Constructing Intelligent Living Space Controlling System with Bluetooth and Speech-Recognition Microprocessor

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Abstract
This study focused on designing an intelligent living-space with automatic control system to control all home appliances in the space. First of all, the system was constructed with two parts; one is remote control mechanism with Bluetooth (BT) module mounting on both master controller module (remote controller) and slave receiver module on every home appliance, the other is to design the remote controller with speech-recognition and function of self-learning human voice so that people could directly give command to control appliances. Therefore, the technique of BT communication and speech-recognition microprocessor became the most important in this study. After implementing the finished projects, the whole system was proved successful and the final result of this research has achieved both National patent and National Award of Practical Projects Design authorized by Taiwan Education Ministry.

Keywords: Intelligent Living Space, Bluetooth, Speech-Recognition, Home Appliance

1. Introduction
This paper mainly focused on exploring the intelligent living-space issues of daily life especially when mankind steps into 21st century leading by concept of 3C. Since Japan and Korea have invest a lot of resource in researching and developing digitalizing living-space many years, those strategies really upgraded the competition potential of country’s economy and created many related brand-new industries for 3C. Taiwan now positively touches into this category of manufacturing industry by initiating from Far-eastern Constructing Co. Ltd., which proposed “Digitalized Community” and began the research category of the intelligent living-space. In this paper, an intelligent living-space based on blue-tooth system and speech-recognition function implemented into intelligent system was practically designed and implemented in a living room, which was supported by the Taiwan Education Ministry under “Projects of Improving Teaching Superiority of Taiwan colleges”, and the whole system was finally proved to be successful with its steady functions. The related techniques developed included software developing of blue-tooth modules, hardware design of interface transition between blue-tooth and RS-232, decoding of message package, pairs matching, speech-recognition & processing microprocessor SPCE061A and communication mode switching in multi-modules. The study purposes of the system are: 1. to study the related techniques of blue-tooth modules and its communication mechanism implemented in an intelligent living-space. 2. To research and develop a remote controller with speech-recognition and self-learning for human voice so as to be used to control every appliance in the living space. 3. To develop the interface between blue-tooth module and RS232 mounted on any microprocessor or PC.

2. Related Knowledge and Theory

2.1 Knowledge and Lab. For Speech Processing
Speech processing technique could be divided into speech coding, speech synthesis, speech recognition, speech enhancement, and speech analysis.[1] Speech coding is converting sound wave traveling in the air into analog signal like voltage or current value through converter such as microphones, and then convert analog into digital signals through ADC (analog to digital converter)[2]. Finally the microprocessor would fetch change digital-value of sound wave and its aptitude within certain period and fixed sampling rate. Each sampled point would be indicated its aptitude with fixed bits and stored in larger space in microchip. In order to decrease the coding bit number [3] and enlarge transition frequency band-width, it is necessary to adapt compression coding method with different compression ratio.

Speech recognition is to make machines understand mankind language and commands to perform precise action. Speech recognition could be divided into units of syllable [1] or sentence, and usually the shorter the sentence is, the more easily understood with the sentence. Though speech recognition with syllable is shorter than sentence, it is easy to generate recognition errors and to be affected by successive syllables in front of or behind the recognized syllable. Speech synthesis is to reorganize speech units that were divided into variable units to be one language model and use many different commands to combine those language models into different speech to response mankind.

2.2 Function Structure of Speech Microprocessor
In this study we adapted single-chip microprocessor SPCE061A[6], a16 bits MPU with powerful interrupt function, speech recording and playing, especially the public functions library (SACM) that provided managing to speech processing made of SUNPLUS Corp. Ltd. and its function was extended from traditional control to Digital Signal Processing as shown in Fig. 1. The speech processing can be divided into A/D, encoding, storing,
decoding, and D/A. Each processing step was constructed corresponding function library and can directly call its application program, API as shown in Fig. 2[6].

![Fig. 1 SPCE061A](image)

SPCE061A has 8 10-bit ADC channels [6, 8], in which MIC_In is the input channel of speech analog signal through microphone. The signal proceeded A/D conversion after AGC (Automatic Gain Controller) and OP amplifying, after completing conversion the signal was stored and decoded, finally was converted into speech analog signal through DAC (Digital to Analog, DAC) channel to output to speaker. During designing the DAC output circuit of speech, the stability of DC voltage must be taken in account because the shifting of the voltage aptitude would cause noise sound of speaker.

