Theoretical applied questions and their implementation in development of hierarchical computer control systems (CNC) of facsimile copy machines for art engraving on minerals

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ABSTRACT: *The technological scheme implementing machine engraving on a mineral and facsimile transfer of the halftone image from the personal computer is offered. The dot (microstroke) image is formed by a pulse system together with an electromechanical converter, such that the integral optical density of separate fragments equals optical density of the same fragments of the initial image.*

Structural construction and separate parameters of a two-level hierarchical control system are formalized. The description of the top level of the developed hierarchical control system is given.

Facsimile copy machines controlled by CNC systems, are a branch of digitally controlled machines, and belong to a class of mechanotronic systems. The raster approach to creation of halftone image on the surface of the polished mineral by slotting is described below. Proportional electromechanical converter with a chisel is used for that purpose.

The control system of the machine is a two level system, based on main hierarchical principles. The top level is implemented on the personal computer. Image is entered in the computer as a videosignal, quantized in time, or as a scanned image. This signal is stored as a bitmap (pixel array) and can be considered a lattice function of two arguments. The interpolated values obtained in continuous space, which is defined by the trajectory of the chisel, are submitted in fragments via communication channel to the lower level, implemented on a programmable controller (PC). PC is a base of a digital cyclic open impulse system.

The implemented technological process of machine engraving on a mineral produces facsimile transferring of a halftone image from personal computer. The impulse system together with the proportional electromechanical converter creates dot or microstroke image, in which integral optical density of separate fragments equals the optical density of the same fragments of the initial image [1]. The impacts on the surface of the material are created by the proportional electromechanical converter, in which the electromagnetic energy creates force F, which is proportional to a signal $U_{jvideo.}$. The force F is applied to an anchor with a chisel and forces it to move, thus creating kinetic energy.

The complexity of implementation of facsimile transferring of the flat image on a plane with exact reproduction of all grades of optical density forces to use dithering, which is a 2-dimensional kind of impulse modulation, where the 2-dimensional spectrum of a continuous signal is replaced by a sampled image and, correspondingly, its spectrum, which is possible without deterioration of visual perception based on Nyquist theorem. To produce it, scanning moves of a chisel parallel to the surface of the blank are used to create dots or microstrokes, and the size of the dots is defined by the moves in normal plane (raster moves) [2].

In reproduction systems the human vision acts as a lowpass filter, creating continuous signal from the impulse train. It experimentally shown that the vision system perception of reference periodic images with different spatial frequency decreases monotonously and at some boundary frequency the eye does not recognize discrete structure. This characteristic was offered by Ju.S.Andreev and described as a frequency response of the vision analyzer

$$W(v) = \exp(-0.343v), \tag{1}$$

where v – spatial frequency [mm^{-1}]

The available array of pixels is recalculated to obtain required image size with respect to the physical image size and drive step. From the grayscale image, which is quantised by level, frequency and amplitude of the chisel moves are defined, such that they result in the same optical density D.

The quality of the obtained image depends on the quality of the initial image, which can be described by the following parameters:

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(Receiwed, revised version received August 2, 2002)

1. Distribution of the colors and the key of different areas, i.e., spectrum of the whole image, which is an amplitude desription of the image in macroscale.
2. Sharpness of the image, which defines the microstructure – small details and small changes in color – contours, it is defined by the speed of optical density change, i.e., spectrum of the image in microscale.

Fig. 1 represents block diagram of two-level hierarchical system used for control of cyclic equipment with variable algorithm of functioning (including modular, special and facsimile copy machines) [3], where:

- C_0 – coordinator, which solves the task D_0;
- $C_1,C_2,\dots,C_n$ – implement lower level elements (LLE), which solve the tasks $D_1(\gamma_1),D_2(\gamma_2),\dots,D_n(\gamma_n)$ correspondingly;
- $P_1,P_2,\dots,P_n$ – subprocesses of common technological process P;
- $H_1,H_2,\dots,H_n$ – feedback elements connecting the subprocess P_i to other subprocesses;

The interaction of coordinator C_0 with the lower level is carried out by the set of feedback signals $W = \{w_1,w_2,\dots,w_n\}$ and set of coordinating signals $\Gamma=\{\gamma_1,\gamma_2,\dots,\gamma_n\}$, which depend on information being processed, including feedback signals.

