Design of a non-contact head-control mouse emulator for use by a quadriplegic operator

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ABSTRACT

A non-invasive scanning mechanism has been designed which is microprocessor controlled to locate and follow head movement in a defined zone about a persons head. The resulting head movements may then be mapped onto a computer screen and can further be used to control the cursor, thus replacing the necessity of using a standard PC mouse. To demonstrate the concept, a Graphic User Interface (GUI) of a push button telephone has been designed, and a procedure is outlined below by which one may select and highlight a digit or group of digits, and in turn dial the chosen number.

1. INTRODUCTION

Applied research is ongoing at the Department of Control Systems and Electrical Engineering, focusing on development of non-invasive computer input/output mechanisms. The intention is that the devices will be of benefit to everyday PC users, but in particular the aim is to create innovative devices which will enable quadriplegic or other persons with upper limb disability operate a computer.

Research to date has centred on a number of specific areas of application. The original application focused on developing a *non-contact head-movement electric wheelchair control device.* The objective was to design an interface which could replicate and replace a standard joystick wheelchair controller. Ultrasonic transducers positioned on a specially designed frame attaching to the wheelchair were microprocessor controlled to transmit and receive pulses which resulted in the wheelchair travelling in the desired direction of the occupant. This work was carried out by the principal researcher in part fulfilment of studies leading to his PhD degree (Coyle, 1993). The concept of control by this method was developed following an appraisal of related work by researchers at the Palo Alto Veterans Administration Medical Centre (Jaffe, 1983).

A second ongoing application is that of design of a *non-contact PC virtual keyboard emulator*, with the intention of enabling a person with upper limb disability work in a Microsoft Windows environment by simply moving the head in a defined area about the central relaxed head position. The virtual keyboard will take the form of a graphic display on the computer screen allowing the user to type without the requirement of a standard keyboard. A scholarship has been awarded by the Irish Health Research Board in support of this project.

A number of design routes have been investigated with a view to optimising on both hardware and software design. In the current system two sets of piezoelectric ultrasonic transmit/receive transducers are strategically placed on a mounting frame to the side and rear of the user's head. The transmit transducers are microprocessor controlled to cyclically transmit pulsed signals, which upon reflection from the surface of the head are picked up by the matching receive transducers. The microprocessor users a trigonometric algorithm to determine the current head location within a mapped zone about the central relaxed head position. Head movement is used as an alternative input device, replicating keyboard typing and hand-mouse action. The microcontroller is programmed for both the monitoring of head movement and as a PC Serial Mouse emulator.

This paper will outline the development of a prototype system in which a Graphic User Interface of a push button telephone has been designed (using Microsoft C in a DOS environment). This application was developed to enable critical assessment of the proposed ultrasonic head-control mechanism. Further work has resulted in development of a Windows based GUI virtual keyboard (C++), while in yet a separate project an approach has been taken in which the appropriate signals in response to ultrasonic information are inputted directly to a hardware modified mouse. A brief on these latter two applications will be given in Section 4, further project developments.

2. ULTRASONIC HEAD LOCATOR

2.1 Overview

Upon energisation with an appropriate electronic gating circuit, an ultrasonic transmit transducer emits inaudible sound waves which propagate through the air until they strike an object. An attenuated portion of the transmitted signal is then returned and picked up by an adjacent receive transducer. By application of Pulse Mode transmission the time taken for a "burst" of pulses to travel from transmitter to receiver is determined, providing a measure of distance travelled. The velocity of sound in a homogenous medium is finite (331 m/s in air) and the delay is proportional to the distance travelled by the signal.

The ultrasonic head-control unit used comprises ultrasonic transmit/receive transducers positioned on a semi-circular tubular steel headset. Two sets of *transmit* and *receive* transducers are utilised, located at angles of approximately 45 degrees in the plane to the rear of the operator's head. Head position may be estimated by obtaining the time delay for each set of transducers consecutively and applying a trigonometric co-ordinate calculation. Measurements are made relative to a central position (axial point (0,0)), located mid way between the left and right side transmitter pairs (figure 1). The system is designed that position and height of each transducer pair and of the supporting frame is possible, thus enabling best fit to meet individual user requirement. Inexpensive piezoelectric transmit and receive transducers with resonant frequency 40 KHz have been utilised.

