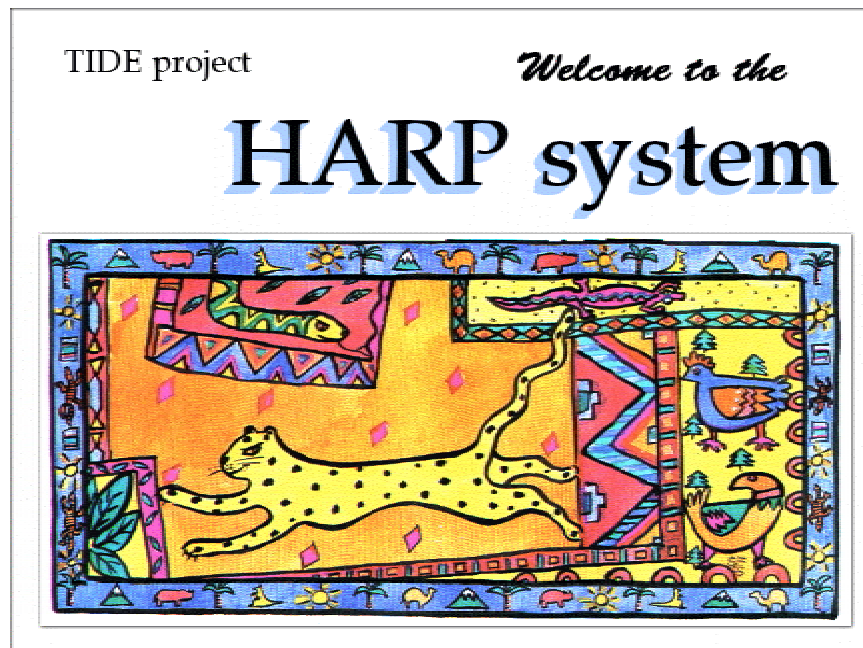May 15th, 1996

TIDE Project 1060

HARP

An Autonomous Speech Rehabilitation System
for Hearing Impaired People

FINAL REPORT

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Foreword

This document is the final report, suitable for publication, of the TIDE project N° 1060 "An Autonomous Speech Rehabilitation System for Hearing Impaired People" (HARP).

The purpose of this report is to provide an overview of the work carried out and the results obtained under the contract. More details on the scientific and technological contents of the project can be found in the documents listed in the annexes.

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2. EXECUTIVE SUMMARY

This final report of the TIDE project N° 1060 "An Autonomous Speech Rehabilitation System for Hearing Impaired People" (HARP) details the work carried out and the results achieved under the contract. The report looks also at the market potential of the system. HARP was designed as a two-year project whose aim is to develop a visual speech training aid for hearing-impaired speakers.

The project developments include inexpensive PC-based software and courseware suitable for use in schools, clinics and in the homes of hearing impaired persons. The system, available for both French and English in the first instance, has been developed for both children and adult speakers, with four main groups in view : the pre-lingually deaf, post-lingually deafened speakers, elderly speakers and cochlear implant users. The achieved demonstrator is a system able to process the voice of hearing impaired speakers in order to automatically identify and give advice on pronunciation errors thereby providing rehabilitation assistance. It guides the user through a set of lessons which should gradually improve pronunciation and restore the speech of hearing impaired users to a more normal form.

One of the key design features of the HARP system is its use of developments in multimedia technology to provide a flexible, accessible and highly motivating teaching tool. A second factor in ensuring the effectiveness of the system is the range of speech analysis facilities provided. Indeed, the work of HARP used as its point of departure the results of the previously successful ESPRIT project 7153 : SPELL (Spoken European Language Learning) which had developed courseware for language teaching for foreign language learners.

The work carried out during the two years of activities of the project led to major achievements including :

- Identification of accurate specifications for the system, obtained in particular through a detailed evaluation of the needs of the users,

- Completion of a prototype courseware integrating exercises on pitch, loudness, intonation, vowel and consonants, using widely multimedia technology,

- Extensive series of user trials and evaluations of this prototype by both therapists and patients,

- Production of a detailed coherent plan for the approaching exploitation of the HARP technology.

3. OVERVIEW OF THE PROJECT

The TIDE contract N° 1060 "An Autonomous Speech Rehabilitation System for Hearing Impaired People" (HARP) was designed with the purpose of developing a speech rehabilitation system for speakers with a hearing impairment. It covered two years of activity.

The global aim of the European Consortium involved in HARP was the achievement of a visual speech training aid for hearing-impaired speakers, widely based on multimedia technology to provide a flexible, accessible and highly motivating teaching tool. This system would help speech therapists in their work with the hearing-impaired by providing high quality visual feedback on parameters such as voice fundamental frequency, intensity, spectral quality and timing, using the latest developments in multimedia and a range of speech analysis facilities.

The principal objective was to develop a flexible teaching tool, based on a standard multimedia PC, which would be used to complement and extend the services offered by speech therapists and teachers of the deaf to their hearing-impaired clients. There are a number of such systems already on the market, but they have major problems including their cost, their unreliability in some cases, and the need for constant supervision by a therapist. These factors can mean that the systems do not get used as often as required or enough to justify the expense of purchase. The key aim on this project was therefore to design a system that was inexpensive and accessible, so that clinics and schools could afford to use it, and which was also flexible and motivating, so that therapists and their clients would be keen to continue with therapy. The system has been developed to provide instructions for deaf speakers of both French and English in the first instance, though the system is modular enough to allow teaching material in other languages to be added in a subsequent stage.

The development of the HARP system has exploited technology built for teaching pronunciation to foreign language students. This technology, coming from the previously successful ESPRIT project 7153 : SPELL (Spoken European Language Learning), provided visual feedback on features of intonation, rhythm, vowel quality and consonant production. These capabilities were to be extended and enhanced within the HARP project, to adapt the system to the speech problems of the hearing-impaired and to make the system suitable for use by those with limited auditory feedback. As well as extending the analysis capabilities of the system to cope with the particular distortions found in the speech of the hearing impaired, the project has attempted to make appropriate use of existing technology for multimedia communication, in order to build an accessible and motivating user interface. The project has also endeavoured to work closely with speech and hearing therapists, ENT (Ear, Nose and Throat) specialists and teachers of the deaf, to involve users fully at all stages of development, and thereby ensure that the design of the system meets the requirements of users.

Such objectives were quite compliant with the general aims of the TIDE programme. In particular, the user-focused approach was a permanent guideline throughout the project, with users intimately involved with the specification, creation, critique and asssessment of the courseware. Also, the project was strongly market oriented with

significant resources devoted on the one side to market analysis and on the other side to publicize the availability of the technology near potential users. Furthermore, HARP addressed the extended context of information technologies applied to the problem of improving communication skills in terms of technology adaptation and verifcation. Indeed, the project concentrated on the feasibility of extending speech technology down to the operative stage by embedding the proven SPELL software with existing technology for multimedia communication and by taking widely into account the aspects of reliability and robustness from the point of view of hearing impaired speakers. Finally, the project, as detailed later, has been organized around a multidisciplinary approach with a Consortium involving a well-balanced set of academic institution and industrial SME's.

In terms of practical work and taking into account the existing technology when compared to the objectives of the project, four distinct research areas were identified leading to a comprehensive workplan organized around a number of workpackages and tasks. Activities included :

- Research on phonetics focused on the enhancement and extension of the capabilities developed within the SPELL project to perform analysis of intonation, rhythm, vowel quality and consonant production in order to make the system suitable for the speech abilities of hearing impaired users,

- A full series of evaluation studies carried out throughout the project. The first stage involved close interaction with disabled users to monitor initial reactions to the system and to seek advice and critique of the design. The second stage tried to gather information about the system to allow improvements. The third stage represented a controlled trial of the system where subjects selected in the cohorts of users had to use the system.

