylindrical coordinate. With this setting, the angle of motor 3 (θ_2) can be derived by trigonometric relation:

$$\theta_2 = \cos^{-1}\frac{({L_1}^2 + {L_2}^2 - L^2)}{2L_1L_2} \quad (1)$$

Then, the configurations of the other joints can be computed:

$$\theta_{11} = \tan^{-1}\frac{Z + D\sin(-\emptyset) - H}{R - D\cos(-\emptyset)} \quad (2)$$

$$\theta_{12} = \cos^{-1}\frac{L^2 + {L_1}^2 - {L_2}^2}{2L_1L} \quad (3)$$

$$\theta_1 = \theta_{11} + \theta_{12} \quad (4)$$

Then, the angle θ_3 can also be determined:

$$\theta_3 = 360 - \theta_1 - \theta_2 + \emptyset \quad (5)$$

On some occasions when the hand is located above the desktop with a nontrivial height, the lamp is not able to provide the light from a higher location owing to size constraints. In this case, the angle θ_2 is fixed at its maximum reachable value (i.e., 120°), and the angle of the lampshade ($\emptyset$). The distance L is fixed to:

$$L^2 = {L_1}^2 + {L_2}^2 - 2L_1L_2\cos(\theta_2) \quad (6)$$

The angle $\emptyset$ can then be derived by the Pythagorean Theorem:

$$(R - D\cos(-\emptyset))^2 + (Z + D\sin(-\emptyset))^2 = L^2 \quad (7)$$

Next, the angles θ_1 and θ_3 can be derived in the same way described in (3) to (5). The actual joint angle of the motors from motor 2 to motor 4 can then be computed. The angle of motor 1, equal to angle θ, can be determined by the mapping from Cartesian coordinates to cylindrical coordinates as:

$$\theta = \tan\frac{Y}{X} \quad (8)$$

According to the described motion algorithm, the workspace of Disco Lamp is $0 < x(\text{cm}) < 47, 7.5 < y(\text{cm}) < 67,\ 0 < z(\text{cm}) < 63$. Note that the Disco Lamp should be placed outside the workspace to prevent the Leap Motion Controller sensing the lamp itself, which generates iterative and wrong motions. In this tracking mode, all 13 LEDs illuminate simultaneously, providing high-intensity white light.

The motion and light conditions of the lamp in entertainment mode is mainly determined by the spectrum of the audio signal. The audio signal is directly recorded by the laptop via its audio input. The audio signal is recorded at 44.1kHz. The Fast Fourier Transform with Hanning window is applied for every 10,000 samples. Four frequency ranges are selected as the key frequencies for lamp response, including the lamp joint motion and the LED. The average amplitudes of these four frequency ranges are chosen to control the LEDs with four different colors by four different thresholds. The most important frequency range is 40–50 Hz, which falls within the range people have a rhythmic reaction to (i.e., 40–80 Hz). This signal is used to control the white LEDs. The frequency ranges of 90–100 Hz, 140–150 Hz, and 525–535 Hz correspond to the blue, green and red LEDs respectively. As for the joint motion, different combinations have been tried in order to make Disco Lamp move rhythmically. Finally, two frequency ranges were chosen instead of four because the performance of the 2-DOF motion looks best. The chosen DOFs are the first and the fourth DOFs, each corresponding to the highest and lowest frequency ranges, respectively. The first

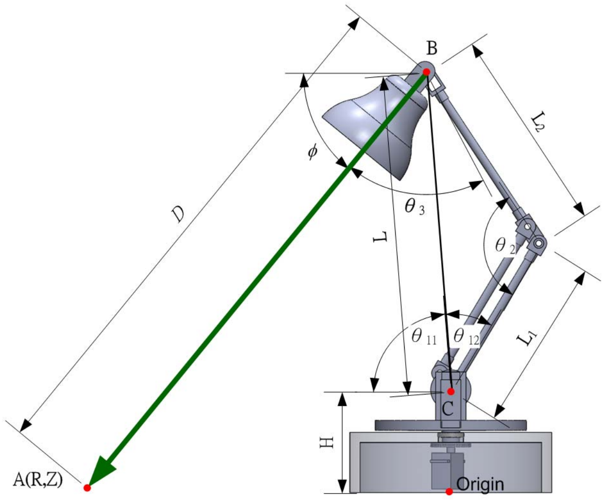

Fig. 5. Symbols for joint angle computation of Disco Lamp.

