"FOVEAL"

A foveally coupled print procedure

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Acoustics and Sensory Physics, October 1977

LABORATORY FOR TECHNICAL PHYSICS
LORENTZWEG
DELFT

With thanks to: E. Tenkink
J.H. ten Kate
E.E.E. Frietman
W. Willems
J.K. Faase

Acoustics and Sensory Physics, Delft, October 1977.

INTRODUCTION

Some time ago, the so-called Eye-Letter-Selector was developed and built in the Biophysical group (Frietman and Willems 1974, van den Dool and Vastert 1975). This is a device that enables communication for severely paralyzed patients who still possess oculomotor control. Using horizontal eye movements, characters are selected from a 6x6 matrix in the following way:

Looking to the left, i.e., beyond an adjustable (trigger) threshold, initiates the periodic illumination of the individual vertical columns at a certain frequency. When the column containing the desired letter is reached, looking to the right stops the illumination. This is followed by a similar procedure for the desired horizontal row. The selected character is then printed.

The illumination frequency determines the maximum typing speed.

This selection procedure places minimal demands on the patient's eye movement system and requires only horizontal eye movement detection, but it is slow. After optimization, the maximum typing speed for healthy test subjects was found to be 15–20 letters per minute (ter Haar Romeny and Tenkink 1976 and 1977).

The idea of using direct gaze at the desired character for a certain duration as a selection procedure has existed for a long time. However, this requires vertical detection of eye movement, which is impossible with the infrared limbus reflection method since there is no visible iris-sclera transition (limbus) vertically. Placing all characters in a single horizontal row would make the system too sensitive to minor deviations.

The research question was: Is it possible to use the pupil-iris transition, possibly in combination with slight movement of the lower eyelid, for vertical detection?

In practice, it is not crucial what is being detected, as long as two distinct levels can be discerned.

Is it possible to achieve typing speeds of 80–100 letters per minute with this "foveally coupled matrix"? If so, this would reduce the memory demands on the patient.

How this was implemented—such that the above questions could be answered affirmatively (albeit only for one test subject)—is described below. The experiments were conducted on an exploratory basis.

DESCRIPTION OF THE SETUP AND PROCEDURE

The test subject (in this case, the patient) sits with their head fixed using a "bite-bar" and a forehead and chin rest at a distance of 1 meter from the display. This display consists of three horizontal rows: the top and bottom rows each contain 15 characters spaced 2° apart, and the middle row contains 15 yellow LEDs, also spaced 2° apart, providing visual feedback.

The characters are 20 mm tall and clearly visible. The two rows of characters are positioned 10° apart vertically. The four outermost characters have special functions, while the remaining ones form the alphabet and the punctuation marks '.' and '?'. See Figure 1.

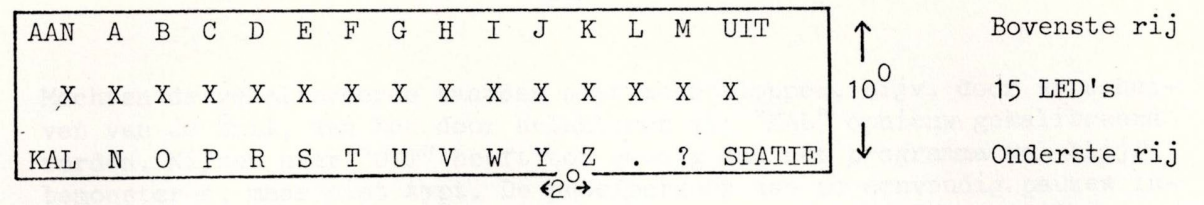

Fig. 1. The display with the characters.

Horizontal eye movements are measured on the left eye using the limbus reflection method, while vertical eye movements are measured on the right eye. Both eyes move almost identically under constant convergence (Hering's Law). The vertical detection ring, with its infrared LED and two phototransistors, is rotated 90° relative to the horizontal ring, and the infrared LED is positioned nasally.

A digital computer (PDP 8/E) samples the horizontal and vertical components of the eye movement at intervals determined by the voltage output of a potentiometer adjustable by the test subject. This voltage is sampled by a third ADC. See Figure 2. This interval, the time between two letters, thus determines the typing speed.