**2.3 Compression Technique of Audio Frequency**

<table>
<thead>
<tr>
<th>SIGNAL TYPE</th>
<th>FREQUENCY RANGE (HZ)</th>
<th>SAMPLE RATE (KHZ)</th>
<th>QUANTITY PRECISION (BIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>phone</td>
<td>200~3400</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>AM</td>
<td>50~7000</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>FM</td>
<td>20~15K</td>
<td>37.8</td>
<td>16</td>
</tr>
<tr>
<td>High(FM)</td>
<td>20~20K</td>
<td>44.1</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 1 shows different level of technique standard of coding of audio frequency. The range of compressing process for audio frequency signals in SPCE061A was phone-audio frequency from 200Hz to 3.4 KHz.

The algorithm of audio-frequency compression for SPCE061A can be divided into three types according to compression ratio and the quality rank of audio signal is A2000> S480> S240 as shown in Table 2.

<table>
<thead>
<tr>
<th>COMPRESSION TYPE</th>
<th>COMPRESSION RATIO</th>
<th>CODING RATE</th>
<th>SAMPLE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPCM-A2000</td>
<td>8:1</td>
<td>16Kbit/s</td>
<td>16K</td>
</tr>
<tr>
<td>SPCM-S480</td>
<td>8:1.25</td>
<td>20Kbit/s</td>
<td>24K</td>
</tr>
<tr>
<td>SPCM-S240</td>
<td>8:1.5</td>
<td>48Kbit/s</td>
<td>24K</td>
</tr>
</tbody>
</table>

Table 2 Compression Type

The related application includes function format, functions, parameters, and echo value of API (Application, API) [6]. Speech functions can be defined as initialization setup, getting speech data and fill with decoding queues, playing, stopping playing, pause, recovering from pause, volume control, gaining status of module, initializing decoding, decoding, initializing queues, filling queues, and verifying queues. Interrupt service functions was used by timer-interrupt mode during recording and playing of audio-signals to achieve precise sample rate [7, 8].

In this study, at first, we adapted WaveSurfer software to record speech, and the file format must be WAV. Then, used compress tool produced by SUNPLUS accompanied with mentioned above compression types to transfer the program in PC. Since the playing speed of SPCE061A was 8 KHz, the transferring speed for WAV file should use 8 KHz sample rate to get better effect.

The audio-frequency signals could be analyzed to be waveform, Pitch Contour, Spectrogram, Time Axis, and Power Plot [9] through recording software--WaveSurfer. During the recording experiment, we recorded a section of speech—HELLO, and fetched its waveform as Fig. 3.

![Fig. 3 Audio-signal Waveform](image)

Fig. 3 showed that we used Pitch Contour and Time Axis to analyze the audio-frequency signal of human voice of speaking “HELLO” and the frequency was 200~300Hz that entirely matched the “phone” audio-frequency range. This experiment could be verification for all generated sound or voice frequency.

![Fig. 4 Audio-frequency Range](image)

Fig. 4 showed generated Power Plot by audio signal and from it we could find the different dB value of audio was changed according to the volume of audio signal. Especially, before speaking out “Hello”, there was a lower than 20 dB of volume detected and this is we called “Noise”.

![Fig. 5 Power Plot](image)

**3. Knowledge and theory of BT**

**3.1 Related Knowledge**

Blue-tooth is a kind of wireless and communication system that uses 2.4 GHz ISM jumping-frequency according to IEEE 802.15.4, and defines 79 channels with 1 MHz frequency-interval and jumping-frequency.
of 1600s per time. It also uses Time-Division Duplex, TDD [12]. The stacks of blue-tooth communication protocol were shown in Fig. 6 [11].

Because in this paper visual serial ports were adapted in blue-tooth communication as data transmitting and receiving structures, the serial port profile (SPP) was used and the information of blue-tooth was transmitted with message packages as shown in Fig. 7 [13].

Payload is the location where the data was placed in the message-package. There are two kinds of message-package including asynchronous connection-less (ACL) and synchronous connection-oriented (SCO). ACL message-package was mainly used to send general message and data with asymmetrical transmitting and the rapidest baud-rate could get to 723.2 Kbps while SCO was mainly used to transmit vocal-message. A completed message-package could be accomplished after Header and Access-code were planted into managed payload. In this paper, Link-Matik 2.0 blue-tooth module produced by Flexi-Panel and 8051 microprocessor were composed together to construct the receiving-control-module (slave module), and the transmitting-control-module (master module) was mainly constructed with PC as developing-platform, which connected the master module through RS232 interface. The net topology of blue-tooth was shown in Fig. 8 and could be divided into three kinds, one is point-to-point, the second is star or tree structure, and the third is Scatter-net. In this paper, we used the first one [11],[13].

