The research of the automatic temperature condition control systems for LCD screens of avionics indication equipment

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Abstract. In the aviation industry the primary modern equipment to display an information is color multi-function displays made on the basis of a plane LCD (liquid crystal display) panel. The problem is that LCD screen performances significantly depend on the ambient temperature. Local automatic temperature control systems are used to keep certain thermal conditions of LCD screens in avionics indication equipment. The problem of development a computer model of the automatic temperature control system of the avionics indication equipment is being studied.

1. Introduction

Exploitation of color multi-function display [1, 2] reveals that the device is affected with some exterior climate factors the most important of which are extremely low (minus 40 Celsius degrees) and extremely high (plus 70 Celsius degrees) ambient temperatures.

After several researches and experiments it is clear that the ambient temperature makes a significant impact on the colorimetric characteristics of an image displayed on the LCD panel. There is a shift of the image (x,y)-chromaticity coordinates which can be explained with the ambient temperature influence on the liquid crystals and on the spectrum reflectance of the backlight lamps (light emitting diodes). The absolute shift value of the (x,y)-chromaticity coordinates was estimated with the level of 0.0003 chromaticity unit per each Celsius degree of ambient temperature [3].

The (x,y)-chromaticity coordinates shift causes change of the position and the area of the LCD panel color gamut triangle on the XY-plane resulting change of the observer image visual perception characteristics. In that way the indication equipment color palette encoded with the RGB software codes (R – Red, G – Green, B – Blue) obtained to reach the maximum image contrast on a lighting equipment under the laboratory conditions and normal ambient temperature may become inappropriate when the ambient temperature varies in extremely wide range. This is the reason why it is an essential task to develop and research an automatic control system (ACS) [4, 5] which is capable to keep certain temperature mode of the LCD of a color multi-function display under different operating conditions.

2. Statement of the automatic control system research and parametric identification problem

Computer simulation of the ACS is one of the most effective ways to obtain the automatic control
system quality indices under different operating conditions without long-term full-scale experiments on breadboard models. The most important objective when development an ACS computer model is the model adequacy for describing the real system, compliance with its performances and physical principles which determine the base of the system functionality.

The automatic control system intended for stabilization of the temperature condition of the LCD panel as a main part of the color multi-function display is built as nonlinear automatic system with the relay control law. The classical approach to develop mathematical model of such type of ACS suggests the creation of structural model with feedback, the open circuit consists with serial connection of a relay element (RE) and a linear dynamic unit with a transfer function $W(s)$. The typical structural schematics of the ACS with the relay control law is shown on the figure 1.

$$x(t) \xrightarrow{\text{RE}} W(s) \xrightarrow{y(t)}$$

Figure 1. The typical structural schematics of the ACS with the relay control law.

The problem of the ACS research and identification includes identification of the transfer function $W(s)$ type and subsequent definition of the numerical values of the transfer function $W(s)$ parameters. To solve the problem the mathematical expressions which describe the heat exchanging process in an ACS must be defined and the parametric identification procedure must be done. The initial data for the ACS parametric identification procedure is the data obtained from a real experiment in the laboratory with a color multi-function display unit under the predefined ambient temperature conditions.

3. The model of the automatic system of stabilization of the LCD-panel operating temperature condition

For a comparatively simple ACS of temperature stabilization usually transfer function $W(s)$ is presumed to be first-order aperiodic unit and parameters of the $W(s)$ may be identified using the registered data of the system open loop step response. This simple approach has a disadvantage because heat exchange processes can’t be described precisely by the model with constant parameters when ambient temperature varies in the extremely wide range. The temperature mode of the LCD panel as a part of color multi-function display is affected with the following effects [6, 7]:

- the air ambient temperature of the exploitation conditions (in the climatic test chamber in laboratory);
- heat conductivity and convection characteristics of the indication equipment device;
- the level of power which supplies the LCD panel heating element;
- the operational mode of the internal cooling fan which changes the convection characteristics of heat exchange between the LCD panel and the environment.

The development of the temperature stabilization ACS model is based on the second law of thermodynamics and the laws of heat exchange:

- the heat exchange process which uses the thermal conductivity is described with the Fourier’s Law;
- the convection process is described with the Newton-Richmann Law.