- Successful attempts to exploit recent advances in multimedia user interface such as interactive computer graphics and speech processing. As stated in the objectives, the project completed a detailed investigation of how such multimedia schemes can be exploited for pronunciation teaching for hearing impaired people,

- Production of a detailed market survey, to define viable products deriving from the work of the project to include intonation teaching, vowel pronunciation and consonant production courseware. This survey contributed to build a future marketing strategy for the HARP products in terms of cost-effectiveness and user acceptability.

To achieve the objectives of the project and to carry out successfully the identified tasks, the Consortium was established to exhibit complementary expertise in phonetic analysis, multilingual aspects, signal processing, system development and marketing. The Consortium limited in size, but strongly motivated, included one academic institution and two industrial companies. The partners in this collaborative project and their roles were as follows :

- AGORA CONSEIL, a business office from Grenoble, France, acting as coordinator and apart from the general management of the project, mainly involved in marketing aspects and in activities related to the evaluation of the system, as well as in adaptation of the system to the particularities of the French language and market,

- Future Speech Systems (FS2), a recently incorporated SME of Lanark, Scotland, specialising in the exploitation of speech technology for the disabled especially for the blind. FS2 brought valuable expertise in signal processing, product development and marketing, and had a leading role in these areas.

• The Centre for Communication Interface Research (CCIR), Department of Electrical Engineering, University of Edinburgh, Scotland, with experience of research and development, since many years, in speech technology and human-computer interface design, provided expertise in speech processing, phonetics, interface development, and evaluation design.

In order to ensure efficient progress of the work, workpackage managers with technical responsibilities on specific topics were installed. More general issues and major decisions were taken by a Steering Committee chaired by the Project Manager and involving one representative of each partner.

The project also benefited from the involvement as sponsoring partners of institutions which deal with the education and rehabilitation of the hearing-impaired. These comprised both hospital departments and schools for hearing-impaired children. The sponsoring partners gave valuable guidance and advice for system development, as well as access to the four main user groups for trialling and evaluation. Their involvement, and that of the hearing-impaired users themselves, was crucial in ensuring that the project focused on user requirements from a very early stage.

4. STATE OF THE ART

4.1 Speech training aids for the hearing-impaired

The use of computers to give visual feedback to deaf speakers, to compensate for their reduction in auditory feedback, has been the subject of research for over twenty years. The aims of this research have been to make speech therapy more effective, not only by providing objective feedback to supplement the efforts of the therapist, but also by freeing the therapist from time-consuming practice sessions, and giving the hearing-impaired users greater opportunities for practice using stimulating and motivational material.

In this time a range of systems has been developed, using both acoustic and physiologically-based measures of speech performance. Acoustic systems, using only a microphone for input (e.g. the RNID's Visispeech system), have the advantage of simplicity of operation and relatively low cost, but are unable to give feedback on many aspects of production, such as nasality and tongue position. Physiologically-based systems overcome this limitation by supplementing the acoustic information with more sophisticated measurements such as airflow, laryngeal behaviour and electropalatography (e.g. the Visual Speech Apparatus and the Panasonic Technologies Aid), but the equipment used to obtain these measurements is often delicate, prohibitively expensive and difficult to use without extensive training.

Despite the considerable research effort devoted to this area, very few of these training aids have become widely available commercially. The best known is perhaps the IBM SpeechViewer, which provides a wide range of awareness and skill-building activities (e.g. loudness, voicing, fundamental frequency, vowel accuracy, consonant production and segment chaining) with entertaining games and graphics, using the IBM PS/2 family of PCs.   Others include Kay's Visi-Pitch 3300, which offers training on vowel and sibilant consonant production using both technical displays and computer games; the Indiana Speech Training Aid or ISTRA, developed at Indiana, which provides feedback on word pronunciation using a speaker-dependent speech recogniser to drive a set of video games; and the Video Voice speech training system from Microvideo, which covers aspects of pitch, loudness, voicing and segmental articulation using a range of games formats.

All of these systems use only acoustic measures, since this technology is relatively simple, cheap and non-invasive. They are all, however, still relatively expensive, and require either dedicated PCs (e.g. SpeechViewer) or specialised hardware units which are added on to a standard computer (e.g. the ISTRA system). These considerations have hindered their widespread acceptance into schools and clinics, and ruled out the provision of additional units for use in the home. This is particularly unfortunate, since it appears that home use can be a significant factor in stimulating the interest of the speaker's family, and boosting the speaker's motivation to improve their speech quality. Many also have problems of robustness: the IBM SpeechViewer, for example, has been found to respond poorly to low-intensity, hypernasal or high-pitched productions, and in certain modules will often give a "correct" response if the user simply blows on to the microphone. Inadequate and demotivating feedback is another problem, particularly for those systems which use whole word distances or overall "goodness" scores, such as ISTRA and Video Voice: users of these systems

may be unable to judge exactly which parts of their utterance are unacceptable, and may not be able to interpret the displays in a way which allows them to modify their production to move it nearer to the intended target.

These problems mean that many of the aims of computer-based teaching are not being met, since users either have restricted access to systems, or find that they cannot use the system without constant supervision by the therapist.

4.2 Evolution since the start of the project

Since the start of the project, a number of new products have appeared on the market, clearly aimed at filling the need for a low cost system which therapists and schools can afford to buy. Three such systems are Viewtalker, TalkMate and the STAR system (Sherston Publishing/DRA Malvern).   Viewtalker and TalkMate are relatively cheap systems providing various forms of visual feedback, but have a number of weaknesses, in particular the lack of any form of normalisation to allow valid comparisons between target patterns and those derived from the utterances of clients. The STAR system is rather more sophisticated, and uses advanced speech recognition technology - specially configured for children's speech - to provide feedback on word and phrase pronunciation; however, this is based on a whole-word distance measure (between the child's attempt and a multi-speaker template), and the system is not capable of any other form of feedback (such as pitch, loudness or vowel quality), nor of commenting on the actual nature of any pronunciation errors.

These developments (with the exception of the STAR system) are unlikely to make a great impact in the area of speech training: although inexpensive, they lack both the robustness and the user support which therapists require.   Their presence is an indication, however, that interest in this area is continuing to expand in the speech therapy profession.

5. MARKET POTENTIAL

This section of the report gives an account of the market potential for the HARP system, looking at the awareness of the market with regard to such systems, the size of the market and the target customers. The report then describes the computer infrastructure in the market and the penetration of the competitive products within the market. It concludes with the market inputs into this project and further developments that may result.

5.1 Awareness of the Market for HARP

In order to become familiar with the market from every possible angle, a telephone questionnaire was conducted targeting organisations, professional bodies and hospital departments who specialise in the needs of the hearing impaired. The aim was to discover how aware these important members supporting the hearing impaired community are about speech therapy equipment available for speech training. Although only a small sample was used it can be summarised that awareness of such systems is low and that this was probably a reflection of the whole market as the respondents were highly respected and recognised bodies. Indeed, a similar questionnaire carried out by other workers in the United States gave results which were very much the same, a small percentage had heard of such speech training systems but would not be able to point a hearing impaired individual in the right direction if he/she wanted some information on them.

