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## VISIBLE LIGHT COMMUNICATION FOR AUDIO SYSTEMS

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### ABSTRACT

This paper describes an audio system that is well-suited for use in a small confined area with many audio transmitters broadcasting different audio signals. The transmitter of the proposed system is constructed using visible light LEDs, in which current fed to the LEDs is modulated and encoded with audio information or messages. The audio system provides audio signal transmission in a free space optical link. The receiver, combined with an ear jack, is located at some distance from the transmitters.

The handheld receiver is designed to demodulate the optically transmitted audio information and reproduce the messages with the ear jack. For modulating emission of LEDs, an oscillator is used to vary the frequency of on/off periods of the LEDs. The frequency of flicker is high enough to be indistinguishable by human eye and hence the LEDs appear to be constantly illuminated.

Keywords: audio systems, light emitting diodes; audio broadcasting.

### 1. Introduction

This paper relates to an audio system that relies on visible light for transmitting audio information to a receiver located some distance away from the system. The basic idea is based on the fact that light emitting diodes (LEDs) are semiconductor devices and are capable of fast switching with the addition of appropriate electronics. That is, the visible light emitted by the LEDs can be modulated and encoded with audio information. LEDs can then be used as a communication device for the transmission of audio information.

Optical signals have been used for communication and information processing in the field of fiber optics for many years. In this paper, a different use of optical signals for communication is described.

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Contributed Paper

The proposed system depends on a direct line of sight between the transmitter and the receiver. This characteristic can be turned into an advantage in situations where a household has many appliances with audio output such as TV, PC, Hi-fi, radio and phone (Figure 1). Some or all of them could be turned on at the same time and there could be more than one person working in the same confined area. This type of home environment with many audio sources is very common in many congested cities in the world. Infrared transmission cannot solve the problem completely due to the interference and the switching of channels is very inconvenient. The proposed system allows the user to hear from one audio source when the receiver is pointing at that appliance. Multiple users can also work in the same compact environment and the problem due to noise nuisance can be greatly reduced.

There has been rapid advance in the LED technology in recent years. Today, visible light LEDs can reach a luminous efficacy beyond 15 lm/W, which is typical for incandescent lamps [1,2]. The main idea of this paper is to modulate the visible light emitted from the LEDs for communication purpose in open space [3]. Hence, an audio system can make use of ordinary LEDs or LED dot matrix display (as used in a radio alarm clock) to provide audio broadcasting. It makes use of the visible portion of the EM spectrum, which is unregulated by FCC or any countries in the world.

The work reported in this paper differs from the use of infrared (IR) radiation as a medium for short-range wireless communications [4,5]. Currently, infrared links and local-area networks are available. IR transceivers for use as IR data links are commercially available at economic prices. Comparison between the infrared and other media such as radio and microwave is given in [6]. Somehow, there has been very little work on the use of visible light as a communication medium for open-space, short-range transmission. Recent availability of high brightness LEDs makes the visible light medium even more feasible now. Essentially, all appliances with visible LED components can utilize the visible light as an information beacon. This paper focuses on its use

for audio transmission.

## 2. Description of the audio information system

The audio system includes a transmitter and a companion receiver. The transmitter makes use of LEDs or LED display for audio broadcasting. It consists of an audio signal source that provides the modulated audio signal for transmission by the display assembly. The key component of the transmitter is a modulator, which includes a voltage-controlled oscillator (VCO) for varying the switching frequency of light emitting diodes on the dot matrix display. The on/off frequency is high enough such that the perceivable light appears to be constantly illuminated to the human eye. Hence, the transmitter provides a modulated audio signal by frequency modulation (FM).

The receiver makes use of a photo-detector to detect high frequency variations in the light flux. This detected signal is passed to appropriate amplifying and detecting stages to reproduce audio signal transmitted. Both the transmitter and the receiver require low power supply, which increases transportability of the system. As the majority of the circuitry is TTL based, power supply requirements are in the vicinity of five volts.

Referring to Figure 2, the audio signal from the TV, Hi-fi, PC or phone is input to the transmitter. The audio signal may have small amplitude and amplification is necessary. The audio amplifier is used to amplify the weak audio signal and to shift the average voltage level of the audio signal to an appropriate level so that the signal is suitable for input to the voltage controlled oscillator (VCO).

