Synthesized Speech using a small Microcontroller

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Abstract: *Speech was the natural form of human communication. Automatic speech signal generation on computers is commonly called speech synthesis. Speech synthesizer can be created by concatenating pieces of recorded audio speech that was stored in a database memory. Text-to-speech synthesis was an important object in speech interface, which allows low-bandwidth text to supply a user with easy to gain the information. Speech synthesis system has wide range of applications in our daily life. Speech synthesis plays an important role in signal processing. In this paper a Speech synthesized system is designed which is based on microcontroller, a project that performs several commands as defined for the synthesis of the speech signal.*
Index Terms: *Microcontoller, Control System*

I. Introduction

Embedded systems play an important role in our day to day life. Due to limited works this systems can be highly optimized by particular needs [27]. Some of the embedded systems applications were controlling the devices with some amount of intelligence built-in [1].

Speech synthesis system has wide range of applications in our daily life. Speech synthesis plays an important role in signal processing. The natural, intelligible synthetic voices in the expanding field of speech technology had a lot of demand [4]. Speech was the natural form of human communication. Automatic speech signal generation on computers is commonly called speech synthesis. Speech synthesis was the artificial production of human speech [2]. Speech synthesizer can be created by concatenating pieces of recorded audio speech that was stored in a database memory. Text-to-speech synthesis was an important object in speech interface, which allows low-bandwidth text to supply a user with easy to gain the information. In speech synthesis field, a number of research programmes have taken place during the last decade [13]. In 1984 an industry expert Mr Drinkwater said that about the synthesis "synthesis is going to be the next bam-burning technology" [2]. Now a day's synthesis speech was useful for many applications. In 1999 an American business magnate said that "In a few years personal computers will talk back to us" [2].In the past (Allen et al., 1987), the text to speech synthesis was done from a complete knowledge of the acoustics of the language being targeted.

For getting text to speech synthesis different techniques were used [5]. Concatenate method was the simplest method for achieving the synthesis speech. By using this method the speech was generated by linking pre recorded speech segments to build syllables, phrases, or words [2]. the applicable criteria that follow.

The block diagram for the system was shown in the following figure 1.
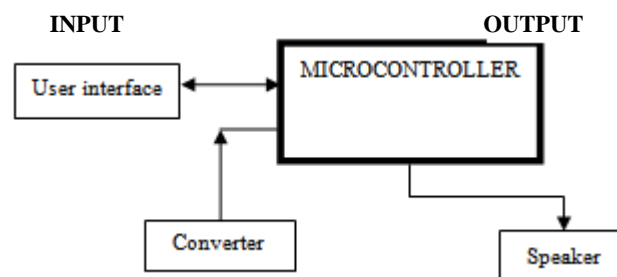

Figure 1: Block diagram of the system

From the above figure the system will have four main sections; the microcontroller of the system would take the commands from user and control the converter. The link between the user interface (computer) and the microcontroller was two ways because after taking the some commands from user the system would also respond with proper feedback. After processing the inputs the output will reflect through the speaker controlled by the microcontroller which was illustrated by the figure 1.

II. Problem Analysis

This Paper was highlighted the requirements for developing the system. These requirements were categorized into two major sections those were hardware requirements and software requirements. Based on the project deliverables the requirements of the system were given below and clearly explained. The block box testing's were also mentioned in the ending of this Paper.

2.1) Hardware requirements of the system

This project "synthesized speech using a small microcontroller" was a type embedded system so it would be a combination of electronic hardware and software code. The following figure was show the system would have electronic hardware capable of control the ISD board as shown in Fig. 2.1 (a).The following figure was show the system would have electronic hardware capable of speech synthesizer which can controlled by the microcontroller. The block diagram for synthesized speech using microcontroller was shown in the Figure 2.1(b)
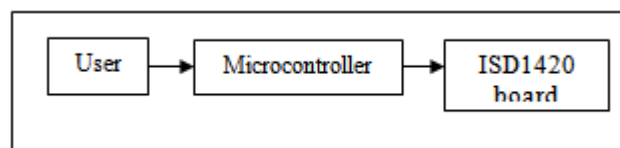
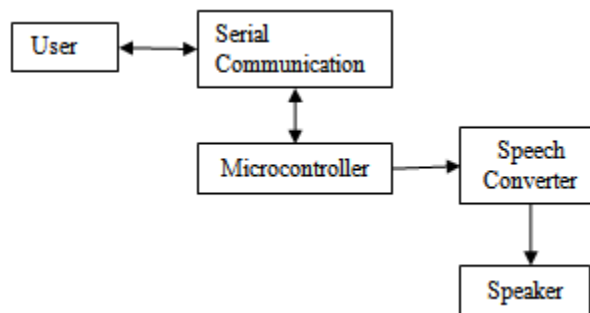**Fig. 2.1 (a)** Block diagram for audio record/playback system

Fig. 2.1 (b) Text to speech synthesis system block diagram

For this system a synthesizer was used for converting the text to speech.

2.1.1) Speech synthesizer

A synthesizer was required for getting the speech from text; it should be controlled by microcontroller. The selection of the synthesizer would also be a challenging task there were many kind of synthesizers available in the market also there were some techniques for hardware as well as software techniques were there for getting speech from text. Software approach was good but in implementation quiet complex so hardware approach was followed in this project. The synthesizer was required for this project which would capable to read the English words, numbers and mathematical functions. The synthesizer chip should be light weight and communicate with the host processor. It should have built in rule database for converting the text to speech.

