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TOUCH SIGNAL DETECTION IN THE PRESENCE OF GAUSSIAN NOISE AND INTERFERENCE

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Abstract. In this paper we determine an optimum receiver for Touch signal detection in the real conditions of ambient sensitivity to which the interference, in addition to the Gaussian noise, is superimposed. The passive component, which is the consequence of the ambient illumination effect and the interference, is presented by the sum of Dirac's pulse. In the second part of the paper we calculate the error probability and we define the threshold for decision about existence or non-existence of optical infrared beam between selective pair infrared transmitter of a receiver.

Key Words: Touch interface, Error probability, Gaussian noise.

1. Indroduction

Touch terminals/monitors are sensitive to the touch on the screen and are applied in the function of input-output devices of the computer systems. The communication in the direction user-computer system is made by the touch on the screen of the monitor cathode tube, which selects one of the presented graphic objects on the screen. On the basis of this the computer system undertakes activities defined by the software [2, 3]. Touch interface is a hardware-software block of the touch monitor/terminal which makes it possible the detection and positioning of the touch on the screen of the monitor cathode tube and is realized on the basis of: a) resistant, b) capacitive, c) optical infrared (IR) and d) acoustic technology [4,5]. The mentioned characteristics of the optical IR touch interfaces recommend them for the application the cases where the great optical resolution in not demanded and where the advantage of the optical IR touch technology is manifested as for instance in military devices, in factories, on the airports, railway and bus stations etc. The imperfection of the optical IR touch technology in relation to other technologies is reflected in a great dependence on the ambient illumination in which the device works. The ambient illumination can range from the total darkness to the case in which the touch terminal/monitor is exposit to the direct effect of the sunlight or reflector place in a short distance. In addition to that the ambient illumination can be such that only one part of the cathode tube screen of terminal/monitor is exposed to the intensive illumination or that the illumination level aperiodically changes etc.

We shall further treat the problems of separation of the active component from the complex Touch signal of Touch signal in the presence of a changeable level of the ambient illumination, Gaussian noise and interference by the adapted receiver. In order to determine performances of the receivers we shall calculate the error probability.

2. Optical Infrared Touch Interface

Mechanically the Touch interface is realized in the form of a frame, which consists of printed boards on which there are elements placed. Within the frame IR transmitter and receivers are positioned fronting each other on the horizontal and vertical sides (Figure 1). To each transmitter the corresponding receiver is attached and they represent the optical IR pair. The frame is placed on the edge of the cathode tube screen so that the light beam between the transmitter and the receiver of every optical pair goes parallels to the screen surface. In front of the screen the net of the optical beams is formed to which the optical matrix is pointed. The finger touch on the screen causes the interruption of at least one optical beam on horizontal and one on the vertical sides. By the software testing of the existence or non-existence of the optical beam it is possible to determine the position in the optical matrix within which the touch on the screen is detected and on the basis of that to locate the position of the touch.

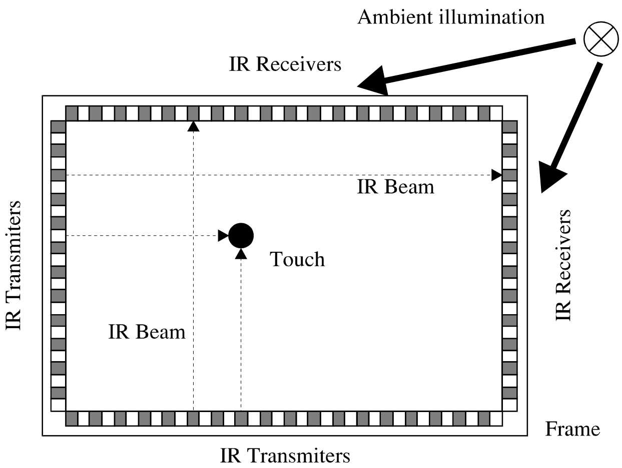

Figure 1. Arrangement of optical IR transmitters and receivers within the Touch interface