Not counting for some differences in the physical processes description which both Laws include there is an experimentally approved fact that the heat quantity $Q$ passing through a surface unit area per time unit $t$ in the direction of normal to the boundary which divide the areas of different temperatures proportionally to those temperatures difference $\Delta T$, in other words the following is true:

$$\frac{dQ}{dt} = \gamma \Delta T,$$

where $\gamma$ – proportionality factor.

And also it is well known that when a heat quantity $\Delta Q$ is transferred to a physical body its
temperature increases by the value $\Delta T$:
\[
\Delta T = \frac{1}{C} \Delta Q,
\]
(2)

where $C$ – a physical body heat capacity.

The dynamics heat exchange processes are being considered when the heat quantity is altering in time, taking in mind the formula (2), can be described as:
\[
\Delta T(t) = \frac{1}{C} \int_0^t P(\tau) d\tau,
\]
(3)

where $P(t) = \frac{dQ(t)}{dt}$ – the heat flow which intensity is changing in time while the system is functioning. The heat flow value is measured with Joule per second.

The expressions (1)-(3) lead to the basic version of the computer model of the ACS of the color multi-function display LCD panel temperature mode stabilization. The ACS computer model is developed in the graphical programming environment Simulink. The proposed model schematic is shown on the figure 2. The output signal of the integrator (Integrator object) with the transfer function $W(s) = \frac{1}{s}$ reproduces the temperature dynamics of the controlled object (i.e. LCD panel) and element Scope_Temp visualizes the process. The value applied to the input $x_0$ defines the integrator initial state, meaning initial temperature of the LCD panel, equal to the ambient temperature value.

![Figure 2](image)

**Figure 2.** The basic version of the proposed automatic control system computer model.

The proposed ACS computer model is developed taking in mind 3 components of the LCD panel heat exchanging process within the color multi-function display:

- the LCD panel self-heating effect because the LCD illumination lamp functioning (in the scheme this heat exchanging path is represented by serial connection of the element LCD_Backlight Relay which controls lamp mode, and the instantaneous element $dQ/dt\_self\_heating$ with a transfer constant $k_1$ Watts which defines the self-heating source energy equivalent power);

- the LCD heat exchange with the environment (intensity of which obviously depends on the difference between the LCD panel temperature and the environment temperature, this is represented by the proportionality coefficient $k_2$ Watt/degree of the instantaneous element $dQ/dt\_Ambient$);

- the LCD panel heating with the set of built-in resistive heating elements sputtered with the thin-film sputtering technology on the glass (the dissipation power is defined with the coefficient $k_3$ Watts and is modelled as an instantaneous element $dQ/dt\_Heater$ in the scheme, element Control Relay Law controls this heating source mode).

The transfer constant $k_4 = \frac{1}{C}$ of the instantaneous element $Q \rightarrow T\_Scaler$ connected to the input of the integrator in the schematic model on the figure 2 has a reciprocal value to the equivalent heat capacity $C$ of the LCD panel which is a part of a color multi-function display. The relay element
**Control Relay Law** is a device with the hysteresis of the following functionality logic:

\[
x_{\text{out}} = \begin{cases} 
0, & x_{\text{in}} > L_{\text{off}}, \\
1, & x_{\text{in}} < L_{\text{on}}.
\end{cases}
\]  

(4)

where \(x_{\text{in}}\) – the relay element input signal, \(x_{\text{out}}\) – the relay element output signal. The trigger threshold levels \(L_{\text{on}}\) and \(L_{\text{off}}\) of the element relay **Control Relay Law** are defined by the ACS developer and correspond to the heater element on-threshold and off-threshold. In the closed-loop ACS it is necessary to set \(L_{\text{on}} > L_{\text{off}}\).

The relay element **LCD backlight Relay** included in the ACS to take into consideration the restriction established by color multi-function display developers, preventing the first switching-on of the illumination lamp of the LCD panel if its temperature is below zero. The necessity to apply such decision became clear after the researches showed that the LCD panel illumination lamp resource decreases significantly if the screen is used often without warming up when the ambient temperature is below zero. The exact numerical values of the ACS model could be obtained after some test measurements of the LCD panel temperature alteration while it is being tested inside the temperature stabilized chamber of tranquil air with any preset temperature. In the temperature test of avionic equipment there is an excessively low ambient temperature preset at the level minus 40 Celsius degrees. The ACS relay control law presumes alternate switching-on and switching-off of the LCD panel heating element when the temperature reaches the low or high preset thresholds of the relay element. The ACS equivalent structural schemes which correspond to the switched-on and switched-off modes of the heater are shown on the figure 3.