The Consortium thus recognises that an awareness campaign would be necessary to support sales, to create demand for the HARP system, indeed a high percentage of respondents were keen to learn more about this subject. Further research showed that, conversely, speech therapists were well aware that such systems existed, although some were unaware of the advantages they could provide for their therapy. The majority were highly interested to learn more about them and were able to give valuable advice on their needs within such a system. The only real barriers to purchase were cost and ease of use.

5.2 The Market

The following details the market for HARP, looking at the segmentation of the market and at the market gateways, as identified by the Consortium.

5.2.1 Segmentation of Users - the hearing impaired

Within the UK there are estimated to be 8.4 million adults and just under 100,000 children with a hearing impairment. Throughout Europe these groups total 67 million and 7.5 million respectively.[1]

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[1] National Deaf Children's Society OPCS Survey 1989. See Deliverable - D8 Section III for further details

5.2.2 Segmentation by Type of Impairment

Users can be segmented by level of impairment as follows:

Mild Hearing Loss of between 25-40 decibels - hearing level

Moderate   41-70 dBHL

Severe   71-95 dBHL

Profound   96 + dBHL

Unaidable   100 dBHL [2]

From the figures given above, only a small proportion of these hearing impaired individuals will actually seek or need speech therapy to overcome speech difficulties related to their impairment. Indeed, market research suggests that only those with a hearing loss of 50 dBHL or worse are likely to have severe speech difficulties where therapy would be needed. From this it is possible to estimate how many individuals throughout Europe are likely to need access to systems such as HARP.

Throughout the whole of Europe, including the UK, there are 7.5 million children who have a hearing loss of 50 dBHL or worse and approximately 19 Million adults.[3]

Further Segmentation

Hearing Impairment can be segmented by type of impairment (as above) and in addition is often characterised as some of the following:

- Pre lingually deaf

- Post lingually deaf

- Cochlear Implant Patient

- Glue Ear patient

and then again by age. This is because speech therapists recognise that post lingually and pre lingually deaf clients have different speech problems, as do cochlear implant patients and, in addition, an elderly person will have different speech difficulties from a child. For example, in elderly speakers, it is loudness that deteriorates, rather than segmental content, which is what is missing from a pre lingually deafened person.

Speech Difficulty

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[2] Royal National Institute for the Deaf, U.K 1993 figures

[3] Dr Adrian Davies, Medical Research Council, Nottingham, "Audiology in Europe", September 1992

A hearing problem is invariably accompanied by some problem in speech production. For this reason hearing impaired peoples voices exhibit a variety of problems resulting in reduction in intelligibility for normal hearing listeners. This prevents a large number of people from participating in the normal hearing society. However, appropriate therapy can help in improving the intelligibility of speech from the hearing impaired.

The majority of speech therapists currently use traditional methods to conduct speech therapy with their clients. Traditional methods may include the use of games and tactile feedback to stimulate the client. Often it is visual feedback that is the key in the therapy and as a result a number of technological developments led to providing the therapists with systems that could provide feedback on screen.

5.2.3 Segmentation by Buyers - the Market Gateways

The HARP system will be sold directly to the speech therapy market. This section briefly summarises the potential buyers in the market. It is important to remember in this market that, although the individual therapists may make the purchase decision, they are not always the fund holders.

Specialist Therapists - Individuals

There are approximately 4000 fully qualified speech therapists in the United Kingdom, of whom 54 are specialised speech therapists for the hearing impaired. For France, figures are quite similar. However, the size of the market is potentially greater than this as a special qualification is not always strictly necessary to work with the hearing impaired. In addition there are several speech therapists with an old qualification which was awarded by the RNID. The last candidates for this qualification were accepted in 1990.

Therapists may work independently or in a clinic where a number of therapists are likely to be responsible for the purchase decision.

Hospitals

Many Ear, Nose and Throat units within hospitals have a speech therapist available to work with the hearing impaired. In addition, a hospital may have a dedicated speech therapy clinic or have provision for a community speech therapist to visit the hospital. Purchase decisions will be made by the group of speech therapists or individual community therapists and his/her manger. They then have several routes to acquiring funds for the purchase. Typically the purchase would have to be cleared by a business manager. Funding could either come from an equipment budget per department or in a trust system, the department would make a bid to the hospital trust. Charitable donations are another viable option.[4]

Schools

The education system provides many opportunities for the hearing impaired, including special schools, resourced schools or units within schools. Depending on the concentration of the hearing impaired in the latter, these schools would be in a position to possess a system so a community speech therapist may visit a child within

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[4] The National Hospital Speech Therapy Department

the school for speech training, without disturbing the child's education too much. In this case the purchase decision would come from both the speech therapist and the teachers involved. However, the money would come from a specialist equipment budget, charitable donations or the Local Education Authority. In some circumstances a charity may purchase a system and lend it out to schools.

5.3 Change in the Customer

It is important to consider the changing needs and wants of the customer and the user. Due to the knowledge of such systems held by speech therapists this market has begun to make a move to change away from a supply led market and into a demand led market. Therefore manufacturers are finding themselves changing from a push to a pull strategy as the customer becomes more knowledgeable and thus more sophisticated in his/her purchase decision. The HARP Consortium have done much to encourage this throughout the project.

Having been introduced to the application of technology to their work, therapists now know more about what is needed and what could be changed, thus the manufacturers can now learn much from listening to the consumer and users. In addition just as technology advances, so do speech therapy techniques and the needs of the hearing impaired. Thus the supply side of the market must now adapt to the changes taking place within the market and take note.

5.4 Computer Infrastructure in the Market

In order to establish the potential of the market, it was important to look at the computer infrastructure of the market as a whole. As the HARP system is designed to run on an IBM compatible PC it was important to know the penetration of IBM compatibles within the target market. A large scale study was conducted on all school and therapy clinics in the market to establish this. The results showed that Acorn, Apple and IBM PC compatibles are the three most popular platforms within schools and the world of speech therapy today. The results varied from region to region, but on the whole, the penetration of IBM compatibles was higher and generally in areas where other platforms were predominant, it was suggested that there would most likely be a move to IBM compatibles in the near future. In the mean time, the Consortium may investigate the possibility of supplying some of the modules for Apple and Archimedes.

## 5.5 Penetration of Competitive Products

5.5.1 Clinics

From the 30 hospital departments and clinics contacted the following results were gathered on product penetration by competitors:

Penetration of Competition in Clinics/Hospitals
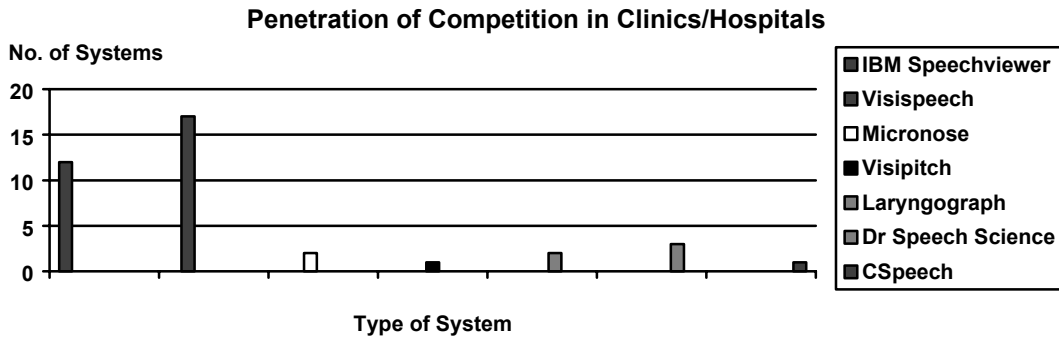
Throughout 30 clinics only two did not possess a system and ten departments owned more than one system. Penetration of competitors in the this target market is high.

