IT CZARS

IMAGINE CUP EMBEDDED DEVELOPMENT

SUNOH

Listen Learn Belong...

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1. Motivation

'Sunoh' means to listen in Hindi. Listening is considered the first step to learning. Robert Frost had once famously said,

> ***"Education is the ability to listen to almost anything."***

We disagree. We do not believe that the ability to listen has anything to do with education. We have seen our team member learn without listening over the past years. We have seen it even closer during the Imagine Cup. You do not need the ability to listen to learn, you just need a will to learn.

With Sunoh, we present a system that would help people to learn even if they cannot listen. We try and make the process a little easier for them. Sunoh is a tribute to the thousands of courageous people like our team mate who have the will to learn despite all odds. It is a humble attempt by the team, to enable people with hearing and speech impairment to learn. Through Sunoh, we hope these people won't have to struggle as much as our team mate had to. Education for them may still remain a tough journey, but listening to the teacher and interacting with her would not be a problem with *Sunoh.* Let's Listen, Learn and Belong.

The report is organized as follows. We first discuss the basic idea of our project in section 2. It follows with a pictorial representation of the system and a brief system overview in section 3. Each module is discussed in detail separately in the section 4. This is then followed by a brief discussion about cost analysis of the prototype and the final product in section 5. We then discuss the Marketing aspects of the system in section 6. We have a look at the team organization in section 7. Section 8 discusses the present status of the project. The report is concluded in section 9 and references are given at the end.

2. The Idea

Like all technologies should be, the idea behind Sunoh is simple. We use Speech-To-Text technology to convert a teacher's spoken words into text and direct it to a Hearing Impaired students' laptop or PDA. Likewise, a speech impaired student's queries are converted from Text to Speech and directed to a teacher's headpiece. This way, hearing and speech impaired students can study at almost the same pace as other normal students. Being taught with the so called *'Normal'* students, this system provides a student with a sense of belongingness to the school and in turn to the society as a whole.

Installing an embedded system inside each classroom provides a cost-effective solution. Since it uses a Real-Time system, the processing delay is marginal. The small size and use of the wireless technologies makes sure it is too small to be visible. Since, the system works in the controlled environment of a class-room; and with proper training of the speech recognition software and control of environmental factors like ambient noise, good levels of Speech to Text conversions are achieved.

This system is the best way to bring Speech Processing capabilities inside a classroom. Though the ultimate aim of such a system should be to be able to move around with the user and provide perfect performance in even noisy conditions. But the capabilities of Speech Processing Technology are limited and such a system is not possible at least for now and is expected to elude us for some time to come. Till such a perfect system is developed, we feel that our system will provide a complete, good performance alternative and would be highly useful to the students who suffer from speech related impairments.

Sunoh, we feel would impact the life of thousands of students around the globe. It would throw open the gates of all educational institutes to these students. Moreover, for universities and educational institutes this would be the first step towards the elusive aim of inclusive education where everyone can come and learn irrespective of his physical and social characteristics. In addition, having such system improves upon the public perception of a university.

3. A Discussion about Innovative Aspects

Speech conversion is considered as the holy-grail for helping hearing and speech impaired people. Though a lot of research (Lovejoy) has been done in this area but a ready to implement system has not been developed yet. There are quite a few reasons behind this:

1. Researchers aim at developing a system that would be the perfect help for hearing impaired people. That is, a system that would work everywhere and in general day-to-day life. Unfortunately, this is not possible yet. The rapid conversations and different accents are a problem with such a system.
2. Other problems of varying difficulty include such things as dysfluencies, repeating words, or saying “um’s” and “ah’s”, or coughing and sighing, things most of us do.
3. The system is not trained by the speaker.
4. Environment problems such as background noise

Sunoh, on the other hand circumvents these problems on the following counts:

1. It aims at environment of class-rooms which can be controlled for environmental effects.
2. Teacher can train the system before-hand which would lead to lower error-rates.
3. Teacher can be careful and speak in a manner which leads to lower error rates avoiding as many dysfluencies as possible.
4. And lastly and perhaps the most important, the student would have other resources such as visual presentations, black board presentations etc. Even when the error rates spike to

more than normally acceptable limits, a student knows what the teacher is talking about. In fact, the student can correct the system and improve its performance.

Hence, our system uses existing technology to solve an existing and serious problem. Since we are able to narrow down our field of implementation, we are able to get much better results. We hence provide a better solution in a targeted environment.