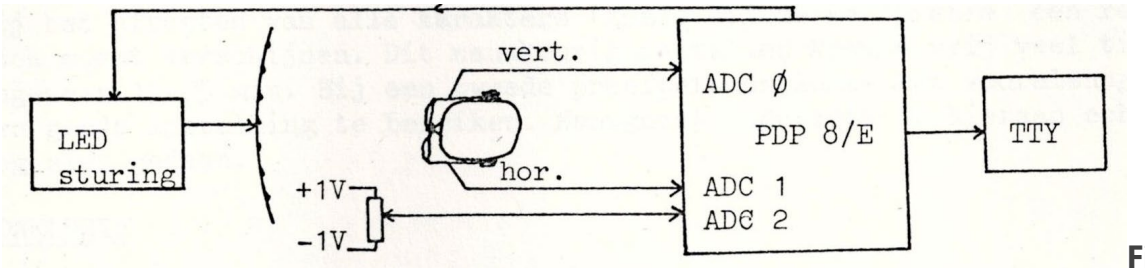

Fig. 2. The setup.

Sampling is performed by taking 10 samples over 100 ms to digitally filter out any noise. The software is provided below under the name "FOVEAL."

The procedure is as follows:

After starting the program, calibration is performed first. The LEDs illuminate sequentially from left to right and back every second. The test subject must fixate on the character above the illuminated LED when moving forward and on the character below the corresponding LED when moving back. Horizontal and vertical eye movements are sampled 450 ms after the shift to ensure the eye is in the correct position. Given the anticipatory nature of the stimulus, this was more than sufficient. A calibration takes 30 seconds.

The sampled values are stored in an array. After calibration, printing begins. The voltage from the potentiometer is sampled, and a corresponding number of milliseconds is waited. Then, the horizontal and vertical eye signals are measured, and for both the top and bottom rows, the best match with the calibrated values is determined. Of the two characters found (one from the top row and one from the bottom row), the one with the smallest deviation from the calibrated vertical eye signal is selected.

The four special characters are easier to reach because their selection area forms a quadrant with the respective character at the corner.

While the character is being printed on the teletype (100 ms), the LED corresponding to this character lights up for the same duration. During the time when no LED is visible to the test subject, a 16th invisible LED remains lit. If the calibrated values no longer match, for example, due to shifting glasses, recalibration can be performed by

selecting "CAL." Looking at "UIT" (OFF) causes the program to continue sampling but not printing. This allows the test subject to easily take breaks. A 1 ms flash of the LEDs provides feedback that no printing is occurring and where the eye is currently looking.

RESULTS AND DISCUSSION

Measurements were taken on one test subject, and after a learning period of about 30 minutes, typing speeds of 60–80 letters per minute were achieved. The most limiting factor was the inability to quickly locate the letters on the display.

For an optimal vertical signal, the vertical detection ring had to be positioned approximately 15 mm further from the eye than the horizontal ring, likely because detection was occurring at the pupil-iris boundary. However, it remains difficult to confirm whether this was indeed the case.

Since the iris and pupil are round, there is mutual interference between the horizontal and vertical signals. Minimizing this interference was facilitated by using an X-Y storage oscilloscope, which displayed a rectangle when scanning all characters (as during calibration). Precise adjustment of this took considerable time, approximately 15–25 minutes. For a second test subject, achieving a good setup proved unsuccessful initially, though further detailed investigation has not yet been conducted.

CONCLUSION

A foveally coupled print procedure is feasible. Typing speeds of up to 80 letters per minute are achievable after short learning periods. It is expected that longer learning periods could further increase the maximum possible typing speed.

PERSPECTIVE

The results of these exploratory experiments provide a starting point for further research into vertical eye movement detection using the infrared reflection method. Testing with more subjects will determine the required learning period and the maximum achievable typing speed.

Expansion to include more horizontal rows seems possible, allowing for additional functions, such as adjusting the time between letters with eye movements. Higher typing speeds may be achievable compared to methods using head movements to select letters from a matrix (Stassen and van Lunteren 1972).

Given the rapidly expanding capabilities of microprocessors, these could replace the computer, reducing costs.

LITERATURE

Ph. v.d. Dool and J. Vastert: An eye-letter-printer system and some measurements of the saccade and tracking system of the eye. Graduation thesis, TH Delft 1975.

E.E.E. Frietman and W. Willems: Communication aid device (Eye-Letter-Selector) for severely paralyzed patients. TH Delft 1974.

B.M. ter Haar Romeny and E. Tenkink: Analysis of the use of the Eye-Letter-Selector. Candidate thesis, TH Delft 1976.

idem — OLK '77. Intern rapport Biologische Natuurkunde, 1977

H.G.Stassen en A.van Lunteren — A lightspot operated typewriter for severely physically handicapped patients. Lab. of ergonomic psychology. Organisation for health research TNO, The Netherlands 1972