2.1.2) Microcontroller

Microcontroller was the heart of this project or one can say it was the master as it controls the other devices so, the selection of the microcontroller would also be a challenging task. Microcontrollers were available from Microchip's PIC with a large range of size and features. In this project the priority was given to microcontroller which one can control the operation of the ISD board and synthesizing the speech within that microcontroller. If the microcontroller was smaller and light weight it would be better to keep the PCB small. Microcontroller with internal features like internal oscillator, interrupts would be better. Microcontroller should have the I/O pins for connecting to external modules. Before making any selection the size and power efficiency could be considered.

2.1.3) Speaker

It was a device which converts electrical signal in to sound. Speaker was commonly used to hear sounds. In this project the speaker should be used for hearing the synthesized speech in the output. A speaker was required for this project which would be small, light weight and it should have low impedance, low power ratings.

2.2) Speech synthesis methods:

Speech synthesis methods were used for converting the speech from the text. A synthesis method which was used in this project, it should be simple and easy to implement the system.

2.3) Serial communication to establish a user interface

A module would be required to establish a user interface to control the system. The system should be user control so it would be serially communicated with the host PC. RS232 and MM232r were used for the serial communication.

2.4) Software requirements of the system

Software program was necessary for microcontroller to control the system. MPLAB was the program development tool which can enable the user to write the program for the PIC microcontroller. MPLAB provided the C18 compiler for writing the program. The program was supposed to write for control the ISD board as well as to generate the synthesized speech.

2.4.1) Programming language, development and debugging tool

There were two popular languages (Assembly and embedded C) available for eight bit microcontrollers, any language can be used for this system. Embedded C was quite similar to the normal C language but only the difference was in embedded C programming the initializations and some special functions were used, on the other hand the assembly instruction set was different to the manufacture of the microcontroller from one to another. It was necessary before writing the program to know about the register set (SFR) of that microcontroller. A program could be written in their own way.

The software tool MPLAB along the C18 compiler was providing the assembler and compiler. Microcontroller did not understand assembly of the C program which was stored in the ROM of the PIC as a .hex file. The assembler and compiler can converts the instructions to the machine code. The MPLAB was also available the debugging features. By using the MBLAB ICD2 programmer and debugger kit the converted hexadecimal file can be loaded into the microcontroller.

2.5) Black box testing

The output of the system was depending on the corresponding input. For this system the input would be user commands and the output would be speaker. The black box testing should be done for the system.
 I. The system should be user interface with the system.
 II. The ISD board should be controlled by the microcontroller.
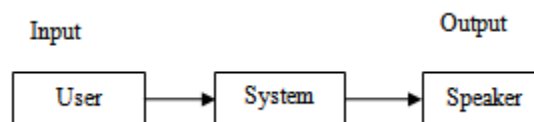III. The speech should be synthesized within a microcontroller.

Fig. 2.5 Black box testing of the system

III. Proposed Problem Solutions

Based on the hardware and software requirements as mentioned before Paper, the solutions were given for both hardware and software. According to the deliverables mentioned in the previous Paper, the first task was to control audio record/playback ISD board and second one was generate the synthesized speech within the microcontroller. The hardware and software solution were given below.

3.1) PIC18F1320 Microcontroller

PIC18F1320 was an 8 bit microcontroller developed by Microchip Company and it was power efficient because used Nano watt technology. This microcontroller was used in this project because it has external oscillator and many other features [30]. PIC18F microcontroller support enhanced USART module and supports RS485, RS232 and LIN1.2 which has auto baud rate and also auto wake up start bit. The microcontroller PIC188F1320 has four crystal modules (LP, XT, HS and HSPLL) and high computational performance. It could be works at high speed up to 16-40MHZ. So PIC18F1320 (Fig 3.1) was used rather than PIC16F series (it works at low speed). For more information about the PIC the references 30 and 27 were studied. It had two ports A and B and port B pins were used in this project. In this project the microcontroller was used to control the audio record/playback device and generating the synthesized speech.
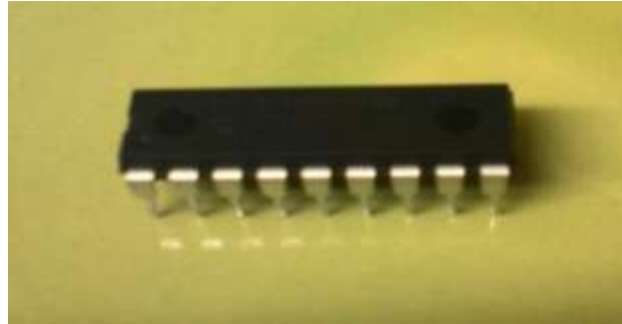
Figure 3.1: PIC18F1320

3.2) Synthesis method
Speech synthesis technologies can be broadly categorized into three categories. They were given below [29]:
- Concatenate synthesis
- Formant synthesis
- Articulator synthesis

3.2.1) concatenate speech synthesis:
In this technology the speech can be generated by linking pre-recorded speech segments to make syllables, phrases, or dip hones. Waveform segments were store in a database. It was the simplest method for speech synthesis [14].

3.2.2) Formant synthesis:
Formants were defined as "resonant frequencies that occur at the main resonant areas of the vocal tract for a given sound". It consists of artificial reconstruction of the formant characteristics to be produced.

3.2.3) Articulator synthesis:
Articulators were speech organs. It was based on computational models of the human vocal tract and it was a most natural sounding speech synthesis. But it was complex [4].
Finally concatenate method was identified, which was used for converting the speech from text [2]. In this project for synthesizing the speech a synthesizer was used. This synthesizer chip follows the concatenate method because it was a simplest method compare to other method.

