PARALLEL LOGIC CONTROL ALGORITHM SEPARATION QUALITY ANALYSIS IN THE SYNTHESIS OF LOGIC MULTICONTROLLERS

Eduard I. Vatutin

Department of Computer Science
Kursk State Technical University
50 Let Oktyabrya, 94, 305040, RUSSIA
Tel: +7(4712) 58-71-05, E-mail: evatutin@rambler.ru, WWW: http://evatutin.narod.ru

Abstract — A strategy for the comparison of the parallel logic control algorithm separation quality is briefly described. Based on the performed computational experiments we found out that the parallel-sequential method can be applied to the zones of strong and very strong technological restrictions. Changing of quality criteria tendencies during increasing average size of control algorithms are determined and functional dependencies of the calculation time growth are given.

1. INTRODUCTION

One of modern tendencies of creating logic control systems (LCS) is general using principals of parallelism and modularity. Parallel modularity LCS also known as logic multicontrollers (LMC) are capable to execute complex control algorithms with theoretically unlimited complexity due to process of its decomposition to a number of components that assigned to LMC modules. Especially interesting LMC that consist of modules (controllers) of the same type and provide very large productivity with good flexibility and testability.

Synthesis of LMC is connected with necessity of solving a number of optimization problems on discrete structures. Most significant of them is a problem of getting separations of logic control algorithms that solved during process of its decomposition. Quality of its decision is directly affect on hardware complexity of multicontroller and executing time of control algorithm. The named problem is belong to a class of $NP$-hard problems and cannot be precisely solved for algorithms with over than $N=15$ vertices (approximately) because excessive time growth (its asymptotical time complexity is $O(N^N)$) whereas practice control algorithms has a lot more size (thousands – tens of thousands vertices).

Well known a number of heuristic methods (for example, [2, 3]) for solving the given problem. One of them [4-5] is realized with author participation and now it is develop as before [7]. During process of decision synthesis given methods are used different principles. Due to the fact that some of them don’t optimize some important criteria like interblock traffic [1, 8] it is interesting to carrying out its comparison and determining best of them on established criteria. Some preliminary results that given with using developed by author instrumental program system PAE [9, 10] and based on using a sample of control algorithms with random structure [11] are published in [12]. This work is present results of carried out comparative quality analysis of separations that given with using program realizations of named above methods [6, 13, 14] with a number of quality improve modifications. For example, program realization [13] of S.I. Baranov method [2] had some errors and it was developed anew, and parallel-sequential method [4-5] was improved with a number of quality improve modifications shown in [7].

2. TARGET SETTING

As show above, problem of getting separations has pronounced combinatorial character and reduced to optimal presentation of source parallel control algorithm into a set of interconnected blocks [1, 4]. Generally each block consist of a number of untied fragments of source control algorithm. Set of blocks with corresponding connections are make up a mesh of source algorithm.

Given blocks in separation and mesh structure are imposed with a number of restrictions that determined by architecture of LMC and its modules, technological restrictions, structure organization of multicontroller, intermodule communications manner and so on. Formalized target setting is given below. Let $H$ – block count in separation;
$W_{\text{max}}$ – capacity of microprogram memory used for allocation of block microcommands (without auxiliary commands for intermodule communications); $n_{\text{LC}} = X_{\text{max}}$ – number of pins on controller package used for receiving signals with logic conditions from control object; $n_{\text{MO}} = Y_{\text{max}}$ – number of pins on controller package used for transmitting signals with microoperations to control object. It is necessary to get separation of a set of vertices $A^0$ of source control algorithm $\text{Sep}\{A^0\} = \{A_1, A_2, ..., A_n\}$ so, that carried out conditions:

$$\bigcup_{i=1}^{n} A_i = A^0, \quad A_i \neq \emptyset, \quad A_i \cap A_j = \emptyset, \quad i, j = \overline{1, H}, \quad i \neq j,$$