4. System Overview

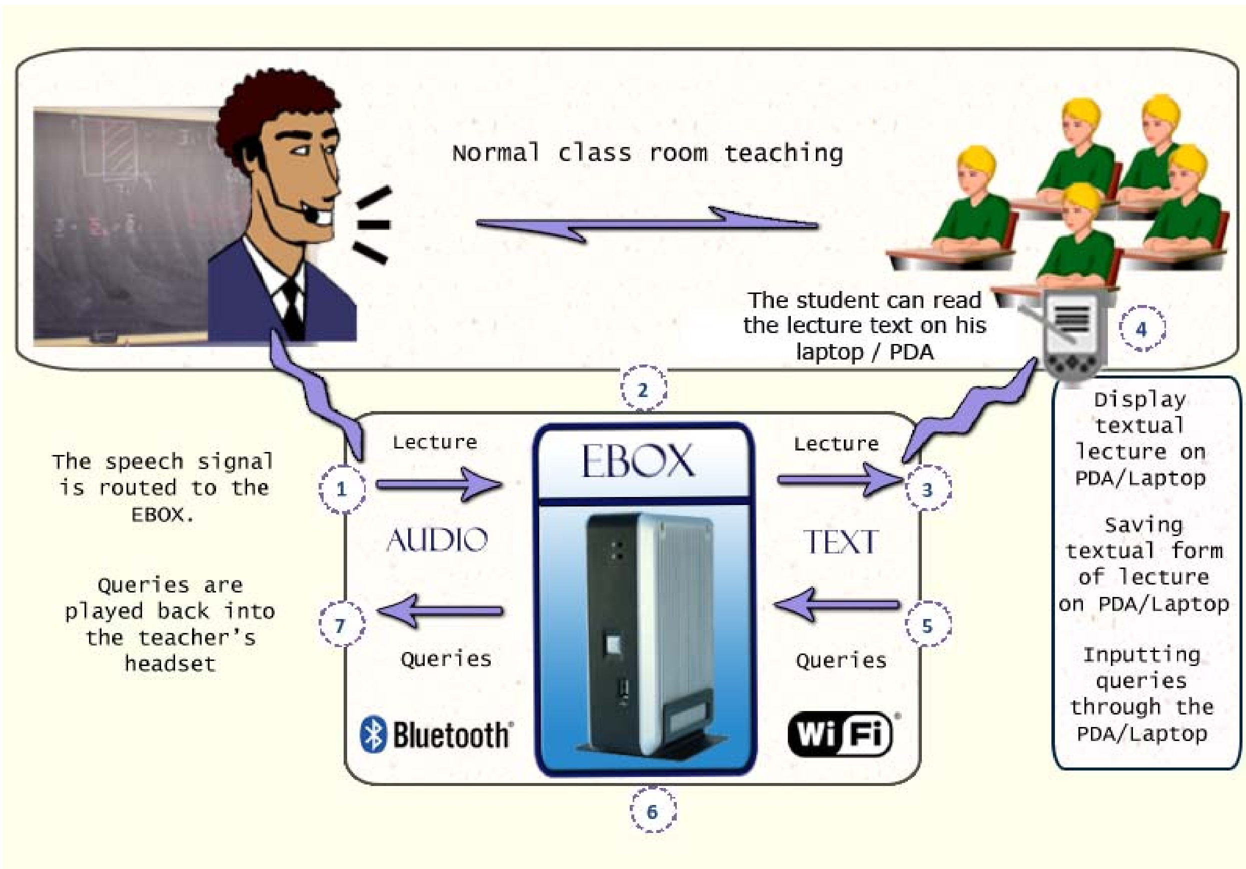

Figure 1: Overview of the system

Figure 1 shows the overview of the system. Various steps shown in the figure are explained below.

1. The lecture from the Teacher is routed to the eBox 2300 via a Bluetooth headset. We use a Bluetooth 2.0 headset and a Bluetooth USB dongle to connect it to the eBox 2300 which runs on a custom built Windows CE 6.0 image.
2. The lecture is converted to text using a speech-to-text conversion. This is done 'on-the-go' with minimum delay to guarantee the required Quality of Service (QoS).
3. eBox routes the lecture text to the students over the Wi-Fi. We use an IEEE 802.11a/b/g supported USB dongle for connectivity.

4. A PDA/Laptop application displays the lecture text in the display area. The application is developed using C#.NET and has an intuitive GUI. The text auto-scrolls and gets automatically saved in a new text file “C:\Lecture Notes\Lecture Text *i*.txt” for each session, where *i* is an integer.
5. The queries typed by the user are routed back to the eBox again using Wi-Fi.
6. The text query received by the eBox is converted into speech using the Speech Processing module.
7. eBox plays this audio file over the Bluetooth connection into the headset that the teacher is wearing allowing her to listen to the query.

5. System: A Detailed Description

From the very beginning, we were able to divide our system into various separate well-defined modules. This helped us immensely since we could use a Black Box approach. This also made the work division easier. Hence, it makes sense that we use the same approach to discuss the technical details of the system. Figure 2 gives an overview of the modules and how they interact with each other.