Incoming audio signal modulates the VCO and generates FM signal at the output, according to change in voltage level of the signal. A VCO chip is used. A square wave VCO is used instead of sine wave because there are only two states (ON and OFF) for the LEDs. The carrier frequency is set at 100 KHz with a maximum frequency deviation of  $\pm 50$  KHz. The modulated signal is transmitted by the switching of the LEDs, through a driving circuit.

The optical link employs intensity modulation of LEDs with direct detection. With appropriate

electronics, the information in the light ray is demodulated to detect the audio signal, which is reproduced with an ear jack for the broadcasting and announcement of the audio messages or music.

A block diagram representation of the receiver design is shown in Figure 3. The circuit of the receiver is divided into eight portions. The photo-detector is used to detect modulated light signal from the transmitter and convert the signal into an electrical signal. The limiting pre-amplifier is used to amplify the electrical signal from the photo-detector for the next stage. Pulse shaping and detecting circuits are used to reconstruct the square wave. Square wave pulses from previous output stages are differentiated and its negative trailing edges are clipped when transmitted through a diode. Next, a pulse generator is used to convert the pulses from the differentiator into sharp pulses, to be used by the integrator and envelope detector in the next stage for the demodulation of the signal. The band-pass filter is then used to smooth out the distortions from the integrator and envelope detector to produce an appropriate waveform. Finally, an audio power amplifier is used to amplify the weak signal from the band-pass filter so that the audio signal would be comfortable for hearing. A speaker, head phone or ear jack can be used for the delivery of the audio messages or music sent from the transmitter. The receiver can be battery powered, or powered by any electrical system.

For appliances that have an LED dot matrix display, like a radio alarm clock with a display of the digital time, the LED on the display can be used for simultaneous display and audio broadcasting. It relates to a dot matrix LED display panel or any LED display assembly for providing a visual signal in the form of light rays and for using the light rays to transmit information. The LED display is controlled through a hardware interface. More details on the use of dot matrix display for audio broadcasting is given in the next section.

## 3. Components of a tricolor LED audio system

In this section, a detailed description of a tricolor LED display for both signaling and broadcasting of audio information is described. The tricolor light emitting diode dot matrix display system is shown in Figure 4. It relates to an LED display panel or

any LED display assembly for providing a visual signal in the form of light rays and for using the light rays to transmit information. The LED display is linked to a computer through an interface circuit. An executive program runs on the computer for the visual display control of characters, decorative pattern or messages on the display panel.

Figure 5 gives the block diagram of the interface circuit. The circuit is connected to the computer through the parallel port. There are seven parts for this circuit.

(a) Row Counter Decode System

This part is used to switch among the rows of the LED display. It contains a counter driven by the information signal, and a decoder for row selection.

(b) Segment Counter Decode System

This part is used to switch among the segments of the LED display. For segment, it means a particular color of a particular character. Again, it contains a counter, driven by a fast oscillator, and a decoder for segment selection.

(c) Pattern Storage System

This part is used to store the LED display pattern of every row and every segment of each character. SRAM is used in this system.

(d) Address Comparison Unit

This part compares the system-generated address ( based on the two counter systems ) against the address sent out by the computer. This is used to ensure that the SRAM data and display will not be disrupted until the LEDs are in the inactive state ( off state ). The data is actually written to the SRAM so that it can be displayed in the next scan. This part contains a bit comparator and a register. This register is to hold the data until the system is ready to write this piece of data to the SRAM.

(e) Status Indicator

This part contains a D-type flip-flop with Asynchronous inputs of Preset and Clear. The non-inverted flip-flop output pin ( strobe pin ) is used for indication of a successful write. On such occasion, this pin will be set high and enables the computer so send next data.

(f) LED Display Unit

This is the part to store temporarily the LED information and hold the LEDs in place. It should be noted that the common ( row ) signal is negative and segment signals are positive. This unit also contains registers to isolate the LEDs with the

circuit. They can also hold temporarily information that will be sent to drive the LEDs. These are used to defer updating of data when LEDs are active and ensure that it is done when LEDs are off.

(g) Parallel Port

This is the outlet of the computer system and acts as the interface to the hardware electronics. Data and control signals are sent out from this port and strobe (status) information is delivered to the computer via this port also.