LLEs, implemented by $C_1,C_2,\dots,C_n$, in turn, are connected to subprocesses $P_1,P_2,\dots,P_n$ by a set of control signals $M=\{m_1,m_2,\dots,m_n\}$ and the set of feedback signals $Z=\{z_1,z_2,\dots,z_n\}$.

In the process Pi the sets of the output signals $Y=\{y_1,y_2,\dots,y_n\}$ and the set of binding signals $U=\{u_1,u_2,\dots,u_n\}$ are distinguished.

The task solved by LLE, is defined by a set of tasks $D(\gamma)=\{D_1(\gamma_1),D_2(\gamma_2),\dots,D_n(\gamma_n)\}$ solved simultaneously in time. The solutions of subtasks $D_i(\gamma_i)$ are defined by the algorithms that form feedback signals w_i and control signals m_i based on coordinating signals γ_i and feedback signals z_i: $m_i=\varphi_i(\gamma_i,z_i)$, $w_i=\delta_i(\gamma_i,z_i)$.

The solution of task D_0 is transformation of feedback signals $w_1,w_2,\dots,w_n$ in coordinating signals $\gamma_1,\gamma_2,\dots,\gamma_n$, i.e., $\gamma_1=g_1(w_1,w_2,\dots,w_n),\dots,\gamma_n=g_n(w_1,w_2,\dots,w_n)$, where $g_1,\dots,g_n$ – local criterion functions.

Thus, coordinator processes the feedback signals $w_i \subseteq W$ and forms coordinating signals $\gamma_i \subseteq \Gamma$, which frequencies are far less than the frequencies of signals in Z, but the common (global) criterion function g is satisfied.

The number of levels of hierarchy can be determined on the basis of the analysis of frequencies of spectra of disturbing influences (external events). The spectrum of external events F can be split in subbands $F_1,\dots,F_m$, where m is the number of levels of hierarchy. For normal functioning of the control system on all levels of hierarchy it is required the lower level had the frequency of events $F_{e,j-1}$ at least an order of magnitude higher than the higher level frequency of events $F_{e,j}$ and processing $F_{p,j}$, and hence the frequency of processing $F_{p,j}$ should be at least an order of magnitude higher than the frequency of events $F_{e,j}$ at the same level j:

$F_{p,j} > F_{e,j-1}$ and $F_{e,j-1} > F_{e,j}$, hence

$$F_{p,j} > F_{e,j}. \quad (2)$$

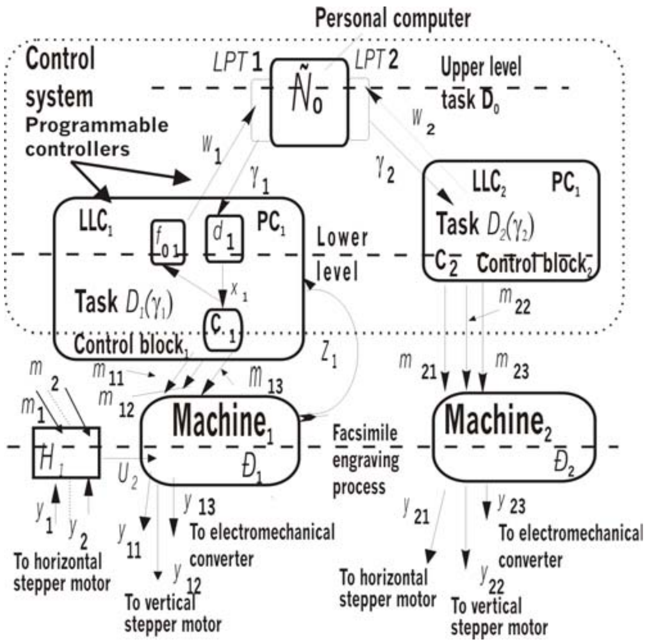

Fig. 1

The number of levels can be reduced. For example, it can be reduced to two levels, if technological process allows blocking (suspension of a moving part) by a control system.