5.5.2 Schools

From the 34 School and Units contacted:

Penetration of Competitors in a Sample of Schools for the Deaf
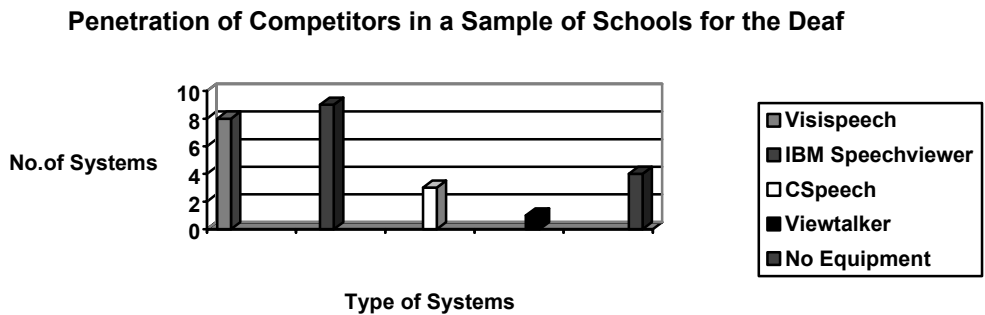
Throughout 34 schools there were 21 systems available for use. This is gives a high penetration rate of 61%, or approximately three systems per 5 schools.

These penetration rates are highly encouraging for HARP as many of those interviewed were aware that their systems were out of date and that some were in fact now obsolete. As older systems failed to meet their requirements new purchases were likely. In addition some schools and clinics were fortunate enough to be able to purchase more than one system so a HARP sale within an establishment that holds a speech aid currently is possible.

5.6 Marketing Input to System Design

The Consortium has been conscious of the need to focus its attention on the future exploitation of HARP and the eventual appearance of market product. As a result, a user group and an interest group were set up to input valuable product feedback and ideas into the project. Group meetings were arranged to demonstrate the system and to gather feedback on the presentation of the courseware and the usability of the system. The system was then changed to accommodate their comments before trialing of the system began. In this way we were able to ensure that the market would receive the system they need thus increasing the systems market potential.

5.7 HARP Awareness

The project itself has managed to boost awareness of speech rehabilitation aids (in particular) HARP within the market place. This was done not only though the user and interest groups, but also through attending exhibitions, sending newsletters to professional bodies and providing demonstrations to specula interest groups set up to look at technology in the market place for speech therapists. In addition, foreign distributors have been contacted to begin discussions on distributing the system not only in France but also in Spain and Italy.

5.8 Future Developments

- Prior to the launch of the system, HARP will be beta tested with those speech therapists who have actively participated in the project. It is intended that this will help confirm whether or not teachers of the deaf would indeed be a viable market for the HARP system thus widening the target group. A recent survey confirmed that there is a strong interest from teachers of the deaf.

- Modular System - the system offers the capability for flexibility in modular product offerings, which is at present being investigated as a further market route . This remains a further possible source of revenue for the HARP system.

- Other Speech Disorders - it has been recommended by several speech therapists that HARP could be marketed to target other groups of speech disorders.

6. MAIN ACHIEVEMENTS AND RESULTS

This section details the main achievements and results from the duration of the project and repeats the aims and objectives and how they were achieved, whilst also looking at the design of the system, the results of subsequent user trials and the increased knowledge the Consortium has gained with reference to this market. Finally this section reports on the significance of this project for the partners involved in the Consortium.

6.1 System Definition

The HARP system represents an attempt to address some of the problems inherent in existing speech training systems by using the latest developments which have taken place in speech processing and PC design, to produce an accessible, robust and motivating speech training tool which will be used in hospitals, clinics, schools and the home. Like the existing commercial systems, the HARP system is acoustically based for ease of use and maximum accessibility, requiring only a microphone for speech input. Unlike other systems, however, HARP is based on a standard multimedia PC (running Windows), with speech input and output performed on a Soundblaster-compatible board, now widely established as the standard for PC-based speech applications; no additional (and expensive) speech processing hardware is required.

The HARP system has been developed for both children and adult speakers, with four main user groups in view: speakers with early or congenital hearing loss, who have never had the benefit of normal auditory feedback and whose speech is typically highly distorted as a result (the *pre-lingually* deaf); speakers whose hearing loss has occurred after the onset of normal speech (the *post-lingually* deaf); elderly speakers experiencing problems with loudness and speech timing; and cochlear implant users, who need training to interpret the feedback provided by their implant. The system is being designed as an aid to therapists during therapy sessions with their clients, but with extensive provision for autonomous use by clients to supplement this supervised training and improve the prospects for the "carryover" from their lessons into their everyday speech.

One of the key design features of the system is its use of multimedia technology to provide a motivating and accessible system. To cater for the wide range of users with greatly differing linguistic and physical abilities, for example, the system accepts input using the keyboard, the mouse or a touch-sensitive screen, with the use of a colour-coded keypad also under investigation. Speech input to the system is generally by means of a headset-mounted noise cancelling microphone, although other microphone options are being explored. Output from the system uses the multi-media facilities of the host PC, including speech, graphics and video playback. In the pitch module, for example, the user controls the playback of a set of short video sequences, their pitch governing either the *speed* or the *direction* of playback of the sequence. Other modules use simple but motivating computer graphics, in the form of a range of voice-controlled games.

A full multimedia HELP system has also been designed and implemented to allow therapists and clients to gain the maximum benefit from the system, and to allow users unsupervised access to the system where this is required. This HELP system provides both text-based information on window content and button functions, for example, and video-based information on the use of the system and the activities available: users can choose between subtitled speech in English or French, suitable for those with lip-reading ability or some residual hearing, and the corresponding sign languages (British Sign Language and Langue des Signes Française).

A second factor in ensuring the effectiveness of the system is the range of speech analysis facilities being provided, using speech technology originally developed within the ESPRIT project 7153 (SPELL) for teaching pronunciation to foreign language students. These facilities have been extended to include a number of analysis modules with *real-time* feedback, in response to requests from therapists and hearing-impaired users during evaluations of the original system. The provision of continuous, real-time feedback by the system allows users to monitor their performance using kinaesthetic or tactile feedback as they watch the visual cues on the screen, giving them immediate and positive reinforcement.

For other aspects of speech performance and language use, the HARP system incorporates sophisticated speech recognition technology, in the form of a hidden Markov Model automatic segmenter which is tuned to the speech characteristics of the hearing-impaired, allowing it to monitor the segmental content of the input. This allows the use of real language materials such as words and short phrases during training, but still permits the system to give feedback on the pronunciation of individual segments where required. It also gives the system greater robustness in the face of gross pronunciation errors or mistakes by the user, and makes unsupervised use a more practical possibility.

6.2 Work Performed

6.2.1 Point of departure
The development of the HARP system is based on SPELL, a PC-based system which was developed for foreign language training as part of the ESPRIT programme (Project 7153). This system, running on an IBM-PC compatible computer (486) with the OROS-AU21 signal processing board for speech capture and processing, gave feedback on a range of speech parameters, including intonation, vowels, consonants and rhythm. The HARP system is based on these earlier developments, but with major improvements and modifications to make the system suitable for the hearing-impaired speakers. These improvements are largely in the areas of hardware choice, the software modules available, the addition of real-time visual feedback and the multi-media user interface design.

6.2.2 Areas of work
The work performed on the project broke down into four main areas:

- system specification and phonetics
- user interface design

- system evaluation

- market analysis

The *system specification and phonetics* theme covered the choice of speech features to be included in the system, and the development of speech processing modules which allow the system to offer feedback in real time - that is, as the users speak rather than after a delay.