Figure 6 gives a schematic of a tricolor LED dot matrix array. In order for a light emitting diode to be on, the corresponding row signal should be high and associated segment selection signal should be low.

## 4. Features of the LED display

### 4.1 Pattern update process

The data is first latched into the register. However, it is not sent to the SRAM data input pins and the segment registers' input pins so as not to disrupt the normal LED display process. The address is transmitted to one of the input pins of the comparator. After the comparator is enabled, this address is compared with the system-generated address. As they are matched, the output of the comparator will be driven low. This will put the data stored in the register to the input data pins of the SRAM. The matched address is already loaded in the address pins of the SRAM. The matched event will trigger the write enable pin of the SRAM, causing the data to be written to the SRAM at that particular address. Another pin affected is the strobe pin at the output of a flip-flop. The pin is enabled high by the event, indicating the computer that the write has been successful and it could continue writing the next data.

### 4.2 Pattern Display Process

The address is composed of two parts. The first part is from the information signal that specifies the row at which the LEDs are active. The other part is from the 12MHz oscillator that specifies the segment for which data is to be latched to the display register. These two portions constitute the address of the data and this is loaded in the SRAM for data request. After the data is retrieved, it is loaded in the appropriate display register and it is

displayed finally.

### 4.3 Software for display and pattern update

The software program used for the display control and pattern update of this tricolor LED dot matrix display is described next. For the write cycle, data is first put onto the bus and latched. The corresponding address is then loaded in the same bus and it is compared with the system-generated address. If they are matched, data is written in the SRAM at the corresponding address. A signal is sent back to the computer, indicating a successful write.

The special dot matrix display developed is very general. Display effects such as scrolling and running is also included. A special character data set used for the tricolor display has been created. Here, 6 x 6 characters are used on an 8 x 8 display so that they can be clearly distinguished when two characters are put side by side. The residue LEDs form a border around the character, which are displayed as background color.

### 5. Application

Figure 1 shows an example of the audio system where a handheld or ear piece receiver is used to receive audio information or music from a selected audio source. The indoor environment has many consumer electronics appliances and each can provide audio output. With the receiver adjusted to point to the transmitter of each appliance when the user is focusing his attention to it, appropriate audio signal is received. The switch from one audio device to another device is quick and natural. The viewing angle of the transmitter and receiver can be adjusted to provide an optimum setting for the user.

It should be mentioned that such a receiver can also be used in many other situations. Suppose an LED or dot matrix display transmitter is installed in an exhibition hall. The information on individual display can be broadcast via the LED transmitter. When a visitor is looking at the LED display panel, he is automatically in the line of sight and thus receives audio messages about the specific announcement. Thus, the sound level of the exhibition hall can be minimized. The same receiver can also be used to receive audio messages or music from all commercial billboards made up

of LEDs.

## 6. Implementation and Results

Two prototypes of the audio information system described in this paper have been implemented in the Industrial Automation Laboratory at The University of Hong Kong. Figure 7 is a photograph of the receiver. Figures 8 shows a simple LED transmitter consisting of LEDs with a luminous intensity of 1100 mcd at rated 20mA driving current. It is a 5mm LED lamp with a 15 degree viewing angle. With just one LED, it can be demonstrated that the transmission distance can reach 390 cm with a 50 mm focusing lens in front of the receiver photodiode. Without the lens, the transmission distance can reach 77 cm.

Figure 9 is a photograph of a tricolor dot matrix display. The display consists of an 8 by 8 LED dot matrix. The receiver was placed at two meters away from the display and satisfactory audio output was obtained. It should be noted that the type of tricolor LED used for the construction of the implemented dot matrix display is commonly available. Large audio transmission range can be achieved by employing high brightness tricolor LEDs [1,7].

The specifications of the tricolor dot matrix display is given below:

Color	red, green, orange
Construction	64 tricolor LEDs
Size	4 cm square
Nominal usage	5 V; 0.24 A
Nominal power consumption	1.2 W
Luminous intensity	180 cd
Viewing angle 20 <sub>1/2</sub> (half power)	80 degrees
Distance for audio transmission (indoors)	40 cm (no lens); 200 cm (with focusing lens)

The radiation pattern of the panel is given in Figure 10. The viewing angle of the display is around 80 degrees. An IIP Audio Analyzer has been used to provide audio measurement for the visible light LED audio broadcasting panel. It has a low distortion signal source with a signal analyzer. In a measurement on the signal-to-noise ratio, the result is shown in Figure 11. Figure 12 shows the

distortion measurement on signals from 237 to 10KHz. The frequency response characteristic of the system is shown in Figure 13.