3.3) TTS256 Synthesizer chip

Figure 3.3: TTS256 speech synthesizer chip

It was very hard to find out the synthesizer for this task because most of the synthesizers (WTS701, SP0256 chips) were not available in the market. Finally after a long searching TTS256 chip was available in speechchips.com. TTS256 was an 8 bit microprocessor and it was programmed with built in 600 letter-to-sound rule database. TTS256 speech chip was a 28 pin DIP and compatible with PIC, BASIC stamp, OOPic [33]. It can generate the speech code from ASCII text and it could be read English words, numbers and mathematical functions. For serial communication parameters it was set the baud rate 9600. The datasheet mentioned in the ref.[33] was studied. The host microcontroller can send up to 128 characters to the TTS256 chip via serial port on 18th pin (RX). The text which was entered by user was spoken when the TTS receives a new line character or the maximum number of characters (128) has been entered.

3.4) Speaker

Figure 3.4: Speaker

The speaker selected in this project, which was having the following feature.
1) It was small and light weight
2) It had low power rating (0.5W) and Impedance (8 ohm)

3.5) MM232R module

It was a single chip asynchronous serial data transfer interface. In MM232R module FT232RQ chip device was used and it can convert USB to RS232 / RS422 / RS485 converters. RS232 and MM232 were the two solutions for serial communication. MM232R was support for 7 or 8 data bits and one or two stop bits. The data transfer rates from range of 300 baud to 3 mega baud (RS422 / RS485) and 300 baud to 1 mega baud (RS232). It can support for bus powered, high bus powered and self powered USB configurations. RS232 was also used for serial data transfer [33]. If RS232 was used the MAX232 IC should be used for voltage levels, then the cost of the PCB will increase so MM232 was used instead of RS232. The signal voltage levels of the MM232 were in the range from 3.3v to 5v.
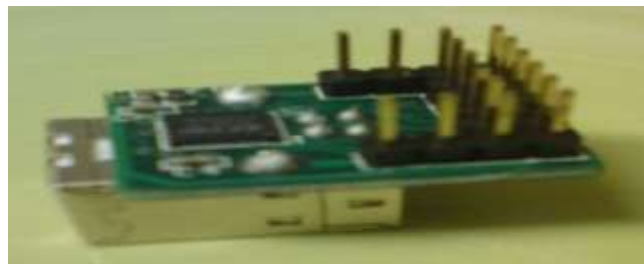
Figure 3.3: MM232R

3.6) Program language

Embedded C was used for the programming the PIC. MPLAB was used for writing the program of the control system as well as speech synthesis system. MPLAB IDE was windows based Integrated Development Environment for programming the microcontrollers. The MPLAB provided the ability to the users to create and edit the source code in the editor window. In MPLAB IDE software tool the C18compiler was available to assemble, compile and link the source code [31]. MPLAB ICD 2 debugger and programmer kit was used for load the hexadecimal code to the PIC18F 1320 microcontroller.

Figure 3.6: MPLAB program structure

Flow chart for control system
The operation of the audio record and playback system was explained in the form of flow chart. The flow chart for control system was shown in the following figure.
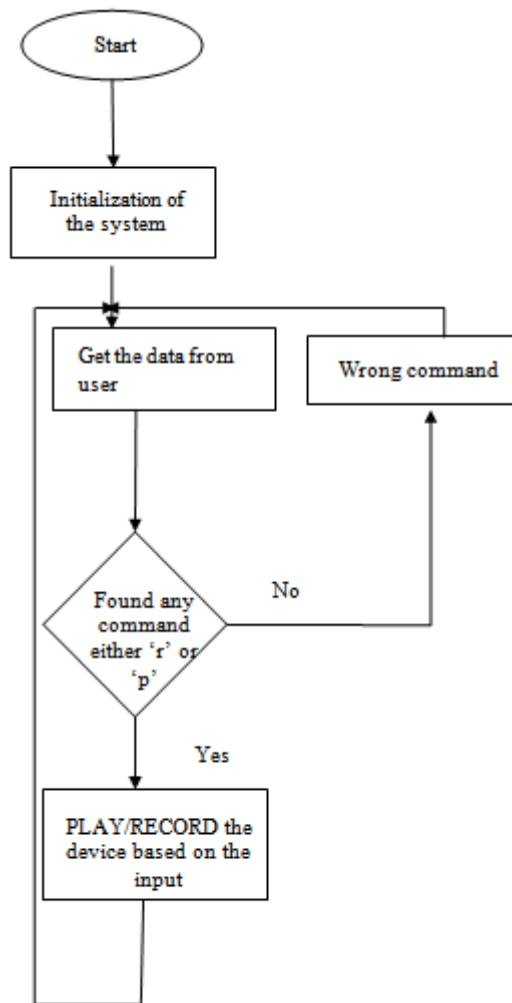
Figure 3.7: Flow chart for control PCB
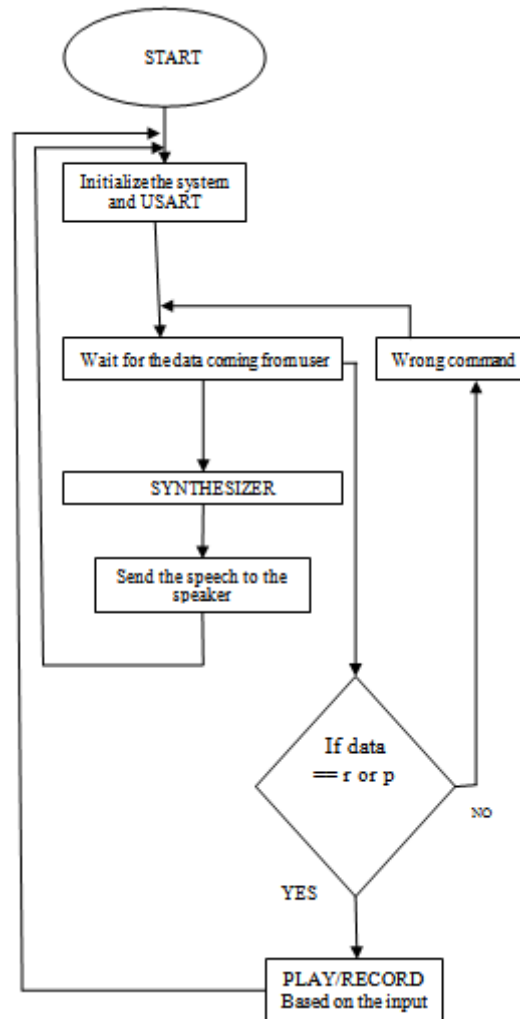
Figure 3.7: Flow chart for Speech Synthesis System