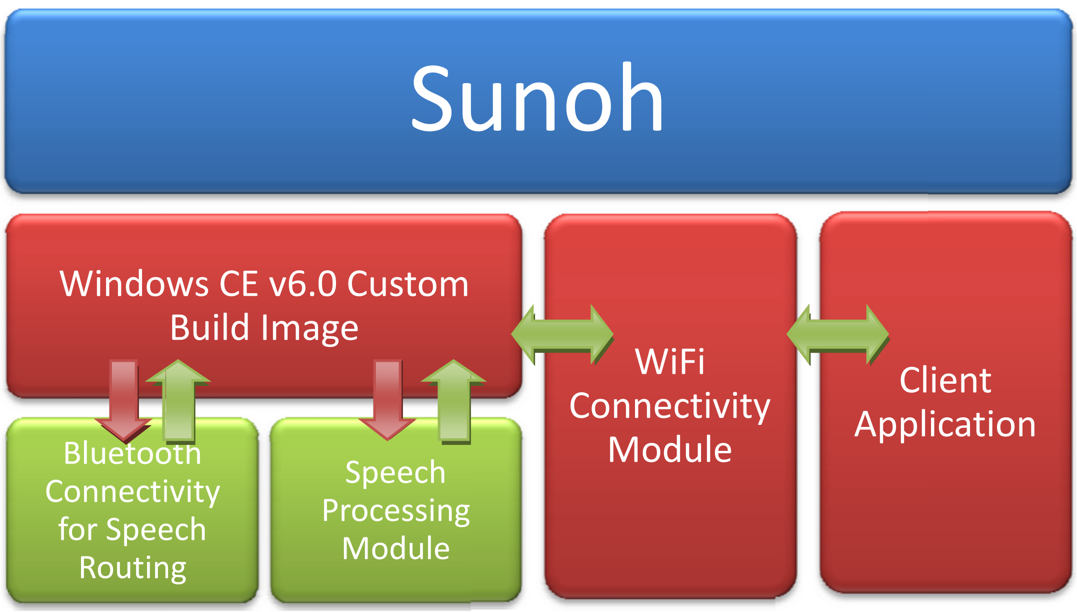

Figure 2: System Architecture

The modules are discussed separately in this section. We also try and justify our choice of technology for each module and discuss why we choose it over other available options.

5.1 Bluetooth Connectivity Module

Routing teacher’s lecture to the eBox was the first step towards designing the system. A prime requirement for good speech processing is that we route good quality, noiseless speech to the eBox at a high baud rate.

We had two major choices: Analog Wireless MIC / Headphones or Bluetooth Headphones. Wireless MIC was an attractive choice since it is already used in many universities (including ours) for amplifying the voice of the teacher in case of bigger classrooms or conferences. Bluetooth Headsets on the other hand provided a cost effective alternative to Wireless Mics. In addition, Bluetooth headphones were considerably cheaper and also hidden from the view of the public. Moreover, they consume low battery power and are easy for the teacher to manage.

Since Windows CE 6.0 supports Bluetooth handsfree profile, we decided to use Bluetooth. In order to connect with the Bluetooth mic, we are using the sample application btagconfig (Microsoft) which takes various parameters from command line. This application makes use of the Audio Gateway Core Component IOCTLs. We call it to connect our Bluetooth audio device to the eBox when the eBox is powered on.

The btscond audio driver for routing audio into software is being used in our project and an application has been developed which records the data coming from the audio device into a wav file. The audio recording is done by an application closely modeled on the lines of wavrec. (Microsoft) The duration of the audio recording can be easily varied and it is closely linked with the delay and performance of the system. This would be done away with when we implement the Speech to text processing on the eBox itself. The speech engine will take data directly from the audio device.

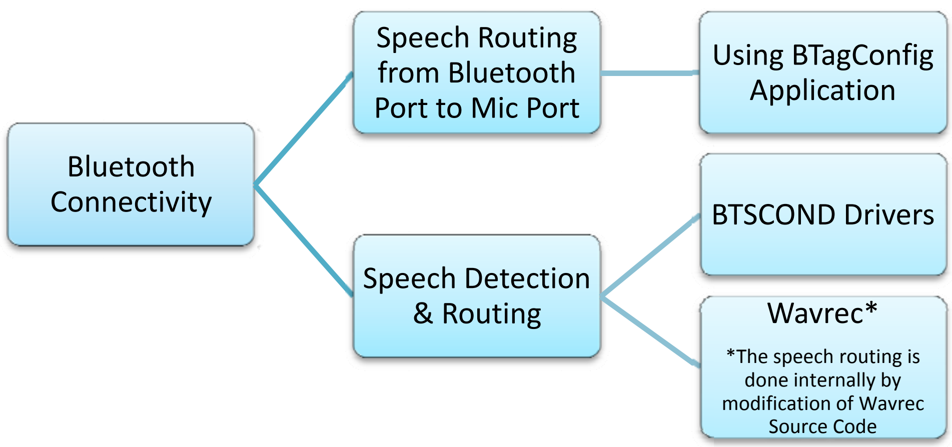

Figure 3: Bluetooth Module

5.2 Speech Processing Module

Speech processing is probably the most important module of this project. We decided to use a *Speech Processing Server* and connect it with the eBox over the Ethernet as a *proof-of-concept* for our application. We aim to integrate this server with our device in the near future. On the other hand, even if the system goes into production today, since we would use a single server to service a number of eBox in different classes, the increase in the cost per system is only slight. In addition, the delay in routing the sound to and from the server is within limits of providing a Quality of Service to the user.

