WCONTROL - Program System for Control Theory Laboratory Education

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Abstract — The program system for the interactive work with the real discrete control was built. The program is running in the real time conditions and allows to define both the structure and the parameters of the discrete controller, which is connected with the real controlled system. In the first was necessary to solve the real time program running. For this problem was done the analysis of the windows possibilities in this area. Finally the multimedia application timing was used for this problem solving.

Index Terms — Windows NT, real-time, multimedia timer, discrete control loop, discrete controller.

INTRODUCTION

Operating systems with real-time support are generally systems, which allow us simultaneous parallel processing of several tasks, programs, processes. It means that they support technologies as multitasking, multithreading, multi-processors tasks processing, exact timing and so on. MS DOS is the typical example of the operating system without the support of the tasks processing in real-time. This system is based as a system, in which is able to process only one process in the given time. Processing of many processes in real-time is able only with many special, often very complex, modifications and operating system upgrades, for example RTMON for MS DOS and C, C++. MS Windows, Unix are some of the operating systems which enable to use multiprocessing. However, these operating systems have some drawbacks, limitations, which inhibit us to create adequate applications which use tasks processing in real-time. Analysis of these limitations in the operating system MS Windows has been done. It was focused on finding as simple solution as possible of the problems connected with the realization of real-time applications in this system. Operating system MS Windows is generally system, which enables us the independent processing of several applications or processes simultaneously. Multiprocessing (multithreading) is supported by 32bit versions of this system. It includes timers with theoretical value of the period down to 1ms and other elements which are necessary for creating applications working in real-time. Their quality and possibilities of usage vary very much. It depends on the version the used operating system. Acceptable quality is received at the operating systems based on the platform Win NT and higher.

WINDOWS TIMING ANALYSIS

Operating system MS WINDOWS is a system based on the processing of messages. It means that arbitrary system event (input – output event, system requirements, etc.) is a direct effect, outgrowth or cause of the processing of the system event. These events are sorted to the events queue a processed by the kernel of the system in accordance with some given rules, as is type and priority of the event. It means in practice that it is not always guaranteed immediate processing of the request, or we do not know, when the event will be processed. By the way, it means that computer time of the processor is not assigned under the exact instants of time to the process, but under the state of the queue of the processes.

System timers

Using system timers we can see following problems, from which it concludes that system timers cannot be used for exact time control:

- counters are not also activated on the request for pausing, but the system, again, send a message about reaching the time interval,
- messages from timers are not asynchronous,
- theoretically it is possible to generate the messages with the interval down to 1 ms, but, however, it is impossible in practice. The basic frequency of the hardware timer on which the timers of the Windows 9x system are based is in the most workstations 54,9 ms with the tolerance of several microseconds. All other adjustable frequencies are multiples of
this 55ms; the situation is similar in the case of the operating system Windows NT/2000 but with the slightly difference, the lowest possible period, which could be set, is 10ms and all other periods are its multiple.

For analysis of the abilities of the system timers in dependence on the occupancy of the system and the value of the interval, the program SysTimer was created. The conclusion of the analysis by the help of this testing program is that the system timers are not suitable for creating the real-time applications working simultaneously with several tasks. (Vaék et al., 2002)

Multimedia timers

These timers are timers used by Windows for exact data processing. They are mainly used for creating the multimedia applications, such as during the timing in the MIDI sequencers. These timers have guaranteed the accuracy down to 1ms and handling the events is not through the messages of Windows, but as a handling of pausing. The higher requirements on the system resources, the dependence on the hardware of the whole PC and the problems during programming are their drawbacks. Multimedia timers permit the small immediate deviation from the chosen period, however, the whole time deviation, error is minimised (in accordance of the timer settings) down to 1ms.

**Computer Program WCONTROL**

WCONTROL application was created in the development environment of *MS Visual C++* with the usage of MFC libraries and it is used for the monitoring and one-dimensional control of external technological processes. The modern programming technique was used during the programming, as *COM Automation*, *OLE Drag&Drop* and others are. The technique makes the work with the application, data processing and export much more comfortable.