There are Payload-header, Payload-body, and CRC (Cyclic Redundancy Check) in ACL message-package [13]. Payload-header was responsible for controlling flow amount of logic channel. The types of message-package in ACL include (1) DM1 (Data Medium Rate 1), DM3, and DM5 that were processed with error-correction. (2) DH1 (Data High Rate 1), DH3, and DH5 that only were processed with CRC. (3) AUX1 (without any encoding processing).

Header has 54 bits resulting from original 18 controlling bits encoding with 1/3 FEC. Access code is composed of 68 or 72 bits, which include 4 bits in Preamble, 64 bits in Sync Word, and 4 bits in Trailer. Preamble and Trailer are used for DC offsetting and Sync Word is figured out from the address of blue-tooth devices.

### 3.2 The Basic Architecture of Bluetooth Network

If two Bluetooth devices want to link together in communicated range, they must link under the defined spec as inquiry and page procedures as shown in Fig. 9. This procedure was called Link formation [17]. Inquiry procedure is used to discover each other while page procedure is used to construct real linking. The device send out inquiry signals is called master and the device receives the signals is called slave. They can connect each other by page procedure. When one master device connected with more than two slaves, they formed a Pico-net, in which all Bluetooth devices formed a net system and shared the same one channel. Each Pico-net has only one master and at most 7 slaves in active status. The net-system connected by several Pico-nets is called Scatter-net, and the processes constructing Scatter-net is called scatter-net formation. Slave device has four working modes in linking status described [13], [17] as following:

1. **Active Mode**: Slave and Master would send data to each other in this mode. Slave possessed AM_ADDR and jumped frequency queue in Pico-net. That is because there were at most 7 slaves in active status in one Pico-net; hence, the slave linking in this Pico-net and out of the original linked 7 slaves must enter the Park status and is not able to send any data in the system-net.

2. **Sniff Mode**: to save consuming power, Slave device could enter Sniff Mode. Slave would extend the signal-intervals on jumping-frequency when receiving master’s signals. But, Slave still kept AM_ADDR and jumped-frequency queue in the Pico-net.

3. **Hold Mode**: when Slave entered Hold mode, it would cease to support ACL Linking, but still support SCO Linking.

4. **Park Mode**: if slave need not send out data without departing from the Pico-net and wish to save consuming power, it could select to enter Park Mode. Meantime, the slave would desert AM_ADDR and...
get PM_ADDR and AR_ADDR from master. One Pico-net can own at most 256 slaves in Park status. Master could keep in touch with slave in Park status through period broadcasting signals sent on Master-to-Slave BC (Beacon Channel). Master could wake up the slave in Park status in Pico-net by sending PM_ADDR in BC and AM_ADDR after assigning Slave to enter Active status. In the same, the slave in Park status in the Pico-net could request Master to wake up the slave through BC.

Bluetooth device defines four different device-addresses [12],[13],[17]. They are BD_ADDR, AM_ADDR, PM_ADDR, and AR_ADDR.

1. BD_ADDR (Bluetooth Device Address): All blue-tooth devices own one unique 48 bits BD_ADDR, security key, jumping-frequency queue, and access code etc. Those parameters were figured by BD_ADDR, which could be regarded as hardware serial-number when out of the company.

2. AM_ADDR (Active Member Address): It was composed to be eight different numbers by 3 bits, and this is why one Pico-net was constrained at most 8 active devices. The AM-AD by 3 bits DR of Master was fixed as 000. Master would assign one AM_ADDR to every active Slave in the Pico-net, and then distinguish each different Slave in the Pico-net by AM_ADDR.

3. PM_ADDR (Park Member Address): When Slave enter Park status, It would get one PM_ADDR composed by 8 bits, and that’s why there are at most 256 blue-tooth devices in park status in one Pico-net.

4. AR_ADDR (Access Request Address): All blue-tooth devices in park status in Pico-net would get one AR_ADDR. It was possible that some devices would have the same AR_ADDR and the Slave wishing to become Active mode needs this AR_ADDR to request Master to wake up the Slave.

4. Hardware and Software Design

As shown in Fig. 5, there are communication protocols in blue-tooth modules [11] as following:

1. The exchanged formats of electronic name-card (v-Cal), electronic calendar, and daily schedules (v-Cal).
2. Conversation protocol (OBEX).
5. Simulation Modem commands set (AT Commands).
6. Service demanding protocol (SDP).
8. Point-to-Point Protocol (PPP).
9. Virtual Serial Port communication protocol (RFCOMM).
10. Logic Link Control and Adaptation (L2CAP).
11. Link Manager Protocol (LMP).