IV.   Problem Implementation

4.1 Hardware implementation of the control system
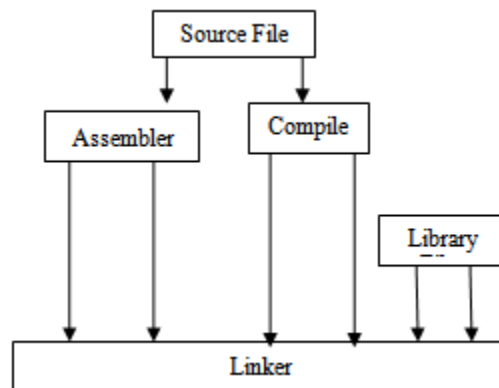
        The solutions for getting the hardware and software code of the system were explained in the previous Paper were finally implemented and explained in this Paper, for some of the hardware problems like stabilization more than one solution were given. The outcomes of some solutions were necessary to discuss at this at this as it was necessary to stick to one approach from here onward. According to the deliverables mentioned in the first Paper the primary aim was control the ISD board and second one was to generate synthesis speech system. The description of the hardware and software for these two tasks were separately given below. The software programs were developed and listed in the appendix for both audio record/playback system and synthesized speech system. Before implementing the control system to control the ISD board, the basic operation of the ISD 1420P device was explained below.

Figure 4.1: ISD1420P PCB

4.1.1) Working of the audio record/playback device (ISD1420p board):
The system was configured with microphone, on-chip oscillator, speaker amplifier, smoothing filter, and two push buttons. The PCB circuit device which was given by the supervisor was shown in the following figure 4.1.1(b). The ISD1420P device was used for audio record/playback system. The following operating sequence was demonstrated the working of chip device.

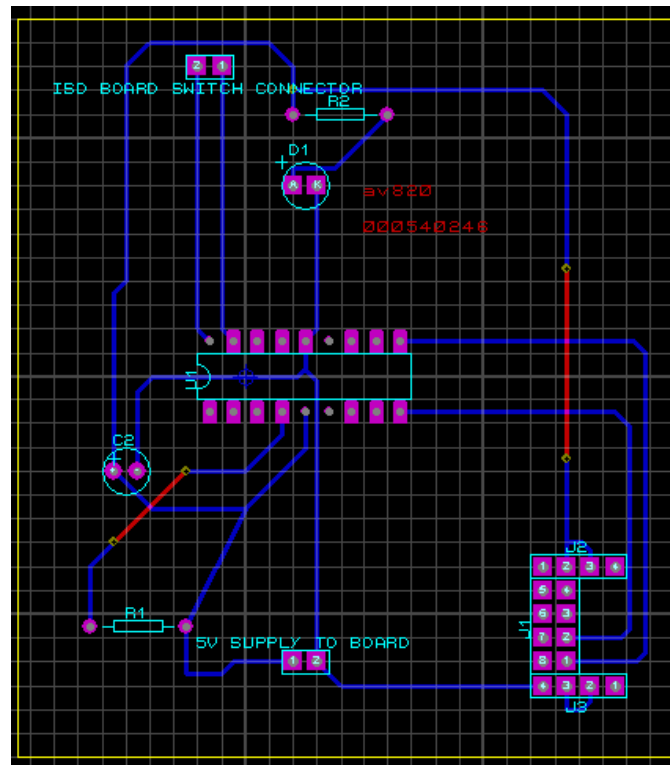**For recording the audio data:** The device which was having two push buttons, one for recoding the data and another was for play backing. When push button (REC) was pressed, then the REC signal LOW initiated a record cycle from the starting of the data space [28]. When recording process was beginning the red LED was glowing until the data space had been filled. Once the data space was filled then the recording was stopped. The power of the device was automatically down then the REC signal was pulled to high.

For playback the audio data:
When the push button (PLAY) was pressed then active low PLAY signal initiated a playback cycle from the starting of the data space which was recorded earlier. If the device was reached to EOM marker then automatically power was down. While the process was going on the green LED was glowing until and unless the EOM marker reached. [28]

4.1.2) Design of PCB for controlling of the Audio record/playback system
Without using of the PLAY and RECORD buttons the ISD1420 device should be operated. For this a control PCB was designed. The schematic diagram for controlling the audio record and playback device system was designed in Proteus ISIS. The Proteus ISIS professional provided the libraries for constructing the schematic designs. From the libraries picked the PIC18F1320, resistors (10KΩ and 330Ω), LED and capacitor then constructed the circuit for control PCB for controlling the ISD kit.

Figure: 4.2 Schematic diagram of Control PCB

The components PIC18F1320, resistors, LED and capacitor were available in the Proteus ISIS library but the component MM232R was not available in the list of Proteus ISIS so four pin connectors were used. The 10K resistor used for avoiding the PIC reset and LED was used for power indication. Some additional elements were also selected like 2 pin Molex connectors for power supply as well as for ISD board.
The following PCB was the implementation of the schematic discussed in the previous Paper. The PCB was designed for controlling the audio record/playback device in Proteus Ares software. The PCB layout of the audio record/playback system was shown in the following figure 4.1.2(b).