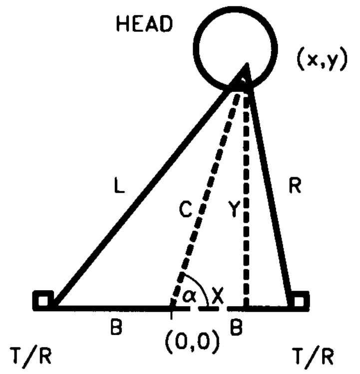

Figure 1. *Arial view depicting head position relative to fixed left and right transducer sets*

2.2 Distance measurement

Prototype transmit and receive circuits have been designed and tests performed to determine the relationship between distance travelled by the ultrasonic signal between transmitter and receiver and the time delay calculated by the microprocessor. Table 1 summaries these tests. The value of speed of ultrasound used to calculate distance travelled was 331 m/s.

Table 1. *Distance-Time measurements of echo ultrasound signal*

Distance between transmitter and receiver (cm)	Time delay to receipt of echo signal (ms)	Calculated distance between transmitter and receiver (cm)
62	1.95	64.55
57	1.80	59.58
52	1.65	54.60
47	1.50	49.60
42	1.35	44.69
37	1.20	39.72
32	1.05	34.76
27	0.90	29.79
22	0.74	24.49
17	0.59	19.53
12	0.45	14.90
9.5	0.38	12.58
7	0.31	10.26
4.5	0.22	7.20

Upon plotting a graph of distance travelled versus time delay, based on the results listed in table 1, a linear relationship is obtained.

2.3 System Control

A Motorola 68HC11 microprocessor has been adapted as the system control unit. Two control signals are required from the microprocessor to enable generation of the transmission signals, one for each of the left and right transducer sets, and the transmission is to occur periodically so that the position of the head may be regularly updated. This has been achieved by utilising the microprocessors output Compares (OC) facility . The timing system of the microprocessor is set at 2 MHz, corresponding to a cycle time of 500 ns (clock increment time). OC2 is used as the control signal for the left transducer set and OC3 for the right. OC2 and OC3 occur for set values of the free running clock, setting respective pins high. A further output compare OC1 has been configured to further clear OC2 and OC3. The returning ultrasonic echo signal causes a rising edge on either Input Capture IC2 or IC3, resulting in generation of appropriate interrupts. A block diagram representation of the system is shown in figure 2.

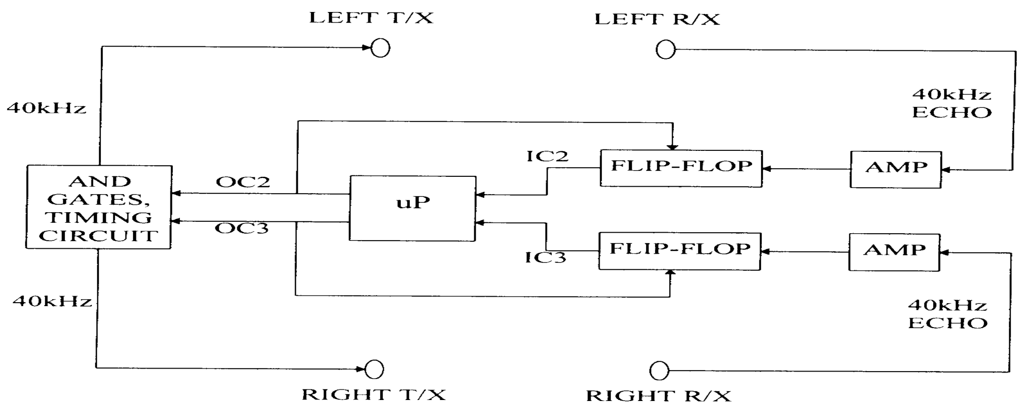

Figure 2. *Microprocessor control of ultrasonic transmission/reception process*

2.4 Averaging

The microprocessor samples head position once for every complete cycle of the free-running timer, corresponding to FFFFhex increments at 500 ns for each increment. This will result in new values for head position at 32 ms intervals. To help reduce 'jitter' associated with slight changes in head position should the user choose to remain still, the timer values obtained have been averaged in groups of 16. The averaged value is then made available for transmission to the PC.