5.2.1 Text-to-Speech

The speech processing server uses Microsoft's Speech Processing APIs (SAPI) 5.2 for Speech-to-Text and Text-To-Speech conversions. With the Microsoft's Speech Processing API, it was not too difficult to develop this module. The text obtained from the clients is used by the TTS engine. We just created an instance of SpVoice class and used its Speak method. The speech is made using a set of pre-defined attributes such as volume and rate and is spoken in the default Microsoft voice. This speech stream is stored as wav file which is then sent over the network to be played into the headset of Professor.

5.2.2 Speech-to-Text

For the STT part; we used the wav files from the eBox as inputs to the speech processing engine. We use an input stream to capture from the wav file and the converted text from the speech engine is sent back to the eBox Wi-Fi Module which multicasts it to all the clients.

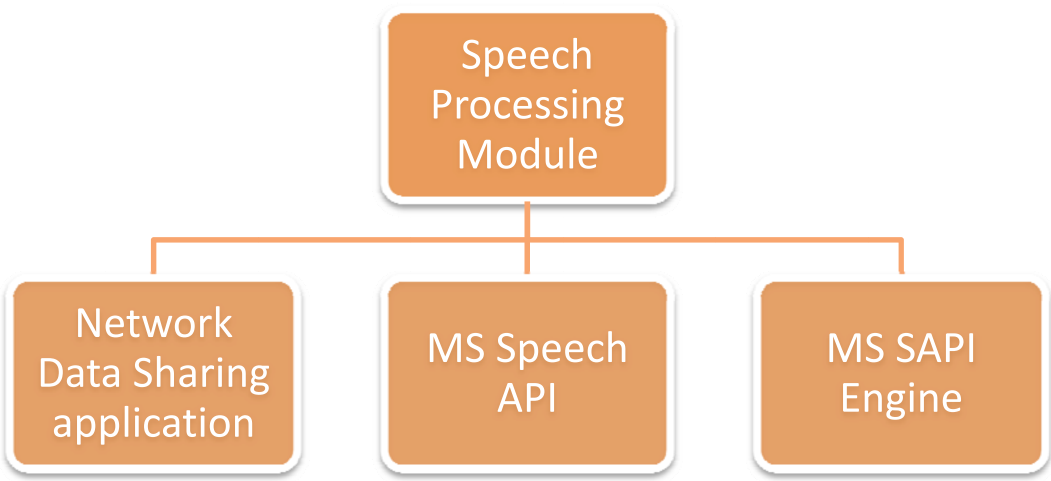

Figure 4: Speech Processing Module

5.3 Windows CE 6.0 Image

The application runs a Microsoft's Windows CE 6.0 image as stated earlier. CE 6.0 is an ideal platform to use in our system:

1. **Real time operating system:** Though we need only need soft real time processing for providing certain guaranteed Quality of Service (QoS) to the user, its performance is very impressive. The real test of the system would be when we are able to integrate Speech Processing on the local device, but we are sure of even better performance since that would cut the routing delay.

2. **Bluetooth / Wi-Fi Support:** Bluetooth and Wi-Fi are inherently supported by Windows CE 6.0. This substantially decreases the development time and efforts. Since a number of

sample application codes are available on MSDN, it was very easy for us to develop applications and integrate these technologies into our system.

3. **Speech Processing APIs:** Windows CE 6.0 supports Microsoft's Speech Processing APIs. Though we were not able to use this capability, as discussed before, but we are sure that this would be very helpful while integrating Speech Server with the device.

5.4 Wi-Fi Connectivity Module

Our system uses Wi-Fi to route the lecture text to and queries from the user to the eBox. This was an easy choice given that Wi-Fi is supported by Windows CE 6.0 and is supported by most modern day Laptops and PDAs.

We are using *MultiCommFramework* (Wilson, 2004) for this module. This framework supports multicasting without the use of a router. An application can don one of the two roles- Listener and Client. We will be using the role of a listener on the eBox while the PDAs or the laptops of the students will act as clients. Listener is responsible for tracking the list of registered clients and distributing information sent by any one of the clients to the others. In addition to the distribution responsibilities, the listener also acts as a client and can send and receive messages just as any other client. All information is sent via UDP datagrams as connection-oriented protocols such as TCP do not work well if network connectivity is intermittent as is often the case with wireless networks.