The connection among the computer environment is realized via the Advantech PCL-812 PG laboratory digital I/O card with the usage of the program support *ADSAPI32* by Advantech. The technological card includes:

- Digital inputs (16x)
- Digital outputs (16x)
- Analog inputs with programmable gain (16x)
- Analog outputs (2x)
- Counter of external events

The WCONTROL program supports the whole set of I/O cards manufactured by Adventech and compatible. WCONTROL has been designed as an object-oriented application mainly because of the users. It means that the users can make the given working project with the usage of particular blocks of the functions much more effectively and quickly. Moreover, thanks to the object-oriented approach, the user effort is as simple as possible. Following blocks of functions are available:

- Analog inputs (with the possibility of filtration of input signal)
- Analog outputs
- Binary outputs Binary impulse outputs with pulse-width modulation
- Definition of set-point history
- Object for visualization and archiving
- Two-step controller with penalization
- PID controller and its modification (Takahashi, average difference)
- General linear controller

WCONTROL has been programmed in accordance with the *MDI (Multi Document Interface)* standard. It means that several projects can be opened simultaneously within one application. However, monitoring or control can only run in one project. This fact is not problematic for advanced users. WCONTROL can run in several instances in MS Windows. Measured data, thanks to the block of visualization and archiving, can be processed in two ways. Each of them differs in the style of visualization, and data archiving and export. The different types of visualization of the measured data were incorporated into the application because of the usage of the program at the low-performance computers.

It is possible to archive the data thoroughly in the mode of *data visualization and archiving*. In addition, the data can be once exported to a file, or immediately to *MS Excel*. This can be done during or after the measurement. The displayed graphs’ scale can be changed dynamically at the same time. Once the project is saved in the drive, its properties are archiving together with the measured data.
The mode of the thoroughly data visualization does not save measured data into the memory of computer, but it shows the current value immediately to the monitor. The usage of thoroughly data archiving to the file is needed when the later data processing is awaited. This approach decreases the requirements of the application very much, especially the computer performance and the size of computing memory. However, the working comfort of the application is slightly decreased.

The different project running, the different technological I/O card installed can be used. The period of inputs measuring and outputs operating of the measuring card can be set 0.1 up to 200 seconds with the step 0.1 second. This value is sufficient for almost all real-time applications working at the technological and laboratory conditions. Minimum value of the adjustable sampling period was chosen in accordance with the possibilities and the convenient load of the operating system MS Windows.

CONTROL ALGORITHMS

Two-step control

The algorithm of two-step control with penalization and a chance of setting the threshold from 0 to 100 % of the set-point value are implemented in the program. The action signal of controller is defined by the following equation:

\[
    u = \frac{u_{\text{max}}}{kp} 
\]

\[
    kp = 1 + \left(1 - \frac{w - y}{y} \left(\frac{1}{pp}\right)\right)(kp_{\text{max}} - 1) \quad (1) 
\]

Where: \( u \) action signal
**PID controller and its modification**

The WCONTROL application allows us to use 3 types of digital PID controller’s algorithm:

**Digital PID controller**

The WCONTROL application uses the incremental algorithm of the digital PID controller in the form

\[
\Delta u_k = r_0 \Delta e_k + \frac{r_0}{T_i} \Delta u_k + r_0 T_D \Delta D_k
\]

The increment \( \Delta u_k \) is a function of the last three values of the sample of the error of the control. It can be written as follows

\[
\Delta u_k = u_k - u_{k-1} = q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2}
\]