2.5 Co-ordinate Mapping of Head Position

The two ultrasonic delay time values obtained from IC routines are processed to enable X-Y co-ordinate values be determined, providing information on user head location. The two ultrasonic distance values **L** and **R** and the distance between the two transducer pairs, 2**B**, are required. By application of the Cosine Rule the X and Y co-ordinate values may be determined. The origin reference point, (0,0), is located mid-way between the two transducer pairs. Taking **C** and **α** to represent the co-ordinates in polar-form,

$$x = C*Cos(\alpha), \qquad y = C*Sin(\alpha),$$

Cosine Rule: $$a^2 = b^2 + c^2 - 2bcCos(\alpha)$$

hence, $$L^2 = B^2 + C^2 -2BCCos(180 - \alpha)$$

$$R^2 = B^2 + C^2 -2BCCos(\alpha)$$

$$L^2 - R^2 = 4BCCos(\alpha)$$

$$\Rightarrow x = (L^2 - R^2)/4B.$$

The height of the triangle, i.e. the Y ordinate is found by application of Pythagoras Theorem,

if R < L: $$y = \sqrt{[L^2 - (B + X)^2]}$$

if R > L: $$y = \sqrt{[R^2 - (B - X)^2]}$$

3. TELEPHONE INTERFACE

In the current application a system has been designed which enables a disabled operator make a telephone call. This is achieved by observing a Graphic User Interface of a telephone pad on the PC screen and by making head movements which allows a number be selected and dialled.

A block diagram of the component elements making up the system is shown in figure 3. The ultrasonic transducers have been mounted on a semi-circular tubular headset, with the user head acting as a non-invasive movement control mechanism.

3.1 Graphic User Interface

A GUI is provided on the PC screen which takes the form of a telephone keypad. Upon activation of the GUI, positional movements of the head will result in placement of the cursor over a desired number. Once this number has been highlighted, a movement to the **S**elect button will result in a highlighted digit being placed in a telephone number array. A complete telephone number can be built up in this fashion and the number dialled by choosing the **D**ial function. A **De**lete button was also incorporated to allow the user remove digits from the array. In addition to these keys a number of function buttons were also provided, giving redial and directory facilities to the user. The directory facility enables the user 'fast dial' a number from a personalised directory, hence minimising upon required number of head movements in achieving a successful dial. **H**elp and **999** buttons provide the user with a quick-dial facility in emergency situations (figure 4).

3.2 Adapted Telephone

The internal configuration of a push-button telephone, the principal of operation of which is based upon the Bell Laboratories Dual Tone Multi-Frequency (DTMF) design concept, was analysed, and an imitation telephone was designed, suitable for usage in demonstrating the project concept. "Dual Tone" infers the addition of two individual tones, resulting in a single tone. The adapted telephone has an attached output speaker to enable one hear the dialled tones. The adapted telephone contains a small speaker, thus enabling one hear the generated tones.