Figure 4.1.2(b): PCB layout of the control pcb system.

Operation of the control system

For controlling of the ISD1420 record/playback device the control PCB was designed. MM232R was used for sending data and receiving data [32]. The 5th pin of the MM232R was connected to 10th pin (RB4) of the PIC18F1320 for receiving the data and 7th pin of the MM232R was connected to the 9th pin (RB1) of the PIC for transmitting the data from the PIC. MM232R pins 2 and 3 were connected to 5v power supply. Based on the command received from the user via MM232R the PIC will control the operation of record and playback device. The RB2 pin of the PIC was connected to the 27th pin (active low REC) ISD board and RB3 pin of the PIC was connected to the 23rd pin (active low PLAY) ISD board. Whenever the user enter the letter 'r' on the HyperTerminal the MM232R send this signal to the RX of the PIC. Then the PIC send an active low signal to the ISD board, this active low signal (REC) was enable the pin then the will ready for recording. At the other hand the PIC was send the ISD device status (START RECORDING) to the MM232R, this message will display on the HyperTerminal window. Same way if the user entered the letter 'p', the PIC sends an active low signal to the ISD board then the device start to play. If any letter (except 'r' or 'p') the PIC was send the status as 'wrong command' to the MM232R.

4.1.4) Testing of the control system

The following hardware tests were done for the PCB.
1) For checking short circuit connectivity of the PCB initially the printed circuit board was tested without placing components.
2) After placing the components these individual pins were tested through digital CRO.
3) The power of the components was tested by using the multi meter.

HyperTerminal was used for creating a user interface to control the audio record/playback device. MM232R communication protocol was used for serial communication from host to the microcontroller for sending and receiving the data. For creating a serial communication, the required HyperTerminal settings were mentioned in the following figure 4.1.4(a).
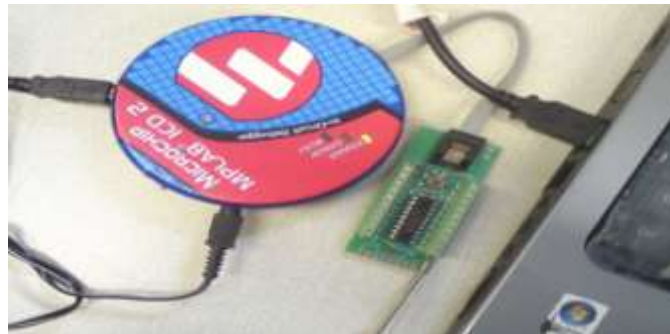
Figure 4.1.4(a): HyperTerminal window settings

Software implementation for control PCB

The PIC18F1320 microcontroller was control the operation of the audio record/playback. For this the PIC should be programmed, so the PIC C program was written by using MPLAB. To write the PIC C program in the MPLAB first selected the new project wizard option, and then PIC18F1320 was selected for microcontroller and C18 compiler was added. The complete PIC C program of control PCB was listed in Appendix. The PIC C program was written in a file save with extension of .C and then this file was added to the source file [27]. For clear explanation the whole program was divided as small sections. As the software code was going to be in embedded C so the initial sections of every C program have a header file followed by some declarations, definitions then the main and other functions. The MPLAB libraries provided all the header files [31].

Figure 4.2(a): Error free code for control system

Hence the program for control system was explained clearly and this PIC C program was compiled by using C18 compiler. The build succeeded program for the control system was shown in the following figure 4.2(a).

Figure 4.2(b): PIC programmed by using ICD2 kit

With the help of ICD2 kit the PIC was loaded to target device. The PIC was programmed on the ICD2 kit compatibility board. This process was shown in the following figure 4.2(b).

Using the MPLAB ICD2 debugger and programmer kit the program successfully loaded into the PIC18F1320. After completion of this loading process in MPLAB window the status of the ICD 2 kit was displayed and it was shown in the figure 4.2(c).
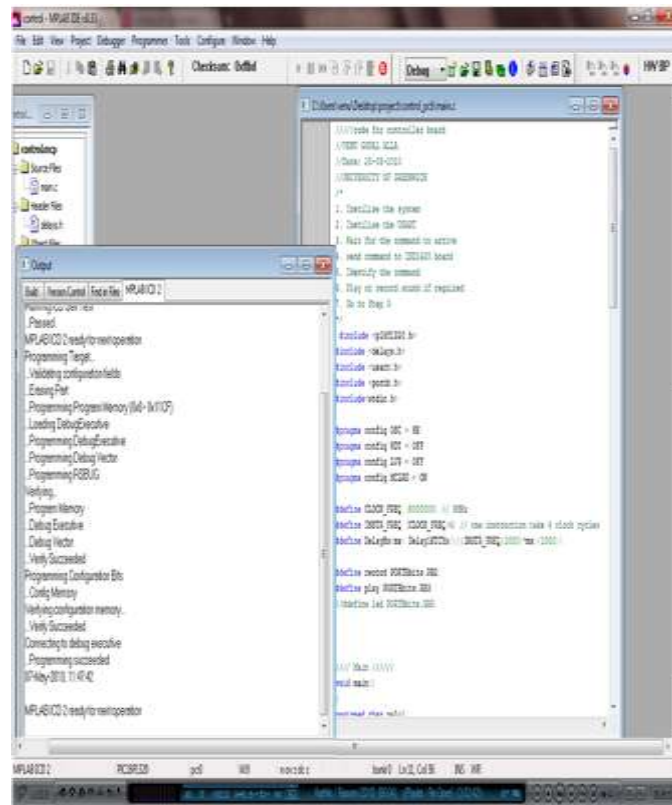
Figure 4.2(c): Successful loaded of the program

After loading the program into the PIC then the microcontroller placed on the control PCB. The complete hardware connections for control the audio record/playback system was shown in the following figure 4.2(d).