The application residing on the eBox uses an instance of *MultiCommListener* class and specifies an integer port on which it will listen and a port at which clients are listening. When the application starts it broadcast an invitation message for any running clients to connect to this listener. Afterwards, the application downcasts to a *MultiCommClient* and sends the speech-to-text converted lecture to all the participating clients. Also, the application receives queries from the students and sends them to the speech processing module. This application starts up automatically whenever we boot into the system and sets up the required infrastructure for communicating with the clients.

5.5 Client Application

The client application running on the user's laptop is written using C#.NET. It is a simple application with an intuitive GUI. The lecture text from the teacher is displayed in the display area. The text auto-scrolls and is automatically saved as a text file for the user to reference later.

The client application is running an instance of a *MultiCommClient* class and after instantiation and starting up; the application starts listening for incoming messages. When it gets an invite message; it identifies the IP address of the listener and the port at which it will be listening to. We have also provided a join conversation button which allows the client application to proactively ask for an invite to join into the conversation. Once connected to the ongoing conversation the client will start receiving the lecture-text and will be able to ask questions. A snap-shot of the application is given below. This application works in conjugation with the chat server running on the eBox.

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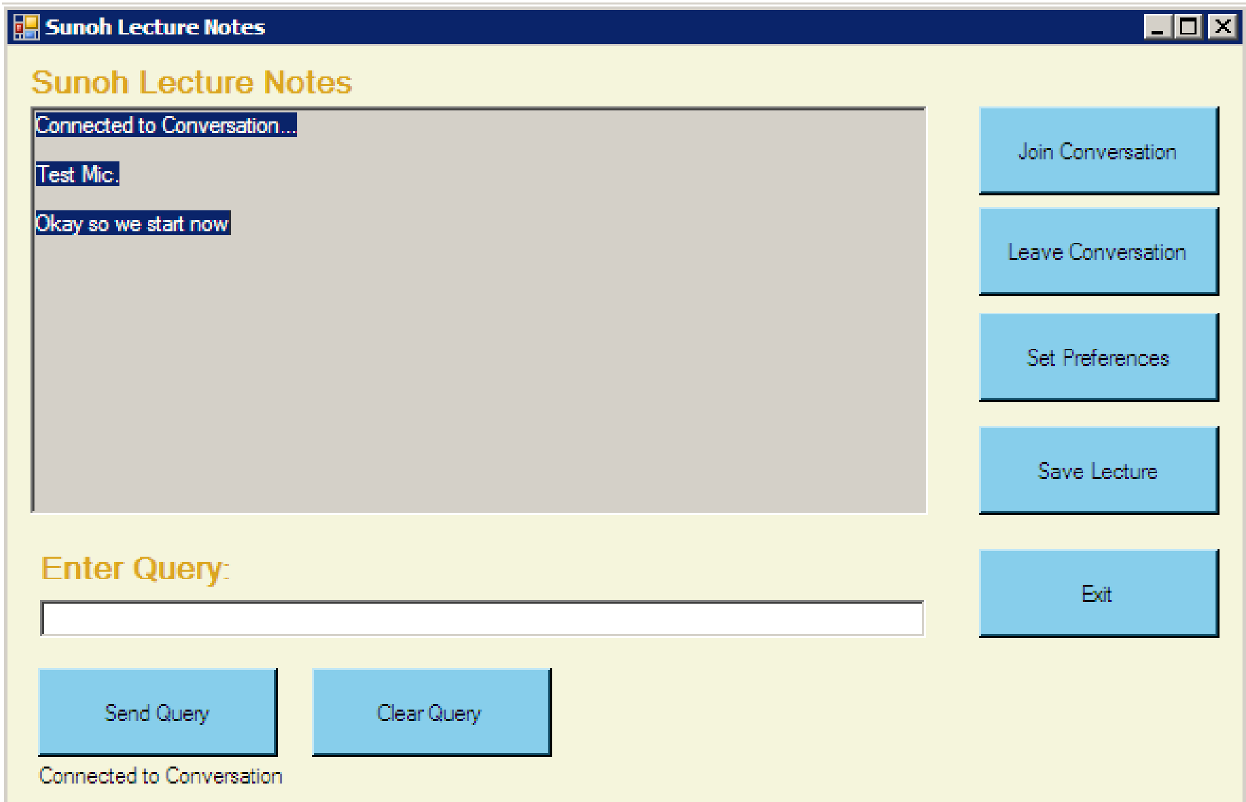

Figure 5: Client Application to display Lecture Notes

The client application is running an instance of a *MultiCommClient* class and after instantiation and starting up; the application starts listening for incoming messages. When it gets an invite message; it identifies the IP address of the listener and the port at which it will be listening to. We have also provided a join conversation button which allows the client application to proactively ask for an invite to join into the conversation. Once connected to the ongoing conversation the client will start receiving the lecture-text and will be able to ask questions.