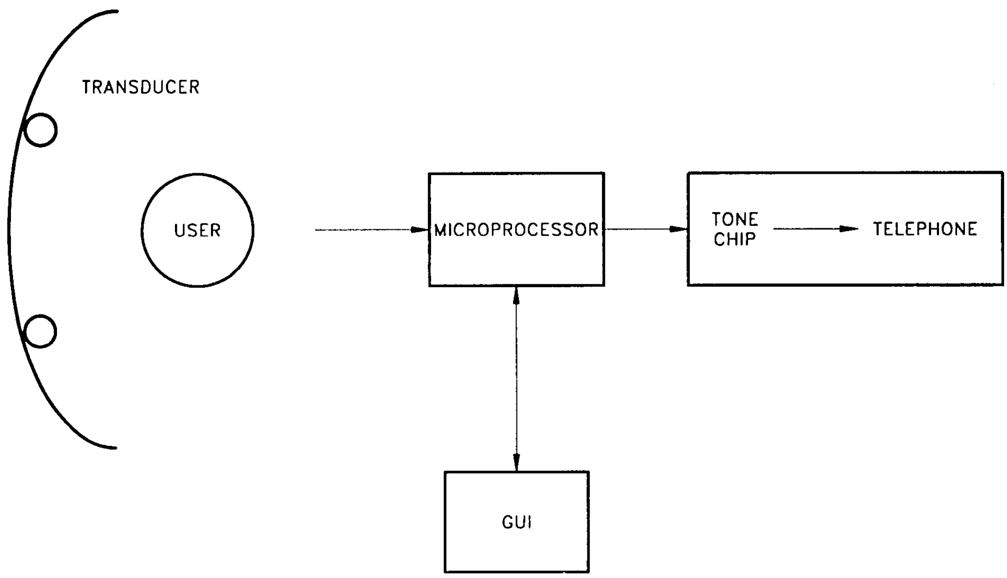

Figure 3. *Block diagram of the telephone interface*

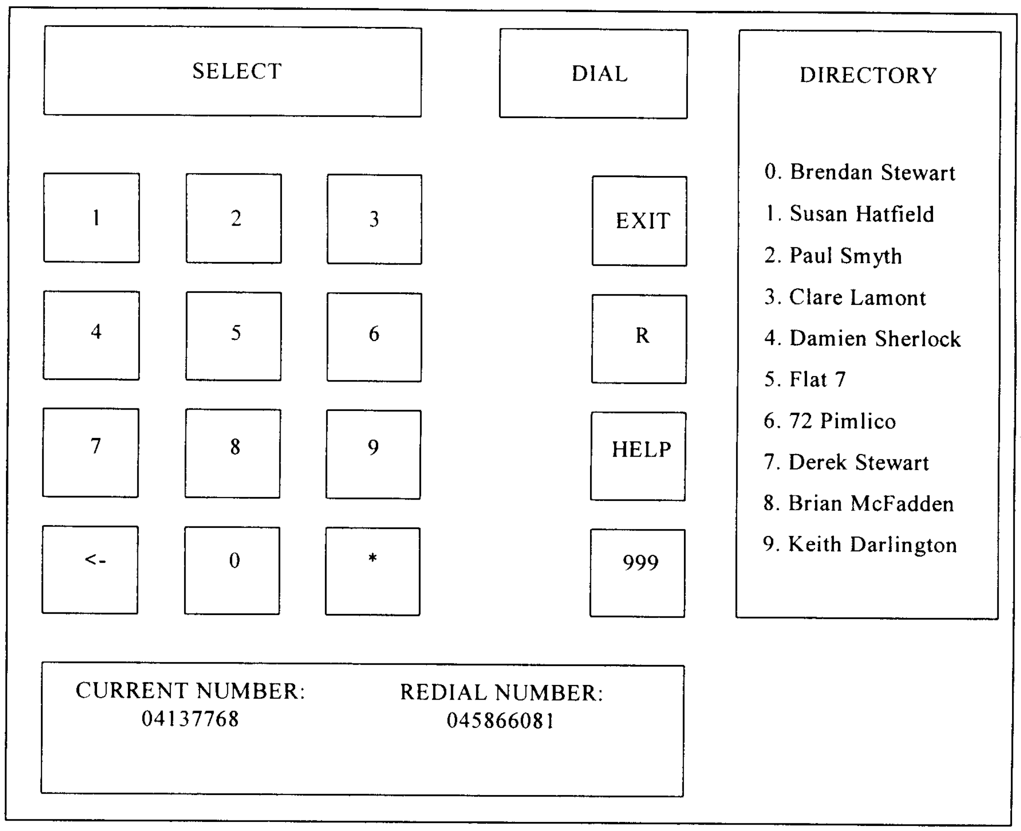

Figure 4. *Sample user interface*

3.3 System Testing

Various programmes have been designed, one of which provides the facility of cursor movement in all directions, as when using a standard PC mouse. However, for the purposes of providing a demonstration of the system, an x and y axial plane was found to be most suitable. The GUI on display was designed in a DOS environment using C language programming.

The prototype system as developed is user friendly and is relatively easy to use. Upon experimenting with the system it is a requirement that the user have reasonably good head movement control, otherwise successful operation of the system will prove difficult. The majority of people who have been invited to test the system have successfully managed to move and locate the cursor at all destination locations and to dial a desired number.

3.4 Serial Communication

The PC and microprocessor are arranged in a master-slave configuration. The PC decides when communication should take place by sending a byte of data to the microprocessor and causing a serial interrupt. The value of the byte determines the service required by the PC. There are three alternatives for the service required

1. The PC requires new time values from the μP to update the screen cursor
2. The PC wishes the μP to store a digit of the phone number
3. The PC wishes the μP to dial the number currently stored.

4. FURTHER PROJECT DEVELOPMENTS

4.1 Microsoft Windows Virtual Keyboard GUI

A further project is underway in development of an ultrasonically controlled system with the intention of enabling a user with upper limb disability interact fully in a Microsoft Windows environment. To enable the user enter text a GUI has been designed to emulate a standard keyboard. The *virtual keyboard*, taking the form of a graphic keyboard on the computer screen, is designed that a selected key results in text entry to a desired Windows application. The *virtual* GUI keyboard has been developed using Windows 'Hooks' to intercept the Windows message system. Although developed to operate by signal input command from the ultrasonic control unit, the virtual graphical keyboard has been designed as an independent entity. It is conceivable therefore that it may be applied in other areas of Medical Rehabilitation employing Personal Computers using Microsoft Windows.