Individual methods differ in the values of the parameter \( q \), which is given in the table below.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>PARAMETERS OF DIGITAL PID CONTROLLER COMPUTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant</td>
<td>( q_0 )</td>
</tr>
<tr>
<td>LEFTRECT</td>
<td>( r_0 ) + ( \frac{r_0 T}{T_i} ) + ( \frac{r_0 T_D}{T} )</td>
</tr>
<tr>
<td>RIGHTRECT</td>
<td>( r_0 ) + ( \frac{r_0 T_D}{T} )</td>
</tr>
<tr>
<td>TRAPEZE</td>
<td>( r_0 ) + ( \frac{r_0 T}{2T_i} ) + ( \frac{r_0 T_D}{T} )</td>
</tr>
</tbody>
</table>

Where:
- \( r_0 \) gain of controller
- \( T_i \) integrative constant of controller
- \( T_D \) derivative constant of controller
- \( T \) sampling period

The transfer function and the equation of the controller are

\[
G_R = \frac{q_0 + q_1 z^{-1} + q_2 z^{-2}}{1 - z^{-1}}
\]

\[
u_k = u_{k-1} + q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2}
\]

Setting parameters: \( q_0, q_1, q_2 \)

**Takahashi controller**
Let us set \( w_k = w_{k-1} = w_{k-2} = w \), so that

\[
\Delta e_k = e_k - e_{k-1} = w - y_k - w + y_{k-1} = y_{k-1} - y_k
\]

\[
\Delta D_k = \frac{e_k - 2e_{k-1} + e_{k-2}}{T} = -\frac{y_k + 2y_{k-1} - y_{k-2}}{T}
\]  

(6)

The modification of the incremental digital PID controller

\[
\Delta u_k = u_k - u_{k-1} = r_0 (-y_k + y_{k-1}) + \frac{r_0 T}{I} e_k + \frac{r_0 T_D}{D} (-y_k + 2y_{k-1} - y_{k-2})
\]  

(7)

For \( k_P = r_0 \), \( k_I = \frac{r_0 T}{I} \), \( k_D = \frac{r_0 T_D}{I} \) the equation of Takahashi modification of the digital PID controller used in the WCONTROL application has a form

\[
u_k = u_{k-1} + k_P (-y_k + y_{k-1}) + k_I e_k + k_D (-y_k + 2y_{k-1} - y_{k-2}) \]

(8)

Setting parameters: \( k_P, k_I, k_D \)

Average difference

The suppression of high changes of the value of the action in consequence of the discrete realization of the continuous operation of the derivation at the error of the control modified by the disturbances is done by replacing the value of the derivation \( D_k \) or \( \Delta D_k \) with the equations, which uses so-called average difference. The averaging of the difference in the discrete calculation of the derivation of the error of the control is based on replacing the derivation \( D_k \) in an instant \( kT \) with the value of the average speed of the change of the error of the control

\[
\bar{e}_k = \frac{e_k + e_{k-1} + e_{k-2} + e_{k-3}}{4}
\]  

(9)

The average speed of the change of the error of the control \( \Delta e_k / T \) is calculated as the arithmetic mean of the speeds of the changes of the error of the control related to the average value, i.e. as the differential quotients

\[
D_k = \frac{\Delta \bar{e}_k}{T} = \frac{1}{4} \left( \frac{e_k - \bar{e}_k}{1,5T} + \frac{e_{k-1} - \bar{e}_{k-1}}{0,5T} + \frac{e_k - e_{k-2}}{0,5T} + \frac{\bar{e}_k - e_{k-3}}{1,5T} \right) = \frac{e_k - 3e_{k-1} - 3e_{k-2} - e_{k-3}}{6T}
\]  

(10)

The final equation for the incremental algorithm is

\[
u_k = u_{k-1} + q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2} + q_3 e_{k-3} + q_4 e_{k-4}
\]  

(11)

Where the parameters for the TRAPEZE methods are

\[
q_0 = r_0 + \frac{r_0 T}{2T_I} + \frac{r_0 T_D}{6T_D}, \quad q_3 = -\frac{r_0 T_D}{3T_D}
\]

\[
q_1 = -r_0 + \frac{r_0 T}{2T_I} + \frac{r_0 T_D}{3T_D}, \quad q_4 = \frac{r_0 T_D}{6T_D}
\]