This application will auto-save the lecture text so that a student can go through the finer points of the lecture later in his free time. The GUI of the application has been kept simple. Click on Join Conversation to participate in a lecture. The user can send his queries and comments by typing them and pressing the send button. One can leave a lecture by clicking on Leave Conversation.

We have also written a similar application for PDAs running on Windows Mobile 5.0. It has similar capabilities but a different GUI to suit its reduced screen size. We have not tested the application on a PDA yet but it is running well on the emulators provided in Visual Studios 2005. A screen-shot of the application running on a laptop is shown in Figure 5.

6. Performance Requirements

From the student's viewpoint it is highly desirable that a high accuracy of speech to text conversion rate is achieved. Poor conversion rates can be compared to reading a book with many words missing or wrongly printed. The entire meaning of a sentence can change when words are not recognized properly. It is also required that the latency or the delay in speech processing is minimal. The student must be able to study at the same rate as other students in the classroom. We must also consider how effectively the text to speech engine is able to handle shorthand words, e.g.: the student might use SMS language in typing his queries. The following factors can be used to study the performance of the system:

1. Accuracy of Speech to Text Conversion.
2. Accuracy of Text to Speech Conversion in cases of shorthand words.
3. Speech processing and other network delays.

7. Design Methodology

After the careful analysis of the requirements through various brainstorming sessions and talks with our mentor, our team came up with a unique design for the project. We divided the whole project into various components as shown in Figure 2. The components have been designed to act as black boxes to each other with only data being passed between the components. As the system is distributed over many different machines; it was critical to have no inter-dependence among modules.

These components were pursued separately with each team member taking over the responsibility of one component and helping another team member with the development of another. All the modules were made separately and tested on the machine they were supposed to run on. Since, some of the functionalities were not supported by emulator we had to directly test it on the hardware. However, the development process was helped a lot be the shared source codes and libraries provided by Microsoft.

8. The End User

There are basically two end users of our system-universities and students. This section describes their expectations and how our system fulfills these requirements.

8.1 Universities

From the university's view point the system should satisfy the following requirements:

1. ***Cost Effectiveness***: The system is extremely cost effective as discussed in Section 10 of the report.

2. ***Ease of Installation***: One of the major reasons of using an eBox is its portability and ease of install. Moreover, as our system is using wireless technology there will be no clutter of wires and a Bluetooth headphone is something that a professor can easily carry around with him.
3. ***Ease of use***: The system is designed with this requirement in mind. A teacher has to just power up the eBox and his Bluetooth headphone before the start of lecture and the system starts working. The eBox automatically loads the required applications and starts the system.

8.2 Students

After our initial surveys with various hearing impaired students we found out that students have the following expectations from the system:

1. ***Performance***: The performance of the system's speech processing engine is one of the major requirements. It has been seen that the system gives optimal performance with students being able to understand the subject better by using this device.
2. ***Ease of Use***: As shown in Figure 5, the GUI of this application has been kept exceedingly simple. We have eliminated the use of menus and the buttons kept at the right hand side provide the required functionality.
3. ***Extra Functionality***: The system provides the feature of storing the transcript of the lecture in text format which is extremely useful even to the normal students as they can concentrate more on understanding rather than wasting time on taking copious amounts of notes.

Apart from this, we plan to make the client application freely available to all the students over the internet.

9. System Testing

It is extremely important to have an error free system design for successful and easy implementation of the system. We followed formal testing techniques to review our design logic before we started the coding stage. There were many issues that we were able to identify as potential risks. We describe the verification and validation testing stages in the following sub sections.

9.1 Verification Testing

- CE 6.0 supports Microsoft's SAPI 5.2, (Microsoft). We had originally decided to use it for developing a local Speech Processing Application. Unfortunately, the signal processing engine was not provided to use these APIs. We had a long and intense discussion over this matter. We also attempted to port Pocket Sphinx (Huggins-Daines), a speech processing engine developed by CMU's Speech Processing Lab to Windows CE 6.0.
- We also analyzed the Bluetooth handsfree profile provided by WinCE to decide on the type and make of the Bluetooth headset and dongle to be purchased.

9.2 Validation Testing

After the development of various modules three levels of testing were done. At first each module was tested as a standalone module to test its functionality. Once we were convinced that each module was functioning as we had foreseen, we moved on to the integration of various modules. We followed a Bottom Up approach to integrate various applications and modules one by one. After each integration step the sub system was tested. With this systematic unit integration we finally tested the system trivially to see if the system was functioning as expected. The acceptance testing stage is expected to continue for a much longer time. We will be collecting usage data for the prototype for further statistical analysis of the data. This will primarily be done to ensure the proper functioning of the speech processing server as it is the most crucial part of our system.