Figure 2. shows the functional block diagram of Touch interface. Selecting of optical IR pairs (Infrared Transmitter – IRT_i, Infrared Receiver – IRR_i) is carried out on the base of the address *addr(i)* by means of functional blocks, multiplexer and demultiplexer. Touch signal, x(t), is formed from signals $x_{IRb0}(t)$, $x_{IRb1}(t)$, ..., $x_{IRb(M-1)}(t)$, by using of time multiplexing, where IRb (InfraRed beam) is the optical IR beam and M is the total number of optical IR pairs transmitter/receiver. The signals $x_{IRb0}(t)$, $x_{IRb1}(t)$, ..., $x_{IRbM-1}(t)$, have been generated as a result of simultaneous acting of IR transmitter ($x_{IRb0act}(t)$, $x_{IRb1act}(t)$,..., $x_{IRb(M-1)act}(t)$) and the ambient illumination ($x_{IRb0pas}(t)$, $x_{IRb1pas}(t)$, ..., $x_{IRb(M-1)pas}(t)$) in which touch interface is located. That is the reason why the resulting signal, x(t) has two components which are: a) the passive component ($x_{IRb0pas}(t)$, $x_{IRb1pas}(t)$,...,$x_{IRb(M-1)pas}(t)$) which is the consequence of the ambient illumination and b) the active component ($x_{IRb0act}(t)$, $x_{IRb1act}(t)$, ..., $x_{IRb(M-1)act}(t)$) which is the result of acting of the appropriate IR emitters. The period of the active acting of IR transmitter is determined by the signal for the time synchronization *w(t)*, during the low logical state, and directly connected with the signal SLED(t) (Select LED). Fig. 3 shows a sequence of the Touch signal in the period of activity of the i-th optical pair.

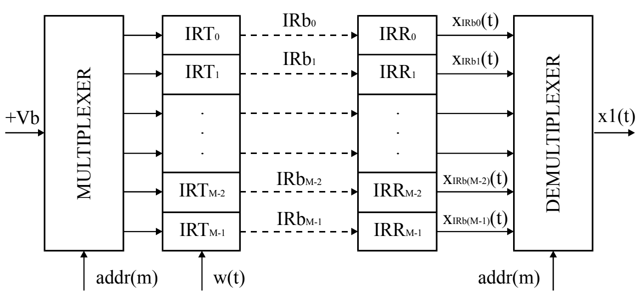

Figure 2. Functional block diagram of Touch interface

The decision on the existence or non-existence of IR beam is made on the basis of the analysis of the active component. Separation of the active component from Touch signal is complicated because of the overlapping of the active and passive components in time and frequency domain. In [7] it is given the description of the algorithm for digital processing of Touch signal where time selection and separation of the active component is done by means of the rectangular window function.

Future in this paper the separation of the active component of Touch signal by means of the adapted receiver.

3. Optimal Receiver

For the i-th optical pair Touch signal has the following form:

$$x(t,i) = \begin{cases} x_{IRbi\_pas}(t), & 0 \le t \le T_{pas} \\ x_{IRbi\_act}(t), & T_{pas} < t \le T_{pas} + T_{act} \end{cases}, \quad (1)$$

where *i=0,...M-1* and *M* represents the total number of optical infrared pairs.

If we neglect the effect of the ambient illumination, the active component of Touch signal can be represented in this form:

$$x_{act}(t,i) = S\left(1 - e^{-\alpha t}\right), \; 0 \le t \le T_{act}, \quad (2)$$

where T_{act} is the period of the active functioning of the i-th IR transmitter, S is the amplitude of the active component and a is the parameter which determines signal time form [6].