SOFTWARE

```
C       F C V E A L                          RCMENY   31/06/77
C       ===========
C
C       FCVEAL.SV IS EEN PROGRAMMA DAT HORIZONTALE EN VERTIKALE
C       OOGBEWEGINGEN SAMPELT EN EEN FOVEAAL GEKOPPELDE MATRIX
C       MOGELIJK MAAKT.
C       DE "MATRIX" BESTAAT UIT 2 HORIZONTALE ARRAYS VAN 15 KARAKTERS
C       ELK.
C       DE VOLGORDE IS ALS VOLGT (DE 4 BUITENSTE HEBBEN SPECIALE
C       FUNKTIES):
C
C        (AAN) A B C D E F G H I J K L M (UIT)
C              . . . . . . . . . . . . . .
C        (KAL) N O P R S T U V W Z . , ? (SPATIE)
C
C       ADC(0) SAMPELT DE VERTIKALE OOGBEWEGING;
C       ADC(1) SAMPELT DE HORIZONTALE OOGBEWEGING;
C       ADC(2) SAMPELT EEN SPANNING DIE EEN MAAT WORDT VOOR DE VER-
C       BLIJFTIJD PER LETTER.
C
C       EERST WORDT GEKALIBREERD.
C
C
S       OPDEF DIXY 6055
S       OPDEF DILX 6053
S       OPDEF DILY 6054
S       OPDEF CLCF 6132
S       OPDEF CLZE 6130
S       SKPDF CLSK 6131
S       OPDEF CLSA 6135
S       OPDEF CLAB 6133
S       OPDEF ADLM 6531
S       OPDEF ADST 6532
S       OPDEF ADRB 6533
S       SKPDF ADSK 6534
S       OPDEF ADLE 6536
        DIMENSION IOOO(2,30),N(31),L(15),M(15)
        IO=0
        IB=0
        IAFW=0
        ITIJD=0
S       JMS TOEKEN
S       DILY                         /Y-AS OP .5
        NX=N(8)
S       TAD \NX;DILX                 /MIDDELSTE LED AAN
S       CLA CLL
```

```
        READ(1,10)KEUZE
10      FORMAT('DRUK RETURN VOOR BEGINNEN.'A2)
S       CLA CLL CMA;CLZE;CLA CLL
S       TAD (6300;CLOE;CLA CLL   /KLOK OP 1 KHZ
140     CONTINUE
S       JMS KALIB
S       JMS CRLF                 /MAX. 64 LETTERS PER REGEL
90      NX=N(31)
S       TAD \NX;DILX;CLA CLL     /16-E LED AAN
S       JMS WISEC
C
C       SAMPLE EN PRINT LETTER
C
S NEXT, CLA CLL IAC RAL          /AC=2
S       ADLM;CLA                 /ENABLE ADC(2)
S       ADST                     /START CONVERSION
S WAD2, ADSK
S       JMP WAD2
S       ADRB                     /READ ADC(2) IN AC
S       TAD (1000;RAL
S       CIA                      /TWO'S COMPLEMENT
S       CLAB
S       CLSA                     /CLEAR CLOCK STATUS
S WT,   CLSK
S       JMP WT
S       CLA CLL
S       JMS SAMP
S       CLA CLL IAC;DCA BOVEN    /ZET VLAG=1 : BOVENSTE RIJ
S       TAD (1000;DCA ADRES
S ONDER,TAD (-17;DCA TELLER      /ZET TELLER OP -15
S       TAD (3777;DCA MINIM
S NXT,  CLA CLL
S       TAD I ADRES              /VOLGENDE ELEMENT VAN IOOG(1,I)
S       CIA
S       TAD \IX                  /BEPAAL AFWIJKING
S       SMA;SKP;CIA              /MAAK ABSOLUUT
S       DCA \IAFW
S       TAD \IAFW
S       CIA
S       TAD MINIM                /TREK VAN HUIDIG MINIMUM AF
S       SPA CLA
S       JMP NEE                  /GEEN KLEINER MINIMUM
S       TAD TELLER
S       DCA \IO                  /BEWAAR I-WAARDE (ONDERSTE RIJ)
S       TAD \IAFW;DCA MINIM      /ZET AFWIJKING ALS NIEUW MIN. WEG
S NEE,  ISZ ADRES;ISZ ADRES      /IOOG IS 2-DIM.
S       ISZ TELLER
S       JMP NXT
C
S       CLA CLL;TAD BOVEN
S       SNA CLA                  /ONDERSTE RIJ AL GEHAD?
S       JMP ERUIT                /JA
S       TAD \IO;DCA \IB          /NU IS I BOVENSTE RIJ BEKEND
S       DCA BOVEN                /CLEAR ONDER-BOVEN FLAG
S       JMP ONDER
S ERUIT,CLA CLL
        I1=16+IB
        I2=15-IO
```

```
C BEPAAL WELKE VERTIKALE AFWIJKING DE KLEINSTE IS
          IF(IABS(ICOO(2,I1)-IY)-IABS(ICOO(2,I2)-IY))100,90,121
100       K=L(I1)
          NX=N(I1)