To make the virtual keyboard easier to view a magnified view of each key on the keyboard has been designed into the system, the current key being highlighted in tandem with cursor mouse movement across the screen. It was important that the virtual keyboard be sufficiently large on the computer screen to be easily viewable but not too large that no other applications could be viewed at the same time. Using the magnified views of the keys reduces the size of the keyboard while maintaining the visibility of each key.

A further design feature includes a facility of updating the more commonly used words by the operator. A pop-up menu as designed to allow the user select a previously typed word with minimum mouse movement. A sample screen is shown in figure 5.

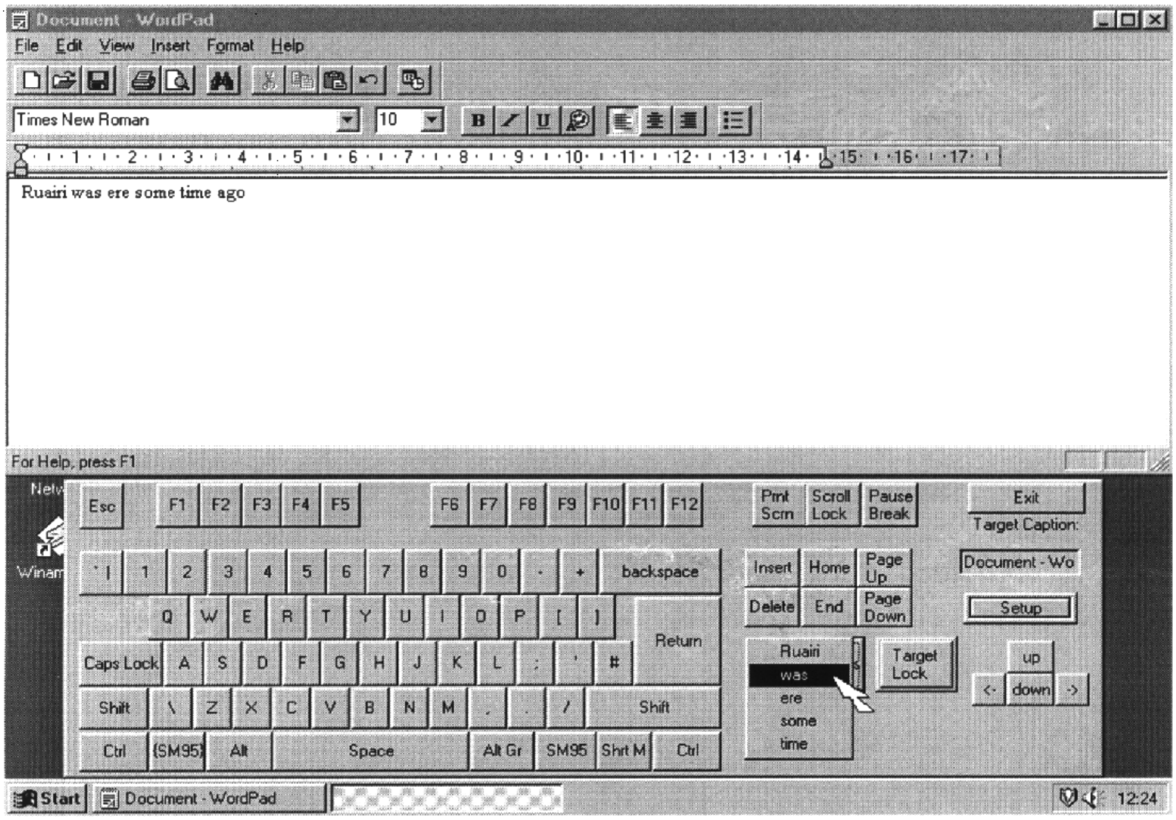

Figure 5. *Sample virtual keyboard with demonstration of 'quick selection' feature*

4.2 Hardware Mouse Modification

A second project has been initiated in which an investigation is underway into design and implementation of a hardware mouse interface. Initial results from this work are proving promising. The internal operation of a mouse may be appreciated by inspection of the diagram shown in figure 6. The push buttons connect to micro switches. This means that if they are pressed and closed a voltage level is supplied to an input pin of the mouse IC. The moving sensor system has mechanical and optical parts. The ball rotates due to the friction between the ball and mouse pad. This rotation is transmitted to two rollers, one for the x and y axes. Each roller is connected to one end of a shaft. The other end consists of a small disc with a small circle of holes. Roller rotation determines up/down and left/right motion.