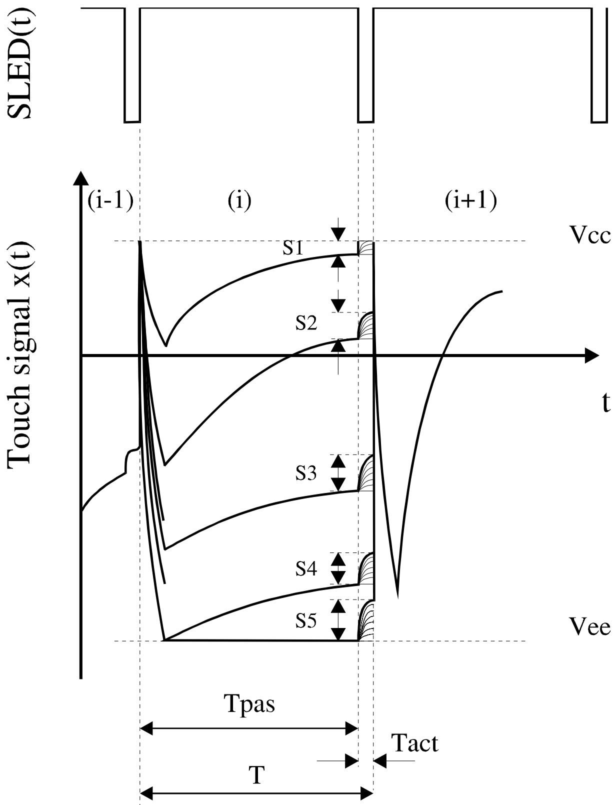

Figure 3. Touch signal in the period of activity of the i-th optical pair

The hypothesis, when during the active period there is no active component in Touch signal, in case when the optical beam is interrupted by the touch of a finger on the screen, we denote with:

$$H_0 : \ \mathrm{r}(\mathrm{t}) = \mathrm{n}(\mathrm{t}) + \mathrm{v}(\mathrm{t}) + \omega(\mathrm{t}); \ 0 \le \mathrm{t} \le \mathrm{T}_{\mathrm{act}}, \qquad (3)$$

and the hypothesis when the active component is present, the case when the optical infrared beam exists between the transmitter and receiver (there is no touch on the screen), we denote with:

$$\begin{aligned} H_1 : \ \mathrm{r}(\mathrm{t}) &= \mathrm{x}_{\mathrm{act}}(\mathrm{t,i}) + \mathrm{n}(\mathrm{t}) + \mathrm{v}(\mathrm{t}) + \omega(\mathrm{t}) \\ &= S\left(1 - e^{-\alpha t}\right) + \mathrm{n}(\mathrm{t}) + \mathrm{v}(\mathrm{t}) + \omega(\mathrm{t}); \ 0 \le \mathrm{t} \le \mathrm{T}_{\mathrm{act}} \end{aligned}, \qquad (4)$$

where *n(t)* is the white Gaussian noise, *v(t)* is causal variable that stands for the passive component of Touch signal, that is the effect of the ambient illumination and *ω(t)* represents the interference (Figure 4).

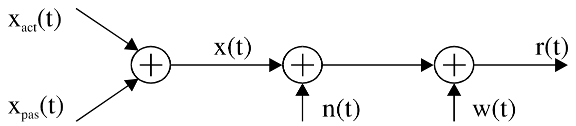

Figure 4. The complex signal on the input in an optimal receiver

We shall express the probability of the appearance of some levels of the passive component via the sum of Dirac's impulses:

$$p(v) = \sum_j v_j \cdot \delta\left(v - v_j\right). \qquad (5)$$

Also we shall express the probability of the appearance of some levels of the interference via the sum of Dirac's impulses:

$$p(\omega) = \sum_k W_k \cdot \delta(\omega - \omega_k). \qquad (6)$$

The authenticity function for the hypothesis H_1 is:

$$\begin{aligned} p_1\left(r/_{v,\omega}\right) &= F \cdot e^{-\frac{1}{N_0}\int_0^{T_{act}} \left[r(t) - x_{act}(t,i) - v - \omega\right]^2 dt} \\ &= F \cdot e^{-\frac{1}{N_0}\int_0^{T_{act}} \left[r(t) - S\left(1 - e^{-\alpha t}\right) - v - \omega\right]^2 dt} \end{aligned} . \qquad (7)$$

The authenticity function for the hypothesis H_0 is:

$$p_0\left(r/_{v,\omega}\right) = F \cdot e^{-\frac{1}{N_0}\int_0^{T_{act}} \left(r(t) - v - \omega\right)^2 dt}, \qquad (8)$$

where N_0 is the spectral density of the Gaussian noise power and F is a constant.