DOF can shake the whole body according to the lowest frequency range. The fourth DOF can shake the head of the Disco Lamp only according to the highest frequency range.

V. EXPERIMENT

The performance of Disco Lamp in tracking mode is evaluated while the hand moves in two different paths: a planar path and a spatial path. In the former, trajectory of the hand and trajectory of the center of light are compared. To simplify the follow-up image processing, the experiment was done in a dark room and the operator wore a white glove with a red LED installed on top of it as a marker, as shown in Fig. 6(a). When the operator moved his hand, the trajectory of the LED marker versus time was captured by the camcorder and treated as the trajectory of the hand. At the same time, the hand trajectory was also be captured by the Leap Motion Controller, and Disco Lamp lit the corresponding area by the method described in the previous sections. As a result, a white area and a red marker appear in each image extracted from the camcorder video as shown in Fig. 6(b). By using the color thresholds, the trajectories of both characteristic markers versus time can easily be extracted as shown in Figs. 6(c), 6(d) and 6(e). The trajectory of hand and light are shown in a blue curve and an orange curve, respectively. In general both trajectories have a similar motion pattern but with a constant side shift. This shifting mainly results from a discrepancy of the "center" of the hand. The center defined by the Leap Motion Controller may not be the same as where the LED marker is installed. Furthermore, the time delay is not obvious, which shows that Disco Lamp can do the tracking mission well. The video of the experiment can be found at http://youtu.be/AFfzcw3qexY.

An experiment where the hand moves in a spatial path was also performed. Owing to lack of a spatial tracking system, the performance in this test can only be evaluated in a qualitative manner. The video recording the whole experiment can be found at http://youtu.be/onE8hbVsLOw, and snapshots extracted from this video are shown in Fig. 7. The video