The second theme, *user interface design*, made full use of existing multimedia technology to produce an interface which was accessible and easy to use, even for young children and elderly speakers. Inputs to the system are made using the keyboard, the mouse or touchscreen facilities, while output from the system uses a range of computer animation, sound and video.

The third strand, work in *evaluation* of the system, has been characterised by a close interaction with user groups at all stages, from the original specification of the system to a full series of formal user trials. This collaboration has helped to ensure that we have developed a system which does what the users require.

Finally, although this was primarily a research project, close attention has been paid to future commercial developments of HARP. The fourth theme was therefore dedicated to detailed *market analysis*, to identify possible products from the research and to determine what features the market would require in a system of this type.

6.2.3 Software modules

A suite of software modules was developed for speech processing for the HARP system. The work of the project concentrated on the development of real-time processing, to give simple, flexible feedback as the user speaks rather than after a delay. These modules offer the following facilities:

- speech endpoint detection to allow users to speak when they are ready

- pitch processing for work on intonation and pitch control

- loudness processing for work on speech volume

- continuous vowel quality assessment

- analysis of fricative articulations for consonant teaching

- speech recognition facilities using a hidden Markov model segmenter, used to provide intonation and consonant analysis.

The analysis of nasality has not been attempted within HARP, because of analysis difficulties, and because there are already several devices which are capable of giving feedback on nasal function.

6.2.4 User Interface Design

The HARP system uses a graphical user interface (GUI), which has been developed for ease of use by a wide range of speakers. The interface makes maximum use of the multi-media capabilities of the host PC. It is Windows based to ensure adherence to existing and future industry standards, and offers a range of input and output modalities, including text (via the keyboard), mouse input, touch screen facilities and

speech input and output via the microphone and speakers. The interface has been implemented using a combination of Microsoft Visual Basic and Microsoft Visual C++.

The HARP system makes extensive use of multi-media digital video within the user interface, to provide improved visual feedback in the rehabilitation process, and also as a more effective and natural way to give information and instructions, in the form of a video-based Help system. Users can choose to see a video presenting subtitled speech (for those with lip-reading abilities, for example, or for the benefit of hearing friends and family) or signing.

The whole user interface has been designed to be bilingual, including the video help system. The languages provided for are English and French.

6.2.5 The HARP Teaching Courseware

A major requirement for the success of a speech training aid is the provision of a body of motivating courseware which allows speakers to learn from the feedback they receive. The system needs to maintain speakers' interest and avoid the frustration caused by the use of repetitive or limited materials. The HARP system therefore provides a range of courseware modules, starting with the acquisition of basic speech skills such as pitch and loudness control, and progressing to more complex skills such as the control of intonational features in connected speech. This has involved the development of a variety of graphical approaches to feedback including contour-based displays, two-dimensional charts and entertaining games formats.

Courseware modules were developed in the following areas:

- pitch teaching (covering aspects such as pitch variation and pitch range)

- loudness (teaching the use of appropriate loudness levels)

- vowel quality (expanding the range of a speaker's vowels and improving consistency of pronunciation)

- consonant production and contrasts (e.g. fricative articulations)

- intonation (the use of pitch in short phrases and sentences)

These modules provide simple, reinforcing feedback to make users aware of variations in these parameters, and offer easily achievable targets as one of the first steps in rehabilitation. All the courseware modules have been implemented using a mixture of Microsoft Visual Basic and Microsoft Visual C++.

The Pitch teaching modules are designed to develop an awareness of pitch variation in speech and the ability to match simple phonetic targets with pitch. The activities provided make use both of simple computer animation (e.g. controlling the flight of an aeroplane across the sky) and of the multi-media video facilities incorporated into the system (e.g. the user's pitch determines the speed of playback of a short video clip, high pitch being equated with rapid movement on the screen). Similarly, the Amplitude modules develop an awareness of loudness variation and an acceptable loudness range; loudness is equated with a number of physical dimensions, including the *size*, the *intensity* and the *proximity* of objects.

For Vowel Quality teaching, users receive feedback on the extent of their own vowel space in comparison with a suitable target, and also on the approximate location of the categories corresponding to the vowel phonemes of English and French. This is done by providing a two-dimensional chart which approximately represents the articulatory dimensions of tongue *height* and tongue *frontness/backness*. A set of vowel targets superimposed on this chart allows users to monitor their own vowel quality as their articulation changes, and to compare the quality they are achieving with these target locations. In order to ensure that these targets are realistic and achievable by speakers, appropriate targets are being provided for different regional accents within each language. The targets can also be moved across the screen, to bring them within the reach of the speaker if necessary.

The Consonant teaching modules offer both continuous feedback, to teach features such as the production of fricatives at different places of articulation, and categorical feedback using whole word utterances to teach segmental contrasts or phonetic features such as the difference between stop and fricative articulations. Feedback to the user is given in a variety of forms, including animated multi-media displays which show the changing position of the tongue and lips, and voice-driven games in which the correct production of the consonant can move objects on the screen.

Finally, the Intonation modules cover the skills needed to integrate pitch control into the production of words, phrases and short sentences. Intonational features help to mark linguistic categories such as statements and questions, as well as to convey paralinguistic information such as the speaker's mood and attitude, and improved control of these features is therefore a vital part of a hearing-impaired speaker's ability to communicate.

Other areas such as rhythm remain to be developed in the future. As part of the courseware development, a short training manual has also been produced, detailing possible applications of each area of courseware.

6.2.6 User Involvement

The HARP project has been characterised by close attention to the requirements of users, with maximal user involvement at all stages in development. This has been a 3 stage process, beginning with an initial stage of consultation, during which the specifications for the prototype HARP system were drawn up as a result of a survey of therapists and teachers of the deaf, and hearing-impaired users themselves. Throughout the development, contact with the users has been maintained through the HARP Interest Group (HIG). Finally, the system has undergone extensive evaluation with users in clinics and schools in the UK and France.

This close contact has helped to ensure that the system performs the functions required by users in the most user-friendly way, but has also served the purpose of increasing the awareness amongst the speech therapy profession of the capabilities and potential of computer-based therapy.

6.3 Application of the results of the project

The developments of the HARP project have a wide application.

In the first place, the system will be used to extend the provision of computer-based training to schools and clinics where speech therapy is already undertaken. The system offers therapists the ability to enrich therapy sessions and to motivate their clients through the provision of rich and varied teaching courseware. The system has the potential for autonomous use by the client where therapists think this is appropriate, and this allows the possibility of use by clients in the home. The importance of this possibility for clients' progress is immense: additional practice at home could reinforce the work done by therapists in the clinic, and improve clients' motivation by involving their family and friends in therapy.

A second area in which the system would have a major impact is in the provision of a portable system for peripatetic teachers and therapists. Existing speech training aids are generally non-portable and are in any case extremely expensive, meaning that they have to be centrally located in the clinic or school. However, many therapists are now required to work away from their base, in the community. A lap-top based system would be of immense benefit to them in their work.

6.4 Market Interaction

In order to compile the above objectives into a system that the market wanted it was vital to interact with the target market. Involvement with the market is a prerequisite for a project such as this, a link between the project team and the market was formed at the beginning so that the needs of the users/purchaser could be met where possible. Thus development of the technology was user led. Involvement with the market was achieved in two ways by firstly establishing a user group through our sponsoring partners and secondly establishing a HARP interest group made up of the target market.