The authentic relation represents the quotient of authenticity functions and is gained in this form:

$$\lambda(r) = \frac{p_1(r)}{p_0(r)} = \frac{\int\limits_v \int\limits_\omega p_1\left(r/_{v,\omega}\right) \cdot p(v) \cdot p(\omega) \cdot dv d\omega}{\int\limits_v \int\limits_\omega p_0\left(r/_{v,\omega}\right) \cdot p(v) \cdot p(\omega) \cdot dv d\omega}. \qquad (9)$$

The authenticity function for the hypothesis H_1 is:

$$\begin{aligned} p_1(r) &= \int\limits_v \int\limits_\omega p_1\left(r/_{v,\omega}\right) \cdot p(v) \cdot p(\omega) \cdot dv d\omega \\ &= \int\limits_v \int\limits_\omega F \cdot e^{-\frac{1}{N_0}\int_0^{T} \left[r(t) - S\left(1 - e^{-\alpha t}\right) - v - \omega\right]^2 dt} \cdot p(v) \cdot p(\omega) \cdot dv d\omega \\ &= F \cdot e^{-\frac{1}{N_0}\int_0^{T_{act}} r^2(t) dt - \frac{S^2}{N_0} \cdot f_1(T_{act},\alpha) + \frac{2S}{N_0}\int_0^{T_{act}} r(t) \cdot \left(1 - e^{-\alpha t}\right) dt} \\ &\cdot \sum_j \sum_k v_j W_k e^{-\frac{T_{act}\left(v_j + \omega_k\right)^2}{N_0} + \frac{2\left(v_j + \omega_k\right)}{N_0}\int_0^{T_{act}} r(t) dt - \frac{2S\left(v_j + \omega_k\right)}{N_0} f_2(T_{act},\alpha)} \end{aligned} \qquad (10)$$

where

$$f_1(T_{act},\alpha) = \int_0^{T_{act}} \left(1 - e^{-\alpha t}\right)^2 dt, \qquad (11)$$

and

$$f_2(T_{act},\alpha) = \int_0^{T_{act}} \left(1 - e^{-\alpha t}\right) dt. \qquad (12)$$

Finally we can write:

$$\begin{aligned} p_0(r) &= \int\limits_v \int\limits_\omega p_0\left(r/_{v,\omega}\right) \cdot p(v) \cdot p(\omega) \cdot dv d\omega \\ &= \int\limits_v \int\limits_\omega F \cdot e^{-\frac{1}{N_0}\int_0^{T_{act}} \left[r(t) - v - \omega\right]^2 dt} \cdot p(v) \cdot p(\omega) \cdot dv d\omega \\ &= F \cdot e^{-\frac{1}{N_0}\int_0^{T_{act}} r^2(t) dt} \cdot \\ &\cdot \sum_j \sum_k v_j W_k e^{-\frac{T_{act}\left(v_j + \omega_k\right)^2}{N_0} + \frac{2\left(v_j + \omega_k\right)}{N_0}\int_0^{T_{act}} r(t) dt} \end{aligned} . \qquad (13)$$

The final form of the authenticity relation is:

$$\lambda(r) = e^{-\frac{S^2}{N_0} f_1(T_{act},\alpha)} e^{\frac{2S}{N_0} X_1} \cdot \frac{\sum_j \sum_k v_j W_k e^{-\frac{\left(v_j + \omega_k\right)^2}{N_0} T_{act}} e^{\frac{2\left(v_j + \omega_k\right)}{N_0} X_2} e^{-\frac{2S\left(v_j + \omega_k\right) f_2(T_{act},\alpha)}{N_0}}}{\sum_j \sum_k v_j W_k e^{\frac{2\left(v_j + \omega_k\right)}{N_0} X_2 - \frac{\left(v_j + \omega_k\right)^2}{N_0}}} \qquad (14)$$

where

$$X_1 = \int_0^{T_{act}} r(t)\left(1 - e^{-\alpha t}\right) dt, \qquad (15)$$

and

$$X_2 = \int_0^{T_{act}} r(t) dt. \qquad (16)$$

The decision on the existence or non-existence of the optical IR beam between the active IR transmitter and IR receiver is made on the basis of:

$$\lambda(r) \underset{H_0}{\overset{H_1}{\gtrless}} \lambda_0 . \tag{17}$$

An optimal receiver adapted to the Touch signal in the active period, which makes the decision in accordance with (14), (15) and (16) is shown in Figure 5. The decision is made at the end of the active interval, when the receiver has access to the whole signal in the active period. On the basis of the relation (15) the impulse response should be:

$$h_1(t) = 1 - e^{-\alpha(T_{act}-\alpha)}; \quad 0 < \mathrm{t} < \mathrm{T_{act}} , \tag{18}$$

$$h_2(t) = 1; \quad 0 < \mathrm{t} < \mathrm{T_{act}} . \tag{19}$$

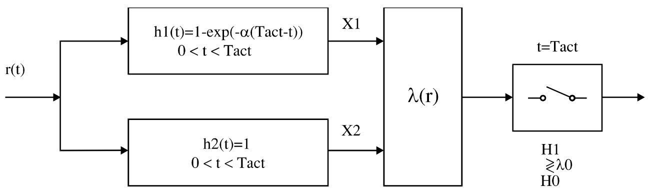

Figure 5. Optimal receiver

4. Error Probability

In the $t{=}T_{act}$ the random variable on the outlet from the filter is:

$$X = \int_0^{T_{act}} r(t)\cdot\left(1-e^{-\alpha t}\right)dt . \tag{20}$$

With the hypothesis that on the inlet there is no active functioning of the IR transmitter, that there is only Gaussian noise and passive component:

$$H_0: \quad \mathrm{r}(t) = n(t) + v(t) + \omega(t), \tag{21}$$

the signal on the outlet at the end of the active interval is:

$$\begin{aligned} \frac{X_0}{v,\omega} &= \int_0^{T_{act}} n(t)\cdot\left(1-e^{-\alpha t}\right)dt + (v+\omega)\int_0^{T_{act}}\left(1-e^{-\alpha t}\right)dt = \\ &= \int_0^{T_{act}} n(t)\cdot\left(1-e^{-\alpha t}\right)dt + (v+\omega) f_2(T_{act},\alpha) \end{aligned} . \tag{22}$$

The mean value of the variable X under the hypothesis H_0 is:

$$\begin{aligned} \frac{\overline{X_0}}{v,\omega} &= \int_0^{T_{act}} \overline{n(t)}\cdot\left(1-e^{-\alpha t}\right)dt + (v+\omega)\cdot f_2(T_{act},\alpha) \\ &= (v+\omega)\cdot f_2(T_{act},\alpha) \end{aligned} \tag{23}$$

The variance of the random variable X is:

$$\begin{aligned} \frac{\sigma_x^2}{v,\omega} &= \overline{\left(\frac{X_0}{v,\omega} - \frac{\overline{X_0}}{v,\omega}\right)^2} = \frac{N_0}{2}\int_0^{T_{act}}\left(1-e^{-\alpha t}\right)^2 d\tau \\ &= \frac{N_0}{2}\cdot f_1(T_{act},\alpha) = \sigma_x^2 \end{aligned} . \tag{24}$$

The distribution density of the random variable X for the hypothesis H_0 is:

$$p_0\left(\frac{x}{v,\omega}\right) = \frac{1}{\sqrt{2\pi}\sigma_x}\cdot e^{-\frac{(x-v-\omega)^2}{2\sigma_x^2}} . \tag{25}$$

$$\begin{aligned} p_0(x) &= \int_v\int_\omega p_0\left(\frac{x}{v,\omega}\right)\cdot p(v)\cdot p(\omega)dv d\omega \\ &= \sum_j\sum_k v_j W_k \frac{1}{\sqrt{2\pi}\sigma_x}\cdot e^{-\frac{(x-v_j-\omega_k)^2}{2\sigma_x^2}} \end{aligned} . \tag{26}$$

The hypothesis that the optical IR beam exists is:

$$\begin{aligned} H_1: \mathrm{r(t)} &= x_{act}(t) + n(t) + v(t) + \omega(t) \\ &= S\left(1-e^{-\alpha t}\right) + n(t) + v(t) + \omega(t) \end{aligned} . \tag{27}$$