RFCOMM, so to speak, as Cable Replacement Protocol, is simulation of serial communication port protocol according to ETSI 07.10. That means the simulation signals of RFCOMM are simulated the controlled and data signals of RS-232 serial port. In this paper the communication protocol and data format was used this kind of simulation signals.

As shown in Fig. 10, the system structure of the whole intelligent living-space is constructed by master blue-tooth-module beside PC and many slave modules separately beside its home appliance.

The master blue-tooth-module which is controlled by PC proposes linking request to the slave one, and then sends controlling data to slave module after successful linking. After completed decoding, the slave module mounted on controlled board will give command to micro-processor 8051 to start its I/O and make home-appliance work. The controlled type of I/O of slave module can be divided into 2 such as single point and multi-point type. The single point type is mainly to control those home-appliances with ordinary single switch such as lights while multi-point is designed for home-appliance with multi-switches such as DVD, micro-waver, TV etc. that have push-buttons.

All controlling codes were encoded with ASCII code and encoded in control-data column of payload in blue-tooth module. The slave module would active according to its received controlling codes which is shown in Table 3. Slave modules should send echo-code to master after receiving command from master to let master module ensure its command having been definitely received by slave.

![Fig. 10 Structure of system](image)

<table>
<thead>
<tr>
<th>Command code</th>
<th>Echo code</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x30</td>
<td>0x0D 0x0A</td>
<td>OFF</td>
</tr>
<tr>
<td>0x31</td>
<td>0x0D 0x0A</td>
<td>ON</td>
</tr>
<tr>
<td>0x32</td>
<td>0x0D 0x0A</td>
<td>The second point ON and OFF after 1 second</td>
</tr>
<tr>
<td>0x33</td>
<td>0x0D 0x0A</td>
<td>The third point ON and OFF after 1 second</td>
</tr>
</tbody>
</table>

The flowchart of the master was shown in Fig. 11. When user pushes down the push-buttons on the controlling screen, which was design an interface with Visual Basic langue in PC, the system would send out the controlling code to slave trough blue-tooth interface according to the encoded controlling code and the address of the paired slave module. The flowchart of the slave was shown in Fig. 12. When slave received the data sent from master and the ATN pin was high, that meant it’s a controlling data. And then the slave’s microprocessor would drive the corresponding switch of
The software operating interface on PC screen was shown in Fig. 13.

![Fig. 13 controlling screen of intelligent living-space](image)

The blue-tooth hardware in this paper was adapted Link-Matik 2.0 produced by Flexi-Panel. The related pins of this module were shown in Fig. 14. PCMS, PCMC, PCMO, and PCMI were pins of sending voice signal; CTS and RTS were responsible for serial communication data-flow-amount control of hardware. If there was not necessary for hardware data-flow-amount control, CTS and RTS needed to short-connect. TxD and RxD were transmitting and receiving serial communication data pins, ESC was used to switch between command mode and data mode, and ATN was responsible for indicating whether the master and the slave were linking together. If the logical voltage level of ATN was high, it meant the couple was linking together successfully and the received message was general data, on the contrary, if the logical voltage level of ATN was low, it meant the linking of the couple was not successful.

![Fig. 15 Diagram of master module](image)

The master module was composed of Link-Matik 2.0 and PC through serial communication port RS-232 as shown in Fig. 15. The practical product of the master module was shown in Fig. 16. Fig. 17 showed the part program designed with VB language in PC to control DTR pin, which connected with ESC pin of Link-Matik 2.0 blue-tooth module, in order to control switching command mode or data mode of BT [15]. The slave module was composed of Link-Matik 2.0 and 8051 microprocessor as shown in Fig. 18 [14]. The practical product of the slave module was shown in Fig. 19. Fig. 20 was part program of 8051 to judge whether the linking was successful and decode the controlling code from BT.

![Fig. 16 Practical product of master control system](image)

![Fig. 17 Program of switching command mode and data mode by PC](image)
5. Conclusion

Now in our daily life, the application of blue-tooth techniques was very popular in many fields. In this paper the BT combined with microprocessor to become a control module to control home-appliance. Although there were many linking way of BT, this study still tried to keep the flexibility and extending purposes and adapted point-to-point linking mode into practical living-space. We modified the existed appliances and added BT control module to those modified appliance in living-space, after really testing and operating, the system proved to be successful and stable. By development of BT module in this study, the whole system could be planted to other remote-control system to engage to data collecting and monitoring, even implementing in industry control.

Acknowledgement

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References