**Figure 3.** Linear models of the automatic control system in test modes:

- a) in the warming-up mode when the ambient temperature is excessively low,
- b) in the cooling mode when device was previously warmed up.

Using the linear system analysis methods it can be shown that for the ACS model which scheme is shown on the figure 3,a the transient process when the initial value of the temperature of the LCD panel is equal to the ambient temperature \(T_a\), may be described with the formula:

\[
T(t) = T_a + \frac{k}{k_2} \left(1 - e^{-k_1 t}\right),
\]

(5)

where for the parameter \(k_1\) either the value \(k_3\) (heater is on, LCD panel illumination lamp is off) or the
value $k_1$ (heater is off, LCD panel illumination lamp is on) must be used according to the color multi-function display selected test mode.

The model shown on the figure 3.b corresponds to the situation when a color multi-function display was warmed up to the temperature $T_i$ and now it is cooling down when the ambient temperature is excessively low $T_a$. In this case the ACS transient process must be expressed as:

$$T(t) = T_a + (T_i - T_a) e^{-kt}.$$  \hspace{1cm} (6)

Numerical values of the parameters $k_1$, $k_2$ and $k_4$ of the basic model shown on the figure 2 may be estimated using the least-squares method for the expressions (5) and (6) together with known test measurement data. The numerical value of the coefficient $k_3$ (heater power) can be found in the color multi-function display technical documentation.

Any further improvement of the offered basic model of the LCD panel temperature stabilization automatic control system must be done keeping in mind the additional specific features of a color multi-function display, in particular when it is exploited in the excessively low temperatures: in the moment when the display reaches the above zero area of temperatures and the LCD panel is switched on for the first time the power of the heater must be reduced.

The final version of the ACS Simulink model is shown on the figure 4. To implement alteration of the heater power, there is an element D-Flip-Flop included in the model, output signal of the D-Flip-Flop controls the Switch element, so the heating element of the LCD panel gets reduced level of the power right after the LCD panel illumination lamp is switched on (30 Watts from the element $dQ/dt_{Heater Low}$ against 90 Watts from the element $dQ/dt_{Heater Hi}$ in the nominal mode).

Figure 4. Final version of the computer model of the automatic control system.

After the procedure of the parametric identification of the automatic control system of the LCD panel operational mode temperature stabilization as a part of a mass production color multi-function display sample the following numerical values of parameters are obtained:

- $k_1 = 2$ Watts,
- $k_2 = 0.4$ Watts/Degree,
- $k_3 = 90$ Watts (in the heater full power mode),
- $k_4 = 0.0045$ Degrees/Joules.

The ACS computer model adequacy for the real device unit can be evaluated through comparison of the dynamic processes in the real system and in the model. The graphs for the both dynamic processes are shown on the figure 5. The relay element switching levels are $L_{on}=25$, $L_{off}=10$ Celsius degrees. Advantage of the proposed computer model of the ACS of the LCD panel temperature stabilization is that parameters non-stationarity may be implemented. Particularly non-stationarity can
be included with the parameter $k_2$ to simulate the altering conditions of the convection heat exchange process. The heat exchange conditions depend on the atmospheric pressure and there is a wide range of variation while a color multi-function display is exploited as a part of aviation equipment.

![Figure 5](image.png)

**Figure 5.** The dynamic process graph of the real automatic control system and its model.

To simulate the dynamics of the $k_2$ parameter changing an additional input for exterior disturbing influence can be added in the automatic control system model. The exterior disturbing influence on the parameter $k_2$ can be expressed with a two-input multiplier model. The similar approach to modelling the ACS parameters alternating dynamics can be used for the coefficients $k_1$, $k_3$ when necessary.

4. **Conclusion**

The proposed computer model of the LCD panel temperature conditions stabilization system is a universal one. The model parameters have a clear physical meaning and can be estimated on the basis of the simple temperature test data [8-10]. It is important to notice that the proposed model is not so complicated being compared with known kind of mathematical models of thermodynamic systems described with a system of non-linear differential equations in partial derivatives which are more accurate in the theory but doubly applicable for the real manufacturing necessities.

The approaches used to develop the proposed temperature conditions stabilization system computer model can be productive too when they are used for non-linear models of other automatic systems which are used in avionics.

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