4.2 Hardware implementation for synthesis speech system

      The main aim of the project was to generate the synthesis speech within a small microcontroller. The schematic diagram for synthesis speech system was designed in Proteus ISIS. The Proteus ISIS professional provided the libraries for constructing the schematic designs. The main PCB was could handle the both systems those were it could control the ISD board and it could be generate the synthesis speech within a microcontroller. The main PCB would reduce the cost of the cost and PCB area. The schematic diagram of the speech synthesis system was shown in the following figure 4.3(a).

      To develop the system the required components were selected by using Proteus ISIS professional software. The component PIC18F1320, resistors, LED and capacitor were available in the Proteus ISIS library

but the components MM232R and TTS256 synthesizer chip were not available in the list of Proteus ISIS so collection of four pin serial in line connectors were used for MM232R and four serial in line connectors were used for construct the TT256 chip. The 10K resistor used for avoiding the PIC reset and LED was used for power indication. Some additional elements were also selected like 2 pin Molex connectors for power supply as well as for ISD board.

Figure 4.2(d): Complete hardware connections of the audio record/playback system
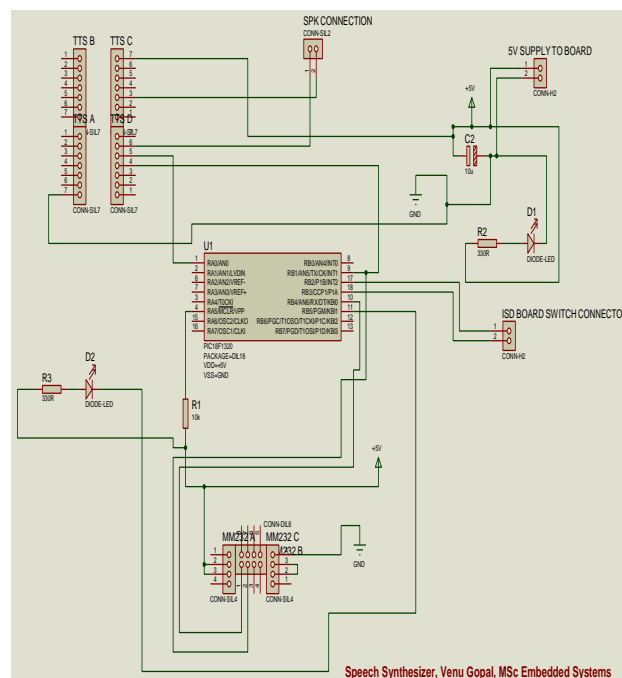
Figure 4.3(a): Schematic design for synthesis speech system

Pin allocation for microcontroller

Detail	Pin No.
Indicator	Pin B5
MM232R Rx, TTS256 Rx	Pin B4 (Rx)
MM232R Tx	Pin B1 (Tx)
Recording	Pin B2
Playing	Pin B3

Software implementation for Speech synthesis system

The PIC18F1320 microcontroller was used for generating the synthesis speech system. For this the PIC should be programmed, so the PIC C program was written by using MPLAB. To write the PIC C program in the MPLAB, first selected the new project wizard option, and then PIC18F1320 was selected for microcontroller and C18 compiler was added. The complete PIC C program of the speech synthesis system was listed in Appendix B. The PIC C program was written in a file, save it with extension of .C and then this file was added to the source file. For clear explanation the whole program was divided as small sections. As the software code was going to be in embedded C so the initial sections of every C program have a header file followed by some declarations, definitions then the main and other functions. The MPLAB libraries provided all the header files.
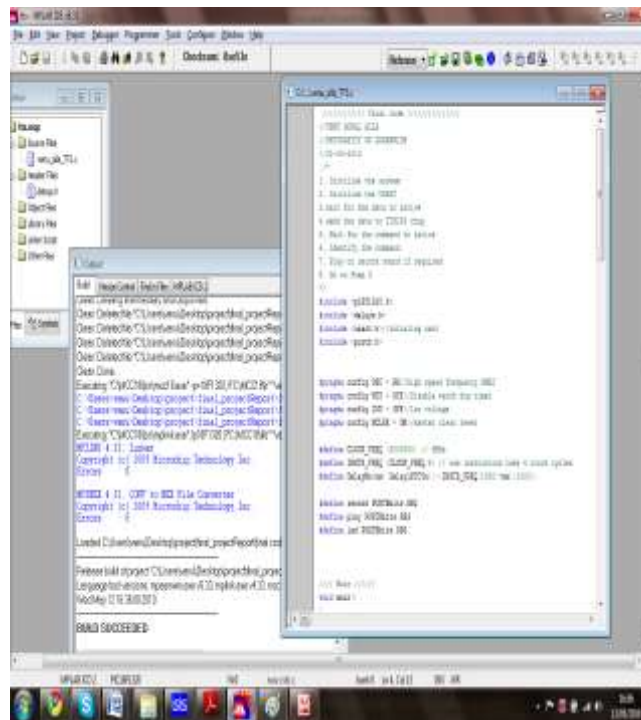
Figure 4.4(a): Error free program