10. Cost Analysis

Since we plan to deploy one system in every classroom, cost is an important issue to consider. The cost of various components of the *prototype* we developed is as follows (Industrial PC to you):

Component	Cost (in $)
eBox 2300	**190**
Windows CE License	**3**
Bluetooth Dongle	**5**
Bluetooth Headset	**25**
Wi-Fi USB Dongle	**12**
Ethernet Cable	**1**
Total	**$ 236**

Table 1: Cost Analysis

This is the cost of the prototype. There would be a variation in cost for the final factory product. Certain post factory cost (such as shipping, custom duty, marketing etc.) would push up the final price of the system slightly. On the other hand, wholesale buying would bring down the cost of the system considerably. The estimated final price of the product would stand at around $ 270 per unit excluding local taxes.

11. Bringing System to the Market

Good ideas need to be turned into good business to make them popular. The team nurtures the dream of bringing *Sunoh* into the market to help hundreds of Hearing and Speech impaired students in Higher education. We hope that the system will help many more who aspire to get higher education. It will help attract many more students to schools and colleges. Hence, we are trying to develop a business model around the system.

11.1 Target Customers

11.1.1 Universities and Educational Institutes

Our prime targets are the Universities. Universities today are keener towards inclusive education than anytime before. These are healthy signs for the society and a great opportunity for *Sunoh.* Not only does this system provide additional student base to a university, it also gives it a preferable public image. In fact, preferential treatment is given to students with disability for college admissions in most of the universities around the globe. In India, 5% seats in all educational institutes are reserved for people with disability and people with hearing and speech impairments form a sizeable number among it. Hence, we have a lot of opportunity and a ready-made demand of such a system.

11.1.2 Government Agencies

In addition, government and government funded organizations around the globe are working hard for the welfare and education of physically challenged students. These organizations form another potential clientele for our system.

11.1.3 NGOs

Non-Government Organizations (NGOs) involved in the welfare of Hearing and Speech impaired people can also be very important customers of our system.

11.2 Marketing the System

All successful initiatives have a humble beginning.

We are scheduled to give a demonstration of the system to our college on 31st of May as B. Tech project thesis presentation for our team members from the senior year. This would be the first public demonstration of the system and would be attended by the senior members of the faculty of most of the departments.

Our mentor is in consultation with the authorities to allow us to demonstrate our system on the EduSat initiative of which our college is a part. It is a recently launched, television based distance education initiative and has reaches out to the entire country. This would allow us to showcase our system to thousand of people and hundreds of university which are a member of the EduSat initiative.

For *Sunoh*, to be successful; we need to showcase it to the world. If we get selected, Imagine Cup – Embedded Development Challenge would provide us a tremendous opportunity for demonstrating the capabilities of *Sunoh*, to showcase our dreams and future goals for the system at an international level.

11.3 Financial Aspects of the System

Sunoh is a financially viable system. As explained above the prototype of the system costs $236. We plan to sell the system within the price range of $275 - $300 per unit. 250 systems would be made available initially to various potential customers to iron out the teething problems of the systems.

Based on the customers' feedback, appropriate changes would be made and the final product would be made available.

At $275 - $300 we expect a profit of around $20 - $25 per unit. At this rate, for every 1000 units produced, we would need to sell 800 units to break-even. This, we feel is a realistic target for the starting-up phase of the business.

From customer's point of view, a price tag of $275 per classroom to make their school accessible to people with speech and hearing impaired people is a good investment. This system projects a socially favorable image to a university. In addition, it gives a university access to students who have been proved to be more committed (since they made it to this level despite their problems) and with higher level of concentration levels (since they are not disturbed by outside noise). In addition, any student can use this system to save the text of the lecture for future references. This makes installation of this system even more useful for the universities.

If the system becomes a financially sustainable and a successful venture we would try to provide the system at lower costs to the organizations involved with hearing and speech impaired people in economically weaker areas of the world. This is very important to make sure that the system achieves its number one aim, that is, to help Speech and Hearing Impaired people around the globe embark upon and complete the wonderful journey of acquiring education.

12. Team Organization

Sunoh is the result of the efforts of the whole team. As we mentioned above, we were able to clearly define the different modules of the system. This also made the division of work easier for us.

The entire team was involved in the designing of the system. Once the project design was complete the different modules were assigned to different team members.

1. Prayag, team captain, was responsible for the Speech Processing module of the system. He was also responsible for documentation of the entire system and compilation of the reports.
2. Parivesh, team vice-captain, was responsible for the Bluetooth module development. He assisted Hemant in developing the Wi-Fi connectivity module of the system.
3. Deepank was responsible for the client side application for Laptops and PDAs. He also assisted Prayag in the development of speech processing module.
4. Hemant was responsible for the development of the Wi-Fi connectivity module. He assisted Prayag in documentation and made most of the illustrative images used in the report. He also assisted Parivesh in developing the Bluetooth connectivity.