6.5 Market Analysis

Every opportunity was taken to ensure close involvement with the market. The HARP Interest Group, with over 150 members, was established consisting of professional bodies, therapists, teachers of the deaf and individual hearing impaired persons. The HARP interest group was utilized to extract relevant information for the purpose of the project. Members were often canvassed with questionnaires or telephone interviews and group meetings took place to allow members to the view the system and to comment. The group offered support and assistance when necessary and some members went on to trial the system. Market research for the project was divided into two areas providing a competitive and market analysis.

6.5.1 Competitive Analysis

For competitive analysis both secondary and primary research methods were used to gain valuable information on over thirty five systems designed for speech rehabilitation that could be used for the hearing impaired. These systems were then classified into high, medium and low competitive threat for further detailed analysis .

Competition both in terms of product and their distributors is small but strong there are few systems in the UK and the rest of Europe that compare to a dedicated speech training aid for the hearing impaired and for those that come close HARP poses a viable threat to their position in the market. Large successful distributors are few and often concentrate on too many products to give adequate support needed for these systems.

The analysis provided important information on prices, distribution and product positioning in the market whilst also allowing the flow of abundant technical information back to the design team.

6.5.2 Analysis of the Market

Again both primary and secondary research material were used in the compilation of an overview of the market as a whole - this included both the users, the hearing impaired and the buyers, speech therapists and teachers of the deaf. The market analysis allowed us to estimate the size of the market and included such detail as the use of computers, the type of computers used within this market segment and speech rehabilitation systems utilised today.

6.5.3 Key Needs and Purchase Decision Factors

PRICE: Price sensitivity appears to be high on the list.

MOTIVATION: A crucial aspect of the system which cannot be over emphasised is that the system must not only be interesting but must be positively enjoyable.

AUTONOMY: Both therapist and users desire some level of autonomy. The therapist would prefer to allow individuals to continue to practice a particular aspect of speech, perhaps outwith the clinic on an instructed basis. The clients themselves desire the flexibility and convenience of being able to practice in their own time.

MODULARITY: A clear need for a modular, yet comprehensive system which will concentrate on the key impairments of speech and yet will allow the flexibility to repeat, skip or customise certain modules.

PORTABILITY: The possibility of being able to move the system from clinic to clinic is very appealing to speech therapists

SUPPORT: Extensive support of the system is a strong selling point in this market.

This information was essential not only for the design of the system but also for the formation of the final market exploitation plan.

6.5.4 Knowledge of the Market

The interest group became the key to the market allowing the team to gather vital information about the structure of the market including how speech therapists work, the needs of the hearing impaired, the computer infrastructure within the market and the fragmentation of the market both in France and the UK.

In addition the interest group allowed a network of contacts to be built within the rehabilitation therapy market through invitations to group meetings and exhibitions from professional bodies and special interest groups for the hearing impaired. This network of people allowed the project to conduct preliminary and secondary trials with ease. As observers exhibitions were attended overseas in order to become acquainted with the market and its supplier within Europe.

6.6 Evaluations and User Trials

The lack of adequate evaluation has been identified as a perennial problem in the development of speech training aids. In order to ensure that the design of the system reflects the needs of users, therefore, the HARP system has been evaluated on a continuing basis, with the help of hearing-impaired speakers and therapists at locations in Britain and France. These evaluations were divided into three stages:

- a preliminary stage involving extensive consultations with user groups
- a period of evaluation of the prototype HARP system
- a set of formal Performance Trials of the system with user groups.

This three stage approach to the evaluation of the HARP system was successful in allowing a certain amount of flexibility in the development of the system, whilst at all times maintaining a close focus on users' requirements and needs.

6.6.1 Stage I: Consultations with Users

During this stage of the work, meetings were held with speech therapists, hearing therapists, teachers of the deaf and hearing-impaired users themselves to discuss the development of the system in detail. These meetings concentrated on issues such as the problems experienced with existing speech training aids, the consistency of feedback, the importance of positive feedback and motivation, the structure of the courseware being provided, and the degree of autonomy the system might be capable of providing.

These consultations yielded a number of important recommendations for the design of the system. In the critical area of autonomy, for example, it was concluded that the HARP system should function principally as an aid for therapists, but with provision for additional unsupervised practice on items which have been covered inside their normal therapy sessions. In the area of courseware structure, a two-tier system was suggested with exploratory activities at stage one being followed by a constrained second stage in which simple targets for performance are introduced. A major finding was the users' desire for much greater flexibility than is provided by existing systems, for example in the design of the User Interface, the nature of the phonetic targets, and the choice of examples and analysis settings for different speakers.

The discussions also touched on the question of the integration of a system such as HARP into speech therapy provision. In the UK in particular, the nature of speech

therapy provision is changing, with more and more therapists now required to go out to their clients (e.g. in schools) rather than working from a permanent, central facility. This means that a *portable* system could be particularly valuable in the future.

Many of the suggestions and recommendations received at this stage were progressively implemented in the design of the User Interface and Courseware during the lifetime of the project. Other enhancements to the system which were suggested - but which have not yet been implemented - included the provision of auditory feedback for the pitch, amplitude and vowel modules; the facility to have two microphones, one for the therapist and one for the client, to avoid the disruption of having to transfer the microphone when the therapist needed to demonstrate a sound; and the ability to store the speaker's best effort on the system to act as a target for future attempts.

6.6.2 Stage II: Evaluations of the HARP Prototype

In the second stage of the User Trials, the prototype system was evaluated in use by therapists and their hearing-impaired clients. These evaluations were exploratory in nature, to gather information about the system and to implement improvements in response to users' requests. They concentrated on aspects of system use such as the degree of training required to use the system, its suitability for both supervised and unsupervised teaching, the acceptability of the User Interface, and the usability of the system in general (e.g. its robustness, clarity of instructions and handling of errors). The evaluations took place over a period of several months, and provided the opportunity for therapists to use the system freely to supplement their normal teaching activities with clients. Usage of the system was logged automatically, to allow reconstruction of therapy sessions, analysis of the choices made by therapists, and the reproduction of errors if necessary. In addition, many of the therapy sessions were videotaped for analysis at a later date.

The first outcome of these evaluations was a great deal of positive feedback on the potential of the system. Users felt that it was very motivating and exciting, and excellent for group work as well as with individual clients. The second outcome was a wealth of suggestions for improvement and expansion of the system, covering issues such as navigation around the system, the suitability of the system for younger children, alternatives to the headset microphone chosen for the prototype, new ideas for the teaching of rhythm, the possibility of using the system with a group of children, and the importance of home use in maintaining the speech skills of older children once they leave school and lose contact with the speech therapy services.

In response to these suggestions, many improvements to the HARP Interface and Courseware were implemented. Additions to the system included the expansion of the vowel teaching courseware to cover different accents, the provision of alternative forms of vowel feedback, increased control of the user interface, and most importantly from the point of view of flexibility, the introduction of basic authoring facilities for therapists in the pitch and vowel modules.

The evaluations also revealed a significant demand for visual feedback systems like HARP in the treatment of other speech disorders, such as dysarthria, aphasia and phonological impairments. Therapists at one site have already begun using some of

the existing modules in their work with a dysarthric speaker (without hearing impairment), with some promising results

6.6.3 Stage III: Performance Trials

The final stage was a set of formal User Trials in which the system was tested rigorously at a number of sites in the UK and France. The main aims of the User Trials were:

- to gather data on the effectiveness and usability of the HARP system in extended, daily use in speech therapy clinics and schools;

- to see to what extent the system met the requirements of therapists and hearing-impaired users in the four user groups.