A study has been made of the digital signals resulting from roller movement and based upon observation circuitry has been designed to enable replication and replacement of the sensor input. A MC68HC11 microprocessor together with the ultrasonic set have been configured to replace the direction sensors and ball. Development is at an early stage, however a prototype system has been developed and has been tested (not as yet by a person with upper limb disability). Some initial difficulties have been encountered and are to receive will further design consideration. Nevertheless the initial objective has been achieved and this presents a way forward which will require less software development than in the earlier described projects.

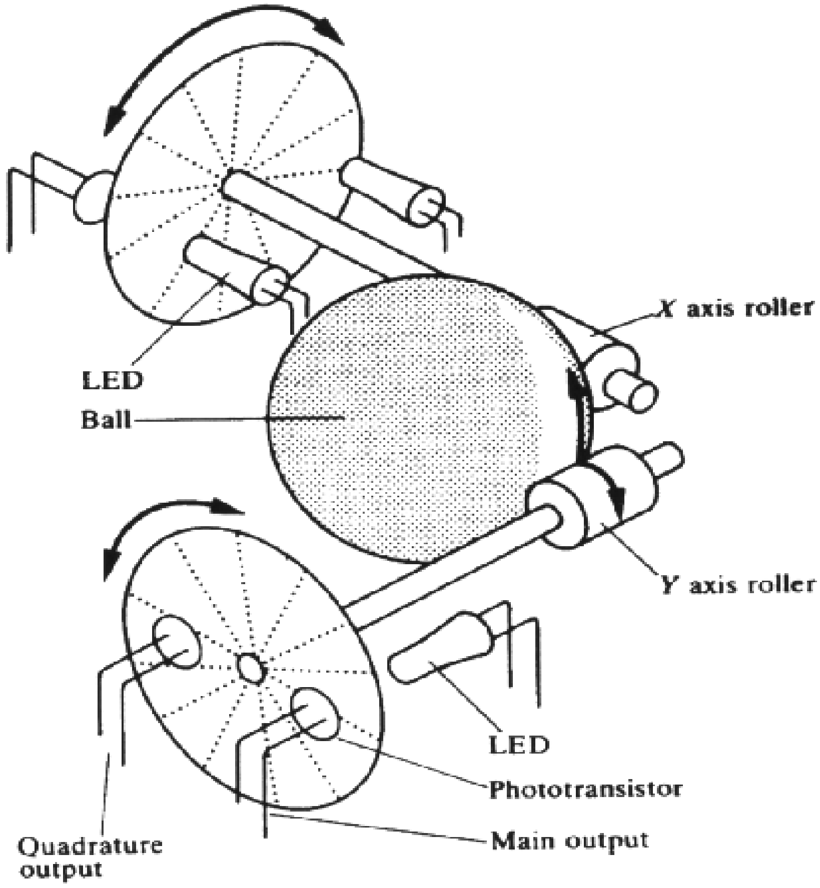

Figure 6. *The mechanical system of a mouse*

5. CONCLUSIONS

Experience has been gained in development of circuitry which has enabled ultrasonic transducers be used as an alternative non-invasive PC input device. Much effort has been made in development of a reliable ultrasonic instrumentation measuring device. A printed circuit board design incorporating a microcontroller, transmit, receive and associated circuitry components, has been manufactured.

The intention is that the measurement device may be used as the basis of and in association with one or more applications which may be of assistance to people with upper limb disability.

The primary prototype application described in section 3 of this paper, *non-invasive head control of a GUI telephone PC interface*, although software designed in a DOS environment, has been retained as an important show-piece of the developed research. The GUI screen as developed is non cluttered and pleasing to the eye and upon experimentation the user quickly gains confidence in controlling cursor movement by head movement alone. A dial tone is heard upon successful movement of the cursor to the dial button location.

Further research has been conducted in development of a small select word vocabulary *Speech Recognition* system (Newsome, 1995) and in *video Input Capture of the Eye* (Bourke, 1998), and it is intended that these additional alternative device input strategies be considered in parallel with non-invasive ultrasonic head/limb movement monitoring. It is envisaged that while results culminating from the three individual research branches will have useful application as stand alone entities, aspects from each may also be incorporated into a single system, designed to accommodate particular individual requirement.

6. REFERENCES

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