$$-(a_0 \land a_j) \quad \forall a_i, a_j \in A_i, \quad i \neq j, \quad k = \overline{1, H},$$

$$W(A_i) \leq W_{\text{max}}, \quad |X(A_i)| \leq n_{\text{LC}}, \quad |Y(A_i)| \leq n_{\text{MO}}, \quad i = \overline{1, H},$$

where $W(A_i) = \sum_{a_j \in A_i} W(a_j)$ – total weight of all vertices to be a part of $i$-s block, $X(A_i) = \bigcup_{a_j \in A_i} X(a_j)$ – set of logical conditions to be a part of $i$-s block, $Y(A_i) = \bigcup_{a_j \in A_i} Y(a_j)$ – set of microoperations to be a part of $i$-s block so, that

$$H \rightarrow \min;$$

$$Z_1 = \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \alpha(A_i, A_j) \rightarrow \min;$$

$$Z_2 = \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \delta(A_i, A_j) \rightarrow \min;$$

$$Z_3 = \sum_{i=1}^{n} |X(A_i)| - |X(A^0)| \rightarrow \min;$$

$$Z_4 = \sum_{i=1}^{n} |Y(A_i)| - |Y(A^0)| \rightarrow \min,$$

where $Z_1$ – interblock mesh complexity for separation $\text{Sep}\{A^0\}$; $\alpha(A_i, A_j)$ – coefficient of blocks connectivity (it is equal 1 in a case of blocks is connected on control from $A_i$ to $A_j$ and 0 elsewhere); $Z_2$ – total number of interblock communications (interblock traffic); $\delta(A_i, A_j)$ – interblock traffic between $A_i$ to $A_j$ blocks; $Z_3$ – number of doubled logic conditions; $Z_4$ – number of doubled microoperations.

So a given problem is a problem of multicriteria optimization on discrete structure (as graph). For the purpose of rating quality of given separations in [15] was proposed an integral value (estimation function)

$$f\left(\text{Sep}_i\{A^0\}\right) = \frac{K_H}{\omega_{\text{max}}} H + \frac{K_X}{|X(A^0)|} \sum_{i=1}^{n} |X(A_i)| - |X(A^0)| + \frac{K_Y}{|Y(A^0)|} \left(\sum_{i=1}^{n} |Y(A_i)| - |Y(A^0)|\right) +$$

$$+ \frac{K_\Delta}{\delta(A^0)} \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \delta(A_i, A_j) + \frac{K_\alpha}{\omega_{\text{min}} (\omega_{\text{max}} - 1)} \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \alpha(A_i, A_j) + K_\Delta \Delta W,$$

where $\text{Sep}_i\{A^0\}$ – separation of $i$-s algorithm given by method $B_i$, $K_i$, $i \in \{H, X, Y, \alpha, \delta\}$ – weight coefficients, $\omega_{\text{max}}$ – parallelism degree of algorithm ($\omega$-power of basic section of algorithm [1, 16], lower bound of number of modules in the LCS), $\Delta W = \max_{i \in \text{LCS}} W(A_i) - \min_{i \in \text{LCS}} W(A_i)$ – difference between component algorithms complexity. Taking into consideration criteria (2) let us assume that separation with $f\left(\text{Sep}_i\{A^0\}\right) \rightarrow \min$ is best.

3. EXPERIMENTAL COMPARISON OF METHODS

Using abilities of program system PAE [9, 10] was carried out a number of computing experiments. For the purpose of most objective rating of quality criteria values was accomplished generation of sample with $K$ algorithms with random structure. For all given quality criteria values (2) and (3) of each method was calculated average value
\( \overline{\gamma}(x) \) and probability of getting separation with minimal value of selected criteria \( \rho(x) \), where \( x \in \{H, X, Y, \alpha, \delta, f\} \). Given results that examine influence of technological restrictions on separation quality are shown in table 1 (\( t \) – computing experiment time for single threaded realization of components of program system that measured in hours on computer with processor Intel Core 2 Duo E6300, 1,86 GHz, 2 Mb L2, CPUID=06F6h).