The above program was loaded in to the PIC18F 1320 microcontroller with the help of MPLAB ICD2 debugger and programmer kit provided by the university. The following figure 33 was show the message after loading the program in to the PIC.
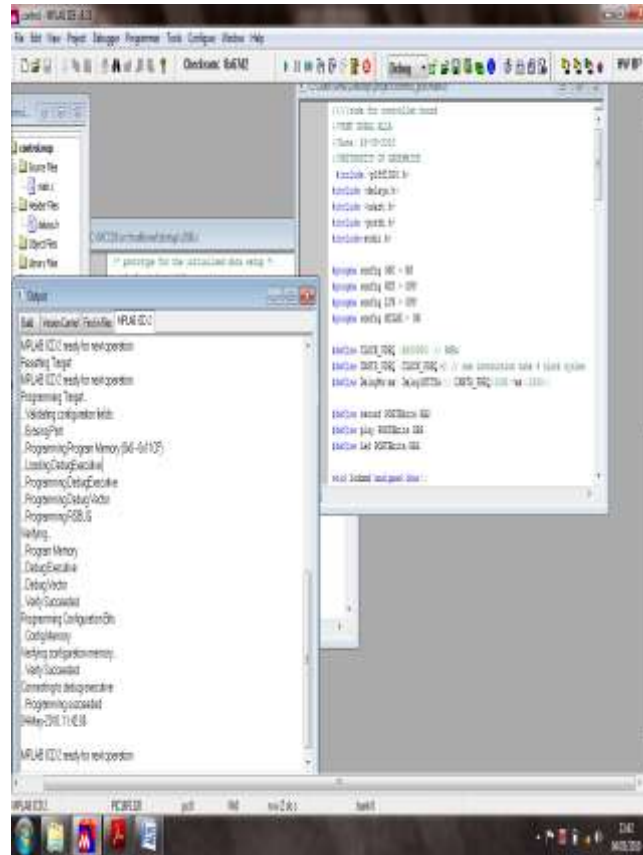
Figure 4.4(b): Successful loading of the program

Working of the speech synthesis system

HyperTerminal was used for creating a user interface to control the ISD board and synthesis speech system. MM232R communication protocol was used for serial communication from host to the microcontroller for sending and receiving the data. For creating a serial communication, the required HyperTerminal settings were mentioned in the following figure. After loading the program into the PIC then the microcontroller placed on the synthesis speech system PCB. The complete hardware connections for the speech synthesis system were shown in the following figure 4.5(b).

MM232R serial communication module was used for user interface. The user could write the text on hyper terminal window, the corresponding speech will be produced by the speaker. Two LEDs were used in this system one was for power indication (+5V) and second one indicates whether the program was loaded in to the PIC microcontroller or not. The resistor 10K ohm was used for avoid the reset of the PIC.
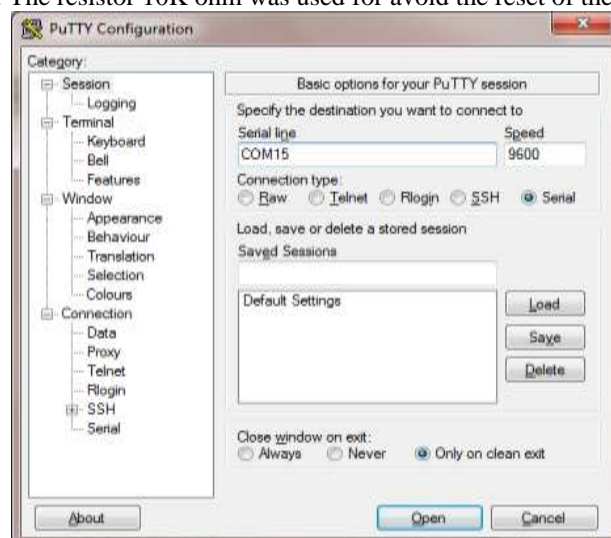

Figure 4.5(a): Hyper terminal settings for serial communication

The final PCB would do the both tasks. The data which was entered on the hyper terminal will send to the 10th pin (RX) of the PIC18F1320 microcontroller then the received data will sent to the 18th pin (RX) of the TTS256 synthesizer chip. The TTS256 synthesizer chip can convert the data which was sent by microcontroller to speech. The 24th pin of the TTS256 chip was connected to the speaker, 14th pin was connected to ground and 28th pin was connected to 5V power supply. The text which was entered by user was spoken when the TTS256 chip receives a new line character or the maximum number of characters (128) has been entered. By using this PCB the ISD board was also controlled. If the user entered the letter 'r' on the hyper terminal, the microcontroller will send the active low signal to the ISD board then the ISD board start recording the voice. Simultaneously when the user entered the letter 'p' on the hyper terminal, the microcontroller will send the active low signal to the ISD board then device could start playing the sound which was previously recorded in the ISD chip.

V. Results

In this Paper the system outcomes were explained clearly. Initially the control PCB was designed for control the audio record/playback device (ISD board). The main task of the project synthesis speech systems results were given and explained in the last section.

5.1) Results of the control system

Based on the command which was entered by the user on the hyper terminal the microcontroller controls the ISD board. When the user entered command 'r' on hyper terminal then the microcontroller send the active low signal to the ISD board the system starts recording. The microcontroller sends the status of the ISD board to the 7th pin (RX) of the MM232R and it was displayed on the hyper terminal. The red LED of the ISD board blink until the system recording the voice. The following figures (5.1(a) and 5.1(b)) were show the process of the system.
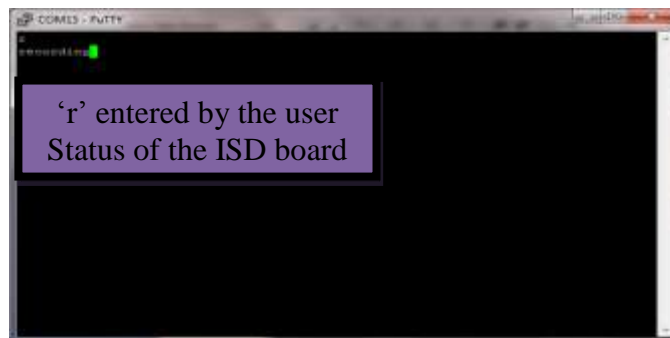