Then the random variable on the outlet at the end of the active interval is:

$$\begin{aligned} \frac{X_1}{v,\omega} &= S\cdot\int_0^{T_{act}}\left(1-e^{-\alpha t}\right)^2 dt + \int_0^{T_{act}} n(t)\cdot\left(1-e^{-\alpha t}\right)dt \\ &\quad + (v+\omega)\int_0^{T_{act}}\left(1-e^{-\alpha t}\right)dt \\ &= S\cdot f_1(T_{act},\alpha) + \int_0^{T_{act}} n(t)\cdot\left(1-e^{-\alpha t}\right)dt + (v+\omega)\cdot f_2(T_{act},\alpha) \\ &= S\cdot f_1(T_{act},\alpha) + (v+\omega)\cdot f_2(T_{act},\alpha) \end{aligned} . \tag{28}$$

The variance of the random variable X_1 is:

$$\frac{\sigma_x^2}{v,\omega} = \overline{\left(\frac{X_1}{v,\omega} - \frac{\overline{X_1}}{v,\omega}\right)^2} = \frac{N_0}{2}\cdot f_1(T_{act},\alpha) = \sigma_x^2 . \tag{29}$$

The distribution density of the random X for the hypothesis H_1 is:

$$p_1\left(\frac{x}{v,\omega}\right) = \frac{1}{\sqrt{2\pi}\sigma_x}\cdot e^{-\frac{[x-Sf_1(T_{act},\alpha)-v-\omega]^2}{2\sigma_x^2}} . \tag{30}$$

$$\begin{aligned} p_1(x) &= \int_v\int_\omega p_1\left(\frac{x}{v,\omega}\right)\cdot p(v)\cdot p(\omega)\cdot dv d\omega \\ &= \sum_j\sum_k v_j W_k \frac{1}{\sqrt{2\pi}\sigma_x}\cdot e^{-\frac{(x-Sf_1(T_{act},\alpha)-v_j-\omega_k)^2}{2\sigma_x^2}} \end{aligned} . \tag{31}$$

The error probability is:

$$
\begin{aligned}
P_e &= P(H_0, p_1) + P(H_1, p_0) \\
&= p(H_0)\cdot p\left(p_1/H_0\right) + p(H_1)\cdot p\left(p_0/H_1\right) \\
&= p(H_0)\cdot \int_{V_T}^{\infty} p_0(x)dx + p(H_1)\cdot \int_{-\infty}^{V_T} p_1(x)dx \\
&= p(H_0)\cdot \sum_j \sum_k v_j W_k \int_{V_T}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_x}\cdot e^{-\frac{(x-v_j-\omega_k)^2}{2\sigma_x^2}} dx + \\
&\quad p(H_1)\cdot \sum_j \sum_k v_j W_k \int_{-\infty}^{V_T} \frac{1}{\sqrt{2\pi}\sigma_x}\cdot e^{-\frac{(x-v_j-\omega_k-S\cdot f_1(T_{act},\alpha))^2}{2\sigma_x^2}} dx \\
&= p(H_0)\cdot \sum_j \sum_k v_j W_k erfc\left(\frac{V_T - v_j - \omega_k}{\sigma_x}\right) + \\
&\quad p(H_1)\cdot \sum_j \sum_k v_j W_k erfc\left(\frac{S\cdot f_1(T_{act},\alpha) + v_j + \omega_k - V_T}{\sigma_x}\right)
\end{aligned}
\tag{32}
$$

5. Conclusion

This paper presents the optimum receiver for detection of the active component of Touch signal in the conditions of the changeable level of ambient illumination. The receiver is determined for the case when to Touch signal the white Gaussian noise and the interference are superimposed. The ambient illumination and interference are represented by the sum of Dirac's impulses. The decision threshold is determined and the error probability in making decisions on the existence or non-existence of the optical IR beam for some characteristic amplitude values of the active component, interference amplitude and a priori probabilities is calculated. The calculated error probability indicates the functional correctness and efficiency of the optimum receiver.

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