Therapists made use of the system with a large number of clients (70 in total between France and the UK) , typically over a number of weeks, to complement and extend their normal therapy sessions, and provided feedback on both the efficacy of the system and any practical difficulties with its use. In contrast to the preceding exploratory phase, at this stage no changes to the system were permitted. Evaluation of the system was performed by means of largely subjective, therapist-based assessments of users' progress, and evaluation of the therapists' own experiences with the system.

The trials concentrated on a range of issues, which can be largely grouped into four areas of interest:

- whether use of the system led to any improvement in the client's performance and intelligibility;
- the effect of the system on users' motivation and self-confidence (identified as two of the chief objectives of speech therapy during early consultations with therapists);
- the clients' sense of enjoyment (or conversely of boredom and frustration) at using the system;
- and the general usability of the system as a whole.

Therapists recorded which modules had been attempted, any problems which occurred with the system, and any observations on their clients' progress throughout the session. Assessment of the system was by means of a set of short questionnaires, consisting of a series of statements with which users could indicate agreement or disagreement on a 5-point Likert scale (*Strongly disagree - disagree - neutral - agree - strongly agree*). These questionnaires were presented as follows:

- During and/or immediately after each session, the therapists were asked to complete an evaluation of the *client's* progress with the modules used, to assess the client's confidence and motivation, and their speech performance during use.

- Once each speaker had completed his or her set of sessions, they were asked to complete (with the therapist's help in the case of young children) their own evaluation of the HARP system.

Therapists were also encouraged to submit any other relevant observations they may have made, or comments on the system as a whole, and many chose to present these in the form of an informal report.

The clients who participated in the trials ranged from 2 years to 76 years of age, the majority being pre-lingually deaf children and young cochlear implant users. With younger children (up to around 5 years of age) the system was used mainly to encourage vocalisation, since this is one of the main aims of therapy at this stage. It was felt to be very effective in this, even though this was not what the modules being tested (pitch and loudness) were designed for. Older children appeared to encounter fewest problems with the performance of the system, while the oldest speaker found the system very motivating and was keen to carry on trying.

The therapists provided a great deal of feedback on the benefits and the drawbacks of individual teaching modules. The pitch modules were among the most used of all the available modules during the trials, and met with varying reactions. There were a number of difficulties, in particular the problem of setting the pitch scale for individual clients, and the interpretation of the movements on the screen: in particular, displays in which pitch changes were represented by speed or by horizontal movement were less successful than those using vertical movements. A display in which the user's pitch controls the flight of an aeroplane across the screen was one of the most popular and most adaptable of the modules, with a variety of uses quite apart from pitch training. The loudness modules, in which the amplitude of the speaker's voice controlled the size, intensity or proximity or objects on the screen, were generally well liked, particularly by the younger children, although in some cases they encouraged excessive volume. The vowel modules were used extensively, and were found to be highly motivating, though perhaps more appropriate for older children and adults. The consonant production modules also proved popular, especially those which used vocal tract animations to show the movements of the articulators for fricative and stop production.

The video-based help system was also evaluated by some therapists during the trials, and was generally felt to be valuable. The possibility of having sign-supported speech as well as subtitled speech was clearly appreciated by some clients. This element needs a fuller evaluation once the remaining details have been developed, to ensure that it performs its task properly.

The responses to the questionnaires were encouragingly positive, in terms both of the therapists' assessment of their clients' progress, and of the clients' own experience of the system. In the therapists' assessments, the overwhelming majority of users appeared to enjoy using the system, even where they reported problems with some of the modules. Most, too, responded positively to the feedback they were given, and were keen to use the system again. Most therapists, however, did not think that clients were ready to use the system unsupervised. The user groups were remarkably similar in their responses, with the exception of the cochlear implant users, who experienced slightly higher levels of frustration and difficulty with the system; this may be because the system did not provide any auditory feedback, which is a central part of their therapy. In the clients' own assessments, the system scored highly for enjoyment, accessibility, ease of use, and interpretability, and most people - including the very young children - felt comfortable with it. Again, the cochlear implant users were slightly more reserved in their judgements than other groups.

In summary, while there are a number of aspects in which the system can be improved, and several recommendations for change, the results of the questionnaires confirm the impression gathered throughout the User Trials that the HARP system is

enjoyable to use, effective at stimulating users' interest in their speech, and capable of motivating them to try to improve it.

6.7 Summary of Project Achievements

A prototype HARP system exists which is a speech rehabilitation aid designed specifically for the hearing impaired, a system which achieves the aims and objectives set out, a system that has already been through extensive first stage of field trials, extensive feedback for further development and excellent acceptance by the market at this early stage.

In addition there is a strongly established interest group with over 150 members, this provides a potential sales database for the future and will be vital for further development stages. And finally a detailed market exploitation plan exists which is supported by ongoing competitive and market research. It is a plan that is ready to be implemented on final completion of the system.

The work conducted on this project has been of great significance to the Consortium as a whole, as well as for the partners taken individually.

A general objective of AGORA is to promote transfer of state-of-the-art technology linked with speech and signal processing to the commercial marketplace in very promising but non-conventional market segments, such segments being not profitable enough 'at least at the beginning) for large commercial organizations. The applications involving speech technology for handicapped have been identified as one of the most valuable market segment. The work and results of HARP, fully in line with this strategy, are therefore of significant importance for the company. The development of the French version of the prototype, performed in connection with motivated therapists, allowed a better perception of the potentialities of this market. The user trials led to another large amount of contacts with patients and teachers, improving the knowledge of the particularities of the sector, including the marketing channels, closely linked with the social organization of the country. With the available results, AGORA plans to invest further in the development of HARP technology, to complement the manufacturing capabilities of the other partners and to establish distribution channels firstly in France, then in other key identified European markets.

With regards to Future Speech Systems the achievements which have resulted from the project mean that Future Speech System is now more widely known in the UK disabled market and has been able to introduce itself to a new segment of the market - Rehabilitation Therapy, the work achieved on the project reflects the capabilities of Future Speech Systems in terms of producers of advanced technical solutions. The interest group has provided Future Speech Systems with a potential sales database allowing for accurately targeted sales which will in turn save both time and money. In addition FS2 has built up a network of useful contacts and has begun to negotiate with distributors overseas (Spain, Italy) thus making its presence known in a wider field and contributing to the TIDE objective of stimulating the creation of as single RT market.

CCIR has benefited directly from the work of the HARP project in a number of ways. The project has seen major achievements in the development of simplified and yet robust speech signal processing modules, capable of working in real time on industry

standard equipment; these developments are well placed to take advantage of the constant improvement in the processing power which is now being offered as the standard in PC technology. The Centre has also enhanced and extended its work on User Interfaces and usability engineering with the development of a true multi-media interface capable of providing for a wide range of users, from young children to the elderly. The User Trials have also given the Centre valuable additional experience in system evaluation. In addition, the collaboration achieved with therapists, teachers of the deaf and hearing-impaired users has strengthened the links between the Centre and the area of disability, an area which is growing in its importance to researchers and designers, and one in which the development of robust applications has great social and medical benefits. Finally, the pressures towards the development of a pre-market product, designed from the outset with the user in mind, have helped to raise the awareness of the importance of marketing and user involvement in any venture into applied research.

6.8 Future work and further developments

While the HARP system has been designed specifically for the rehabilitation of hearing-impaired users, it emerged during the system evaluations that there is a significant demand for visual feedback systems in the rehabilitation of other speech and language disorders.

The speakers who would benefit most from such systems fall into three main groups:

- those with speech production difficulties, such as dysarthria and dyspraxia. These conditions, which disrupt the speaker's ability to articulate, can have serious implications for the intelligibility of their speech.