Figure 5.1(a): Computer received the data from the PIC when the system starts recording
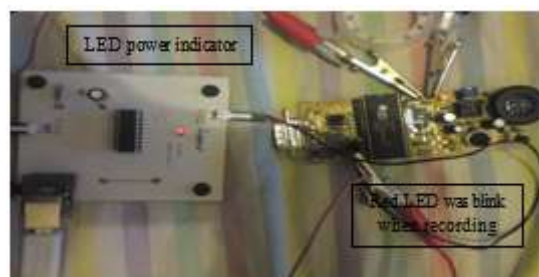

Figure 5.1(b): ISD board when recording the voice

Same way when the user entered the command 'p' on hyper terminal then the microcontroller send the active low signal to the ISD board the system starts recording. The microcontroller sends the status of the ISD board to the 7th pin (RX) of the MM232R and it was displayed on the hyper terminal. The green LED of the ISD board blink until the system would play the voice which was stored previously in the ISD1420P. The following figures (5.1(c) and 5.1(d)) were show the process of the system. When the user entered wrong command then the PIC would send message to the computer and it was displayed on the hyper terminal as "wrong command".
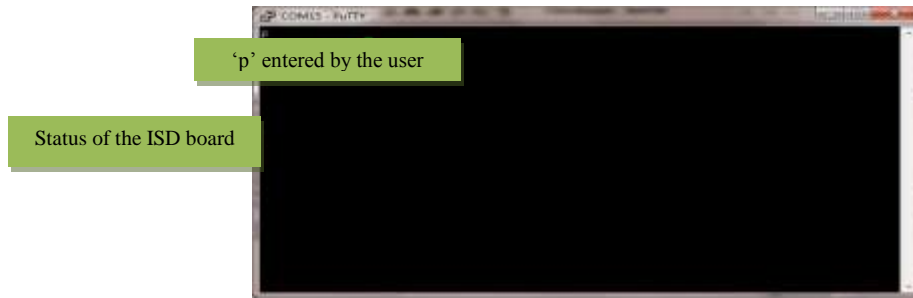
Figure 5.1(c): Computer received the data from the PIC when the system start play

Outcome for the speech synthesis system
The final PCB which was the main PCB, designed for the controlling of the ISD board and synthesis speech system. The following figure which was shows the two LED indicators, one was for power indication and another one for checking the PIC programmed or not.
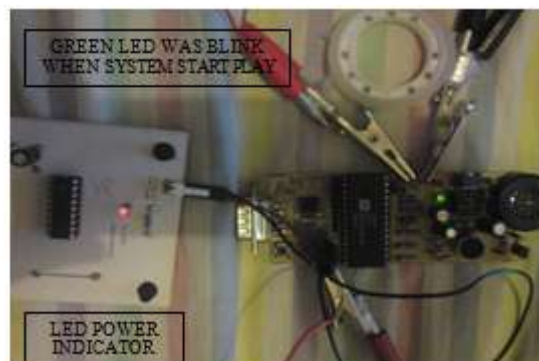

Figure 5.1(d): ISD board when playing the voice

Figure 5.2: The speech synthesis system

In the above figure show the LED power indicator was blinking so the 5V power was coming to circuit. Second one was also blinking so the program was also loaded into the PIC. According to the software program the LED blinks up to 55msec but the LED was continuously blinking. Also when the user trying to enter any character on the hyper terminal window and it was not displayed and also the output speech was not coming from the speaker. The system could not work because the software might not match with the hardware connections of the system or might be problem in the software code. Many changes were done in case of modifying the software code as well as in hardware some connections was changed.

VI.   Discussion On Results
Well the results of the complete system were as expected, but in sometimes it was not picking up the commands entered by the user through the hyper terminal. There was some problem with the playback of the sound possible causes may be compatibility issues of TTS IC. The Embedded C program was logical right and

there were no compiling errors. There was no RJ45 connector on the target board so it was not possible to get the live debug simulation on the MPLAB.

The sound of the speaker was not that good may be because of the quality of the device, but on the other hand it was also not possible to attach a bid speaker directly to the TTS IC as it cannot supply the required source current. Behavior of complete system was good system was capable of doing task to some extent for what it was designed to. With this technical discussion for this project comes to an end.

VII.   Conclusion

After going through this task it was evident that to develop complete system even if its looks simple at first look lots of effort and dedication is required. Various fields required to be combined like good software knowledge, electronics and analytical skills. Sometimes a simple appearing task may take a long time to work accordingly, as happened while tried to achieve a proper communication between microcontroller and the TTS IC. Every element is required to be looked after. Analyzing why something fails or did not worked as required helps a lot and makes the vision clear brings success closer and enhances knowledge.

The work on the project was quite satisfactory, but still there were some shortcomings like sometimes system was not working at all, so some changes are suggested in software and electronic design. Another major addition that could be done in future design is the addition of on board debugging mechanism to attach the ICD kit to the main board this could be easily done by adding a RJ connector. Various features like audio filter circuit which would only allow the audible frequencies to pass to the speaker could be added along with some amplifier and volume control.

In the embedded program additional commands could be added like for volume control, the duration for which TTS is required to be in play or record mode. Some features like to monitor the errors on the system could be added and if any error occurs then could be displayed on the hyper terminal, and even intimate the user by producing speech from the TTS. There is no limit as such to the additions that could be done in the future to this system as the developed project is just the basic one so many enhancements are possible.

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