To make sure that the focus on the core system is not lost, and no irrelevant features sneak into the system, the system of *'veto'* was established. If any team member proposed changes in the blueprint of the system, any member of the team could veto the move. Hence, he would have to convince the entire team of the suitability of the move before it could be integrated into the system design. However, any member could change the structure of his own module after consulting with the team.

Regular meetings were held with the mentor and weekly updates were given on the project status. These meetings provided us an opportunity to scrutinize our work for the past week and brought a lot of insights into the system organization and development.

13. Project Status

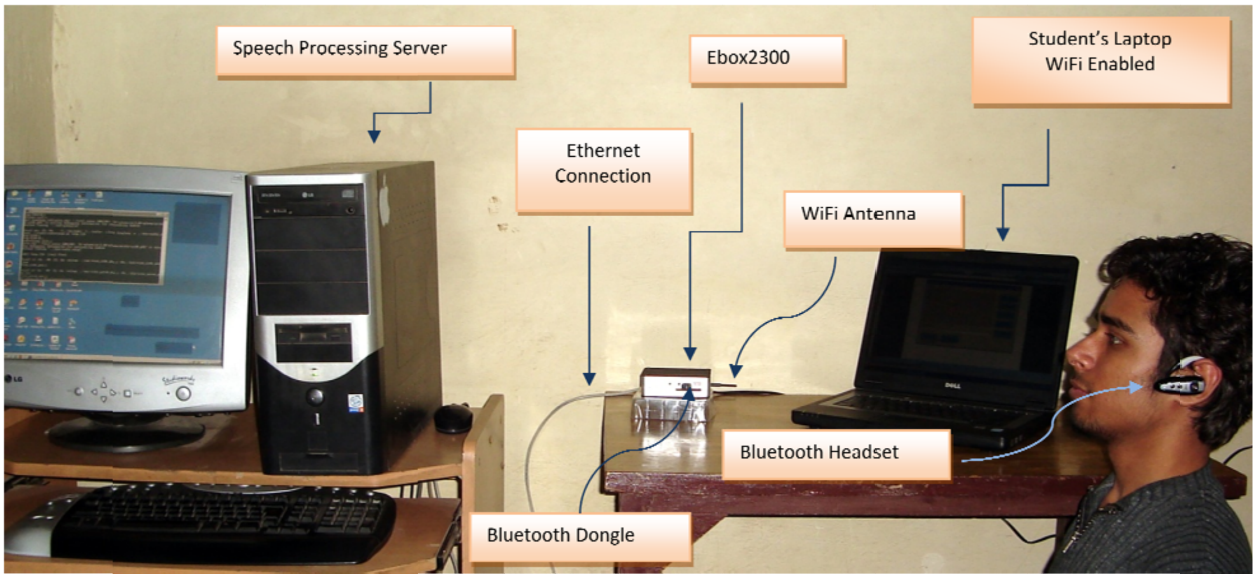

Figure 6: A Working Prototype of the System

The working prototype of the system has been developed and tested. A photograph of the working prototype is shown in figure 6. We have also started the proceedings for getting the system patented and have filed an application for a patent on 10th of May 2007. As mentioned before, we would demonstrate *Sunoh* in our college auditorium on 31st of May.

14. Summary

"Tell me, I will forget

Show me, I may remember

Involve me, and I will understand."

This Chinese proverb sums up our view of education. Education is not about acquiring knowledge. It is about getting involved in the discovery, of wonderful things that lie around us. It is about knowing your place in the world, in the history. It is a quest to self-discovery.

This is why the topic of this Imagine Cup is very special to us. "Imagine a world where technology enables a better education for all." The key word here is ALL. Technology has given tremendous power to us. But as engineers, it is our responsibility to make sure that no one is left behind. When our hearing and speech impaired team mate decided to get education despite all odds, he decided to make a difference in his own life. When he came up with the idea of *Sunoh,* he decided to make a difference in hundreds of other lives like him. Education for everyone is not an easy aim to achieve. Especially, when you have been deprived with the most basic need of a social animal; the ability to exchange ideas freely; the ability to converse.

We believe that it need not be so difficult. We believe that technology can help cross the most difficult hurdle that hearing and speech impaired people face in getting education. *Sunoh*, as a concept is revolutionary in nature and simple in implementation. We believe that we have in our hands an exemplary tool, which can revolutionize the concept of inclusive education.

We hope that you share our vision, and the dream of our team. We dream of a society, where all of its members can get educated, without struggling to fit into the existing system of education. Be it a person with hearing, speech, locomotive or visual impairment. *Sunoh* is just a small but significant step towards this goal.

Imagine Cup has always stood for innovation to solve practical problems. We thank Microsoft and the organizers for providing us this opportunity to try and make a difference in this world. In the end, we conclude by saying that we are all very excited about what we have made, and the world finals at Seoul can provide us an excellent opportunity to show to you and to the world what we have developed. I hope you would give us such an opportunity.

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