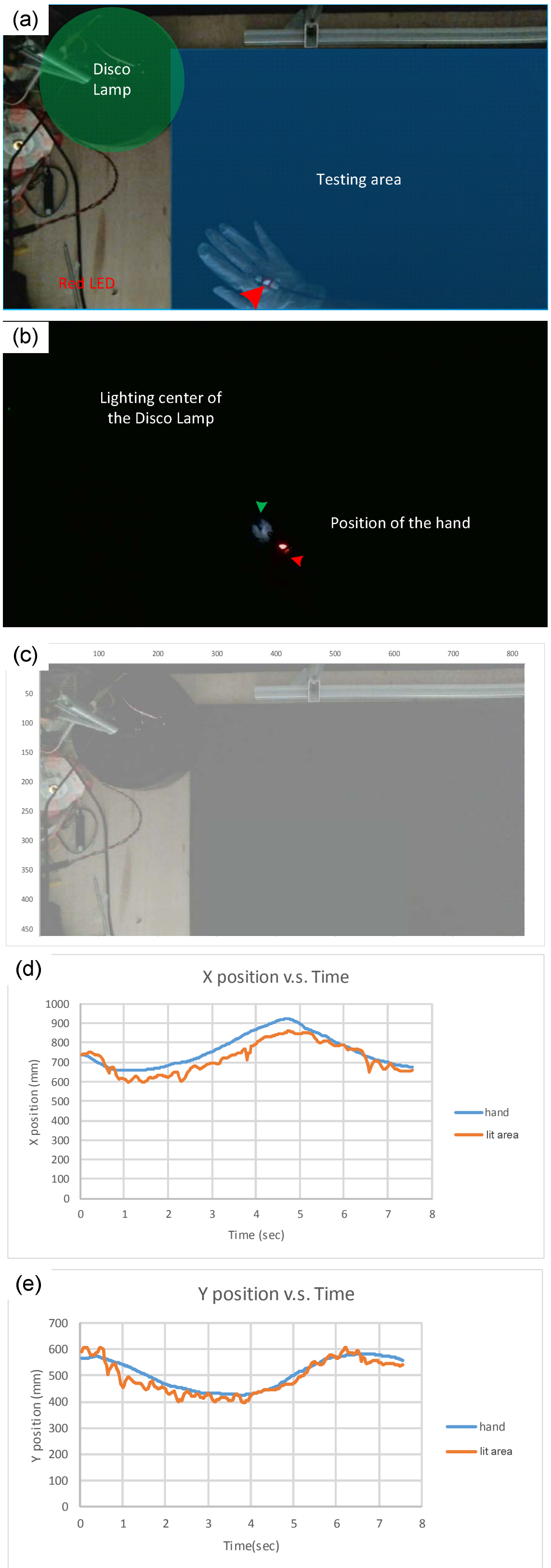

Fig. 6. Experimental evaluation of the Disco Lamp.

confirms that the system, though not perfect, is functional. The motion of the lamp is not smooth but exhibits

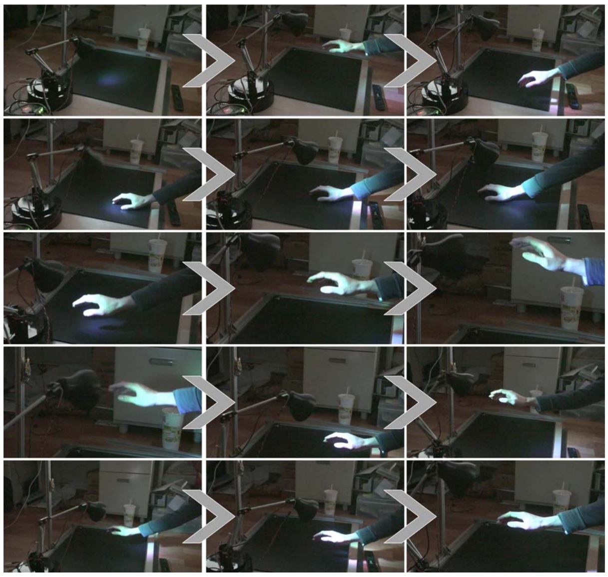

Fig. 7. Snapshots extracted from the experiment.

move-and-stop motions, like the stick-and-slip effect between two sliding surfaces. We believe this phenomenon is mainly generated by the coupled effect of the low-speed and local-feedback of the servo motors as well as the un-modeled lamp dynamics with non-negligible friction and damping within the lamp, which is currently under investigation.

The performance of Disco Lamp in entertainment mode is also evaluated. When the music contains strong signals within the selected frequency ranges, Disco Lamp moves the corresponding servo motors and turns on the LED lights. The video can be enjoyed at http://youtu.be/r78OBPHeR4c.

VI. Conclusion

We introduced an interactive robot arm, which is a 4-DOF desktop lamp with added functions such as tracking a user's hand and reacting to music. In the past decades researchers have been interested in the interactions between robots and people, which offer a fun and novel way of learning. Instead of building a new object as an interactive robot, we built the robot "within" a daily-use desktop lamp by embedding new functionality. The tracking function allows the lamp to automatically track where the hand is. This function is particularly useful when intensive light is required but the working area is large. At any instant only the area with the hand is lit up, so energy is saved. The Leap Motion Controller is used to track the hand motion, and the lamp motion is designed to position itself at a certain distance and at a certain angle to the hand area. The entertainment function brings the lamp to "life," sharing the pleasure of the people when the music is playing.

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