## 7. Conclusions

An audio system made up of light emitting diode (LED) and LED dot matrix display is described. It uses the visual light rays for transmitting audio messages to a remotely located receiver. It has long been realized that visible light has the potential to be modulated and used as a communication channel with high entropy. This application makes use of free space as communication medium and the receiver is required to be in line-of-sight (LOS) with the transmitter.

Such an audio system would be very useful in situations where there are multiple audio sources in a confined area. Here, the direct LOS property of visible light communication is utilized. It should be noted that the transmitter provides easy target for the line-of-sight reception by the receiver. This is because the LEDs, being on all times, are also indicators of the locations of the transmitter. Two prototypes of the audio systems have been implemented and they give satisfactory quality for consumer-use audio appliances. The experimental results in this paper have demonstrated that the proposed idea is totally feasible.

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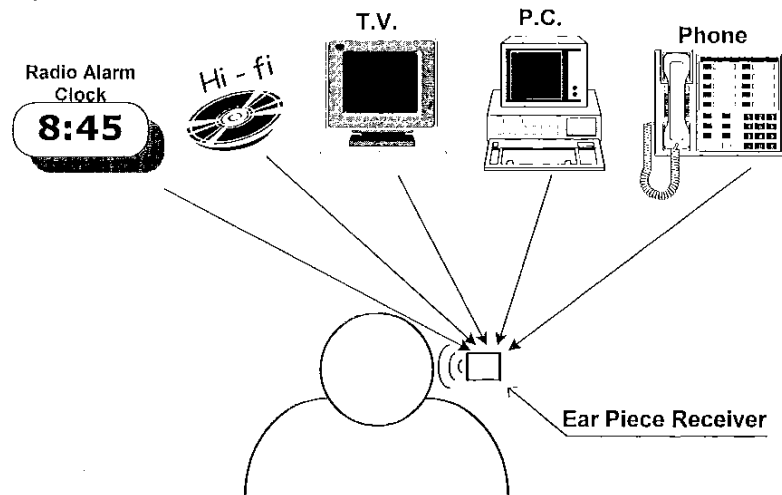


Figure 1 : An audio system with multiple transmitters.

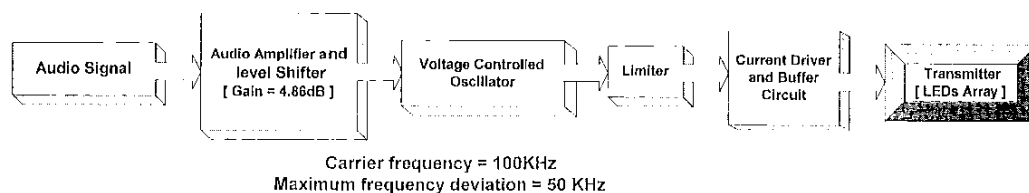


Figure 2 : Block diagram representation of the schematic diagram of the audio signal transmitter.