Two-level hierarchical control system was used for control of two facsimile copy machines. According to the described methodology a control systems containing two levels of hierarchy was selected. In fact, frequency of events at the upper level $F_{e,0}$ was approximately 10Hz (frequency of transactions in LPT port of a personal computer), and processing speed $F_{p,0}$ was 80Hz. Frequency of generation at the lower level $F_{e,i}$ ($F_{e,1}$, $F_{e,2}$) was 200Hz (frequency of stepper motors), and processing speed at lower level $F_{p,i}$ ($F_{p,1}$, $F_{p,2}$) was 100kHz. Thus, the condition (2) was satisfied. In addition to it, control system of the facsimile copy machine allowed blocking. When the programmable controller finished processing of the image line, the next working move of the electromechanical converter was suspended until the information about the new string has been loaded from the computer.

In that system the main task D (engraving of a facsimile copy of the image) was separated in three subtasks.

The task D_0 fulfills the following:

a) Forms the array of pixels, such that the value of each pixel is proportional to the optical density of corresponding image dot;
b) Selects lines from the array;
c) Setting vertical and horizontal dimensions of the image with respect to selected step;
d) Scaling of the pixel array according to selected transfer function of the material;
e) Setting output mode parameters, backlash compensation according to parameters;
f) Forming of coordination signal γ.

Upper level - coordinator C_0 - was implemented on a personal computer. It solved task D_0 by forming coordinating signals γ_1 and γ_2 and receiving feedback signal w_1 and w_2 from two LLE.

Communication of LLE and PC was implemented through parallel ports LPT1 and LPT2. For the top level: $\gamma_1=g_1(w_1)$, $\gamma_2=g_2(w_2)$, where g_1, g_2 – criterion functions of task D_0, γ_1, γ_2 – coordinating signals.

Tasks $D_1(\gamma_1)$ and $D_2(\gamma_2)$ fulfill the following:

a) Stepper motor control (y_1,y_2);
b) Implementation of cyclic data commutation and coordination with stepper motor control (M_1, M_2);
c) Generation of the output videosignal voltage proportional to the pixel value (M_3);

Fig. 2

Software "Copir" was developed for facsimile copy machine, which automatically implements control of the machine [4]. It implements the following modes:

1) Selection of the file containing the image and selection of area to be copied;
2) Setting parameters of the machine (output step, type of transfer function for the bank material, speed of move, backlash correction value)
3) Interface to control the process with three modes:

a. Manual continuous – for manual control of the continuous move
b. Manual stepping – for manual control of positioning step by step
c. Automatic – automatic output control

Program interface is implemented as three pages, which group elements for control and visualization in three listed modes.

Page "Selection" is used for selection and scaling of image. Fragment selection is done in group "Selection, pixels" or by mouse. Switch "Select all" is used to select all picture for output. Scaling is done in group "Position, mm", where the width and height of the image can be defined in millimeters in the corresponding fields. Proportionality constrain can be enabled, so that the dimensions change simultaneously to repeat the proportions of the source bitmap when the image is output.

Page "Hardware" is used to setup output parameters, which define control and coordinating signals at all levels of hierarchy. Step in line and between lines, speed of electromechanical converter, and mode of output can be adjusted. List "Characteristic" is used for setting transfer function of the blank material, according to which the pixel value is transformed in the videosignal level, which controls amplitude and frequency modulation of the signal that drives electromechanical converter. This function depends on the material being used and can be corrected in software for the source image.

Page "Control" is used for positioning and control of machine, and for visualization of output progress, which is done by receiving feedback signals from the machine. Also evaluation of optical density and calibration of the electromechanical converter are done in that page.

Literature

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