- children and adults with learning difficulties or other cognitive impairment (including those with Down's Syndrome). These speakers need a very considerable amount of help to improve their language use and intelligibility, in order to facilitate independent living in the community. However, many do not currently receive therapy, since there are no cost-effective ways of delivering the extensive treatment they need.

- children with phonological disorders. Such children show systematic distortions to the normal patterns of sound found in the language. The exact nature of their disability is not always clear, but it can have a devastating effect upon their speech, and therefore upon their integration into society.

There are also a number of other groups for whom certain aspects of the system would be useful. These include stammerers, speakers with a physical disability (e.g. a facial palsy or those with cleft lip and palate), and speakers with receptive deficits (e.g. those in need of discrimination training).

The HARP multimedia interface, which links sound with graphics, video and animation, would be readily adaptable for many of these groups. Most of the improvements to the HARP system which would be required for all these groups of speakers would concentrate on the provision of more robust vowel feedback, to cope with the distortions in their speech, and on the development of a wider range of real-time feedback modules for consonant articulation.

In the case of speakers with learning difficulties, there would be major challenges to be overcome in the design of a suitable user interface which would be accessible to them and in the development of feedback mechanisms which can be readily understood and acted upon, despite users' often considerable cognitive impairments. Suitable courseware, tailored to the specific needs of this group of users, would also need to be developed.

The developments in user interface design and feedback achieved in this area would have wider applications, in the general integration of learning-disordered people into the community. One aspect of this integration is the ability to use computers to access information and to perform work: at present, standard computer interfaces can exclude this population of users, but a suitably designed interface, which took into account their cognitive difficulties, would have enormous benefits beyond the immediate area of speech rehabilitation.

7. LIST OF PUBLICATIONS AND DELIVERABLES

7.1 Deliverables

The following deliverables were produced by the Consortium during the project. The dates mentioned correspond to the acceptance by the Consortium.

1. Deliverable D1

   Title : Speech Technology Specifications for HARP
   Date : June 17, 1994

2. Deliverable D2

   Title : Specifications of HARP Courseware and Application Software
   Date : June 16, 1994

3. Deliverable D3

   Title : HARP Speech Processing Algorithms
   Date : February 21, 1995

4. Deliverable D4

   Title : HARP User Interface Software
   Date : February 21, 1995

5. Deliverable D5

   Title : HARP Prototype Hardware Specification Documentation
   Date : February 10, 1995

6. Deliverable D6

   Title : HARP Courseware
   Date : July 18, 1995

7. Deliverable D7

   Title : HARP Multi-Media User Interface
   Date : February 23, 1995

For the convenience of the reader, deliverable D8 on market analysis has been divided in three volumes.

8.1   Deliverable D8.1

    Title : Market Analysis, Part I - Market Plan
    Date : August 24, 1995

8.2   Deliverable D8.2

    Title : Market Analysis, Part II - Competitor Analysis
    Date : August 16, 1995

8.3   Deliverable D8.3

    Title : Market Analysis, Part III - Market Analysis
    Date : August 22, 1995

9.   Deliverables D9/D10/D11/D12 (merged in a single document)

    Title : User Trials
    Date : May 9, 1996

10. Deliverable D13

    Title : HARP Video : Film Describing the Project and the Results
    Date : May 10, 1996

In addition, two supporting documents detailing specific aspects of the work carried out during the initial phase of the project, were presented as supplementary deliverables, even if not originally planned in the Technical Annex :

1.   Deliverable DS1

    Title : Speech Production and Speech Training for Hearing-Impaired Speakers
    Date : July 19, 1994

2.   Deliverable DS2

    Title : HARP System User Evaluations
    Date : July 28, 1994

7.2 Publications

Hereafter are listed all the publications, over the whole duration of the project, presented by any member of the Consortium about work related to HARP :

1. Title : HARP - An Autonomous Speech Rehabilitation System for Hearing-Impaired People.
   Authors : E. Rooney, F. Carraro, W. Dempsey, K. Robertson, R. Vaughan, M. Jack and J. Murray
   Conference/Journal : Proceedings of the International Conference on Spoken Language Processing (ICSLP94), pp. 2019-2022, Yokohama, Japan, September 19-22, 1994.

2. Title : HARP - An Autonomous Speech Rehabilitation System for Hearing-Impaired People.
   Authors : E. Rooney, F. Carraro, W. Dempsey, K. Robertson, R. Vaughan, M. Jack and J. Murray
   Conference/Journal : Paper presented at the Fourth Symposium of the International Clinical Linguistics and Phonetics Association (ICPLA), New Orleans, November 14-16, 1994, to be published in *Pathologies of Speech and Language : Contributions of Clinical Phonetics and Linguistics*, edited by T. Powell.

3. Title : HARP - An Autonomous Speech Rehabilitation System for Hearing-Impaired People.
   Authors : E. Rooney, F. Carraro, W. Dempsey, K. Robertson, M. Jack and J. Murray
   Conference/Journal : Proceedings Institute of Acoustics, Vol. 16, Part 5, pp. 97-104, 1994, Paper presented at the Institute of Acoustics 1994 Autumn Conference : Speech and Hearing, Windermere, England, November 24-27, 1994.

4. Title : Project 1060 "HARP" A Speech Training Aid for the Hearing-Impaired.
   Authors : E. Rooney, M. Jack, J.P. Lefèvre and A. Sutherland
   Conference/Journal : in *The European Context for Assistive Technology*, edited by I. Placencia Porrero and R. Puig de la Bellacasa, IOS Press, Amsterdam, pp. 328-331, Proceedings of the Second Tide Congress Paris, April 26-28, 1995.

5. Title : A Multi-Media Speech Training Aid for Hearing-Impaired People.
   Authors : E. Rooney
   Conference/Journal : Paper presented at the Institute of Acoustics Speech Group Meeting : Speech Systems for the Handicapped, CSTR, Edinburgh, June 8, 1995.

6. Title : Multi-Media Speech Training for Hearing-Impaired People : the HARP System.
   Authors : E. Rooney, F. Carraro, W. Dempsey, K. Robertson, M. Jack, N. Pattinson and A. Sutherland
   Conference/Journal : Proceedings of the Second Language Engineering Convention, pp. 17-24, London, October 16-18, 1995.

In addition, HARP activities were advertised in a number of therapist magazines, including :

1. Title : EC Speech Feedback Project.
   Journal : Therapy Weekly, British Society of Speech Therapists, Vol. 21, N° 25, pp. 3, January 12, 1995.

2. Title : Get Interactive.
   Journal : See Hear !, BBC Magazine for Deaf and Hard of Hearing People, pp. 19, January 1995.

3. Title : Would you like to improve your speech ?
   Journal : British Deaf News, British Deaf Association, pp. 5, January 1995.

4. Title : Speech Rehabilitation for the Hearing Impaired : Research & Development.
   Journal : Bulletin !, College of Speech and Language Therapists Magazine, Issue 513, pp. 22, January 1995.

5. Title : Working on Speech.
   Journal : British Association of Teachers of the Deaf Magazine, pp. 5, January 1995.

6. Title : HARP : un projet européen pour la rééducation de la parole chez les sourds.
   Journal : Journal Français d'Oto-Rhino-Laryngologie, Vol. 44, N° 2, pp. 150, Mars 1995.

7. Title : HARP : un projet européen pour la rééducation de la parole.
   Journal : Communiquer, Association Nationale de Parents d'Enfants Déficients Auditifs, N° 121, pp. 34, Mai 1995.