(12)

Setting parameters: \( q_0, q_1, q_2, q_3, q_4 \)

General linear controller

The general linear controller for the general description of the controller with using the polynomial fraction is also implemented in the WCONTROL application. The transfer function and the equation of the controller are
\begin{equation}
G_R = \frac{Q_{(x')}}{R_{(x')}} = \frac{q_0 + q_1 z^1 + q_2 z^2 + q_3 z^3 + q_4 z^4 + q_5 z^5}{1 + r_1 z^1 + r_2 z^2 + r_3 z^3 + r_4 z^4 + r_5 z^5}
\end{equation}

\begin{equation}
 u_k = a_0 e_k + a_1 e_{k-1} + a_2 e_{k-2} + a_3 e_{k-3} + a_4 e_{k-4} + a_5 e_{k-5} - r_1 u_{k-1} - r_2 u_{k-2} - r_3 u_{k-3} - r_4 u_{k-4} - r_5 u_{k-5}
\end{equation}

Setting parameters: \( q_0, q_1, q_2, q_3, q_4, q_5, r_1, r_2, r_3, r_4, r_5 \).

**HARDWARE AND SOFTWARE REQUIREMENTS OF APPLICATION**

The hardware requirements of the WCONTROL application depend on the used visualization method and the work with the measured data. The memory and CPU loading are based on the fact that the WCONTROL program only runs in the operation system MS Windows NT/2000, therefore the program should be run on the computer, which enables the reliable and fast work in these operating systems. When the through data visualization is used, Pentium 200MHz and 32 MB of the computing memory are enough. However, if all of the options of the WCONTROL program are used in the mode of the measured data saving into the computing memory, we have to remember that the large amount of the measured data during the longer measurements overcharge the computer, as from the view of the computing power used for the dynamic redrawing of the graphs, as from value of the full RAM memory. For this case, the computer’s configuration should not been worse than PII/Celeron 233 MHz and the operating memory RAM lower than 64MB. The necessity of installation of the service pack for MS Windows NT 4.0, version 5 or higher, is another condition of the correct running of the program from the view of the used operating system. This fact is because of the new technologies used during the programming of the WCONTROL application. Their support was not included in the basic version of MS Windows NT 4.0.

**TABLE II**

**MINIMUM CONFIGURATION**

<table>
<thead>
<tr>
<th>Device</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Pentium 200 MMX</td>
</tr>
<tr>
<td>RAM</td>
<td>32 MB</td>
</tr>
<tr>
<td>HDD</td>
<td>20 MB of free space for SW and drivers installation</td>
</tr>
<tr>
<td>I/O DEVICE</td>
<td>Advantech family</td>
</tr>
<tr>
<td>SYSTEM</td>
<td>MS Windows NT 4.0 Service Pack 5</td>
</tr>
</tbody>
</table>
EXAMPLES OF PRACTICAL USE

FIGURE 2
PROJECT OF SYSTEM STEP RESPONSE MEASURING

FIGURE 3
SYSTEM STEP RESPONSE MEASURING
Digital PID controller
Remark: The project uses the fan for cooling the system during the measurements. The running of the fan is realized by the binary output „Vetrak“.

FIGURE 4
PROJECT OF CONTROL USING TAKAHASHI CONTROLLER

FIGURE 5
HISTORY OF CONTROL
CONCLUSION

An analysis of the possibilities of the realisation of the real-time applications in the operating system MS Windows has been done. It has been found from the problem analysis that it is good to use the system timers as a source of the exact timing for the running of the user programs. For the sufficient accuracy, the multimedia timers were used. They satisfy the time requests of the standard systems for monitoring and control of the technological processes. Based on this solution, the program WCONTROL was created. It realises a computer controller. This controller is possible to implement to the real control circuit, moreover, it is possible to choose different types of controllers and easily set their parameters. The choice of the structure program system is mainly for the educational purposes and laboratory experiments.

ACKNOWLEDGEMENT

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REFERENCES