S         TAD \NX;DILX;CLA CLL     /I-E LED AAN GEDUR.100 MS
S         JMS PRINT
          GOTO 90
121       K=M(-IO) → 16_IO
          NX=N(-IO)→ 16_IO
S         TAD \NX;DILX;CLA CLL     /I-E LED AAN GEDUR.100MS
S         JMS PRINT
          GOTO 90
C
C         AAN
120       IFL=0
          GOTO 90
C
C         UIT
130       IFL=1
          GOTO 90
C
C         SPATIE
150       K=160
          GOTO 110
C
C         SUBROUTINES
C
S TOEKEN,0
S         CLA CLL
          N(1)=-380
          N(2)=-323
          N(3)=-276
          N(4)=-225
          N(5)=-179
          N(6)=-123
          N(7)=-75
          N(8)=-17
          N(9)=28
          N(10)=78
          N(11)=127
          N(12)=179
          N(13)=228
          N(14)=275
          N(15)=319
          N(31)=385
          DO 5 K=16,30
5         N(K)=N(31-K)
          L(1)=1
          M(1)=4
          DO 6 K=2,14
          L(K)=191+K
6         M(K)=204+K
          L(15)=2
          DO 7 K=5,10
7         M(K)=M(K)+1
          M(11)=218
          M(12)=174
          M(13)=172
          M(14)=191
          M(15)=3
S         CLA CLL
S         JMP I TOEKEN
```

```
C
C       KALIBRATIE
C
S KALIB,0
        IFL=0
        NY=100
S       TAD \NY;DILY;CLA            /BOVENSTE RIJ
        DO 30 I=1,30
        IF(I-15)201,201,202
202     NY=-100
S       TAD \NY;DILY;CLA            /ONDERSTE RIJ
201     NX=N(I)
S       TAD \NX;DILX;CLA CLL
S       CLSA;CLA CLL                /CLEAR CLOCK STATUS
S       TAD (-702;CLAB              /START CLOCK -450 MS
S WCL,  DIXY                        /INTENSIFY
S       CLSK
S       JMP WCL
S       CLA CLL
S       JMS SAMP
        IOOG(1,I)=IX
        IOOG(2,I)=IY
S       CLSA;↑OCLA CLL;TAD (-702;CLAB
S WCL1, DIXY;CLSK
S       JMP WCL1
S       CLA CLL
30      CONTINUE
S       JMP I KALIB
C
C       SAMPLE ROUTINE
C
S SAMP, 0
        AD1=0
        AD0=0
        DO 40 N1=1,10
S       CLSA;CLA CLL                /CLEAR CLOCK STATUS
S       TAD (-12;CLAB               /START CLOCK -10 MS EN WACHT
S W24,  DIXY
S       CLSK
S       JMP W24
S       CLA CLL IAC;ADLM;CLA        /ENABLE ADC(1)
S       ADST                        /SAMPLE
S WAD1, DIXY
S       ADSK
S       JMP WAD1
S       ADRB                        /ADC(1) IN AC
S       DCA \IAD1
S       ADLM                        /ENABLE ADC(0)
S       ADST                        /SAMPLE
S WAD0, DIXY
S       ADSK
S       JMP WAD0
S       ADRB
S       DCA \IAD0
        AD1=FLOAT(IAD1)+AD1
40      AD0=FLOAT(IAD0)+AD0
        IX=AD1/10.
        IY=AD0/10.
S       CLA CLL;TAD \IX;TAD (1000;DCA \IX
S       TAD \IY;TAD (1000;DCA \IY
S       JMP I SAMP
```

```
C
S PRINT,0
S       CLA CLL
        IF (K-4) 101,101,106
101     K1=K+4*IFL
        GOTO (120,130,140,150,120,130,140,90)K1
106     IF(IFL)90,110,90
110     CONTINUE
S       TAD \K
S       JMS TYPE
S       ISZ IAANT
S       JMP I PRINT
S       JMS CRLF
S       JMP I PRINT
C
S CRLF, 0
S       TAD (215;JMS TYPE       /CARRIAGE RETURN
S       TAD (212;JMS TYPE       /LINE FEED
S       TAD (-100;DCA IAANT     /TELLER WEER OP -64
S       JMP I CRLF
C
S TYPE, 0
S       TLS
S TTYFL,TSF
S       JMP TTYFL
S       CLA CLL
S       JMP I TYPE
S WISEC,0
S       CLA CLL
        IDUIZ=-1000
S       TAD \IDUIZ
S       CLAB
S       CLSA
S WIS,  CLSK
S       JMP WIS
S       CLA CLL
S       JMP I WISEC
S IAANT,0
S MINIM,0
S BOVEN,0
S ADRES,0
S TELLER,0
        END
```

Delft, oktober 1977