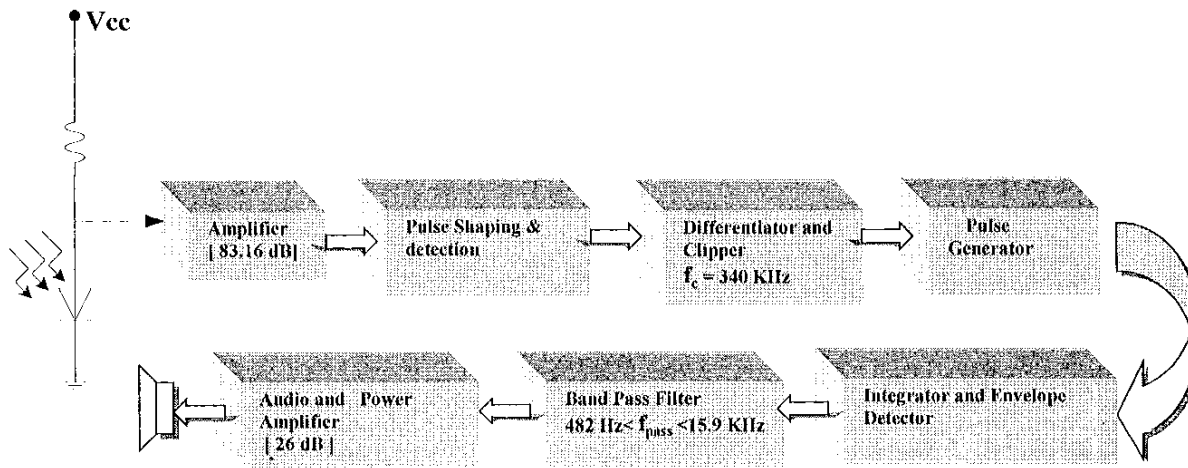


Figure 3 : Block diagram representation of the receiver.

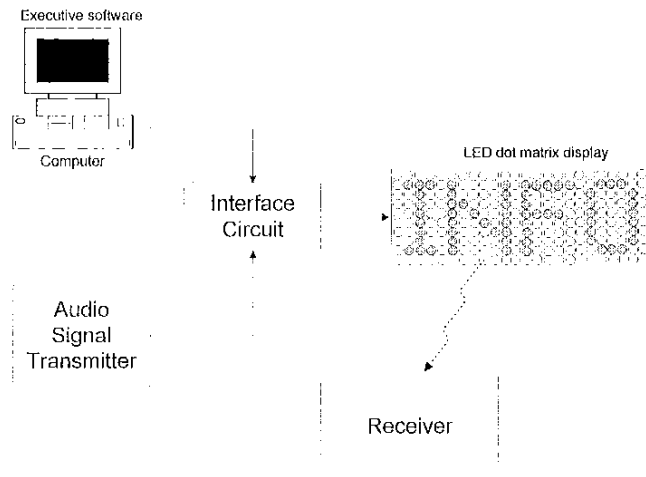


Figure 4 : Block diagram of the tricolor LED dot matrix display system, an interface circuit which links the display to a computer, an audio signal transmitter, and the companion receiver.

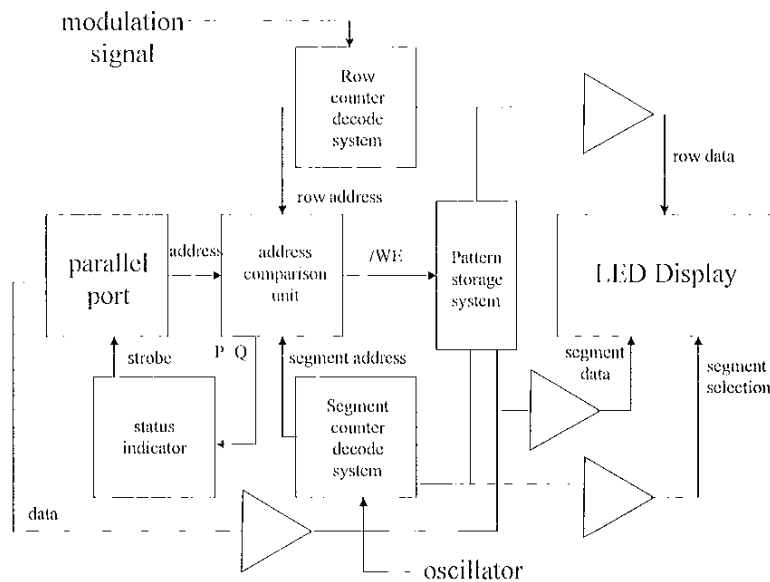


Figure 5: Circuit diagram of the interface design.

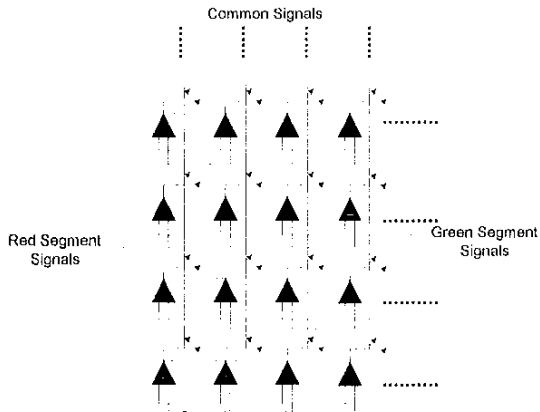


Figure 6: Schematic of a tricolor dot matrix display using light emitting diodes.

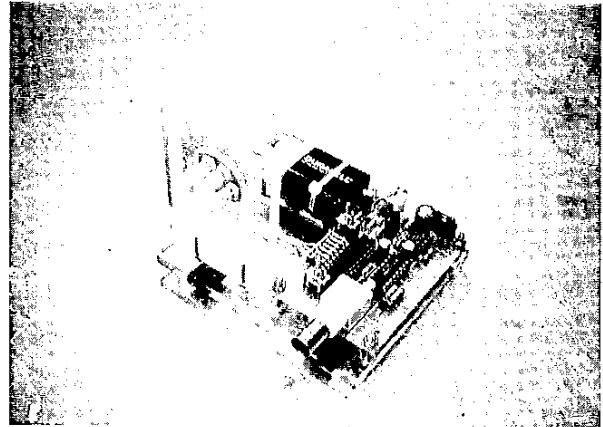


Figure 8: Photograph of the LED transmitter.

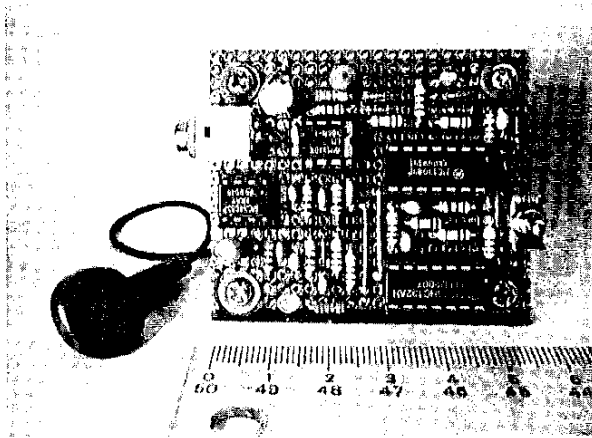


Figure 7: Photograph of a receiver.

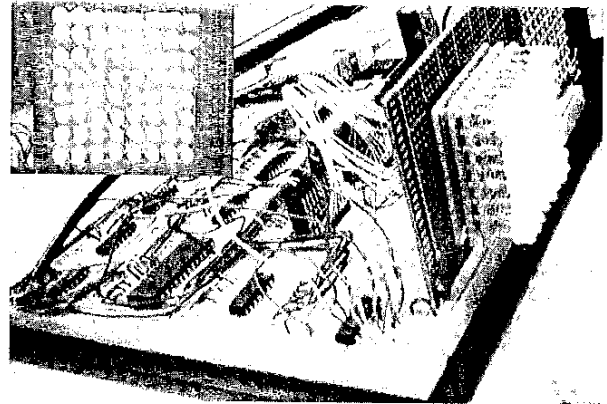


Figure 9: Photograph of the tricolor LED dot matrix display/transmitter.

### Professional Biography

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Dr. Grantham K. H. Pang obtained his Ph.D. degree from the University of Cambridge in 1986 for research in multi-variable control system design and expert systems. He was with the Department of Electrical and Computer Engineering, University of Waterloo, Canada, from 1986 to 1996 and joined the Department of Electrical and Electronic Engineering at The University of Hong Kong in 1996. Since 1988, he published more than 60 technical papers and has authored or co-authored three books. His research interests include expert systems for control system design, intelligent control, intelligent transportation system, neural networks, control theory and computer-aided design. In 1989, he was awarded the ICI Prize for author-

ship of the best paper on the application of the theory of control published in the Transaction of Institute of Measurement and Control. Dr. Pang was the Organizing Chair of the 1996 IEEE Symposium on Computer-Aided Control System Design. He was appointed by the President of the IEEE Control Systems Society as the Chair of the Technical Committee on Computer-Aided Control System Design (1993-95). In 1994, he worked as a Senior Visiting Researcher at Hitachi Research Laboratory in Japan. Dr. Pang has acted as a consultant to many companies which include Mitsubishi Electric Corp. in Japan, Northern Telecom and Imperial Oil Ltd. in Canada. Dr. Pang is an Editor of the International Journal of Intelligent Control and Systems. Also, he is an of the journal Control and Computers published by the International Association of Science and Technology for Development (IASTD). He is a Chartered Electrical Engineer and a member of the IEE, HKIE and IETE.