### Table 1. Influence of technological restrictions on separation quality *

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Restriction values range</th>
<th>Additional parameters</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( 3 \leq X_{\text{max}} \leq 20 )</td>
<td>( K = 500 ) ( N = 100 \pm 5 ) ( t = 4,5 )</td>
<td>An analysis of given results shown that there are present two different regions (called zones) with different correlation of values of quality criterias: weak restrictions zone ( (9 - 15 &lt; X_{\text{max}}) ) and strong restrictions zone ( (X_{\text{max}} &lt; 9 - 15) ). In the weak restrictions zone S.I. Baranov method provide commensurable with parallel-sequential method number of blocks in separations ( (\overline{\gamma}<em>{\text{PSM}}(H) \approx \overline{\gamma}</em>{\text{PSM}}(H)) ). Best quality of optimization of criteria ( \overline{\gamma}(X), \overline{\gamma}(\alpha), \overline{\gamma}(\delta) ) is provided by S.I. Baranov method. Parallel-sequential method provide least value of criteria ( \overline{\gamma}(Y) ). During increasing power of restriction is observed gradual changing zone type to strong restrictions zone. Parallel-sequential method is now provide best values only for ( \overline{\gamma}(X) ) criteria. An integral value ( \overline{\gamma}(f) ) is shown that within weak restrictions zone S.I. Baranov method is preferable, but during transition into strong restrictions zone parallel-sequential method is became more and more preferable.</td>
</tr>
<tr>
<td>2</td>
<td>( 3 \leq W_{\text{max}} \leq 40 )</td>
<td>( K = 200 ) ( N = 100 \pm 5 ) ( t = 2 )</td>
<td>In this experiment can be picked out three zones: weak restrictions zone ( (32 - 36 &lt; W_{\text{max}}) ), strong restrictions zone ( (11 - 12 &lt; W_{\text{max}} &lt; 32 - 36) ) and very strong restrictions zone ( (W_{\text{max}} &lt; 11 - 12) ). In the weak restrictions zone there are ( \overline{\gamma}<em>{\text{PSM}}(H) \approx \overline{\gamma}</em>{\text{PSM}}(H) ) and ( \overline{\gamma}<em>{\text{PSM}}(\delta) \approx \overline{\gamma}</em>{\text{PSM}}(\delta) ), parallel-sequential method is provide some least values of criteria ( \overline{\gamma}(Y), \overline{\gamma}(\alpha) ), S.I. Baranov method – ( \overline{\gamma}(X) ). Transition into strong restrictions zone is leave S.I. Baranov method with best values of ( \overline{\gamma}(X) ) criteria, all other criteria has least values in separations that given with parallel-sequential method. In the very strong restrictions zone S.I. Baranov method is provide best values for ( \overline{\gamma}(X) ) and ( \overline{\gamma}(Y) ) criteria. An integral value provide preferableness of S.I. Baranov method only within weak restrictions zone. Within strong and very strong restrictions zones parallel-sequential method is preferable.</td>
</tr>
</tbody>
</table>

* A.D. Zakrevsky method don’t support technological restrictions and therefore not shown in experiments 1 and 2.

Also we run experiments 3 \( (5 \leq N \leq 100, \ K = 300, \ X_{\text{max}} = Y_{\text{max}} = W_{\text{max}} = \infty, \ t = 5) \) and 4 \( (5 \leq N \leq 100, \ K = 300, \ W_{\text{max}} = 4, \ t = 4,5) \). In this experiments is checked out tendencies of changing correlation of quality criteria during increasing average size of control algorithms without technological restrictions (experiment 3).
and with strong technological restriction (experiment 4). First, given experiments again [12] confirm more poor quality of separations that synthesized by A.D. Zakrevsky method (especially for most significant criteria $\mathcal{T}(H)$ that has indirect influence on all other criteria) and, second, shows that during average algorithm size growth correlation between quality criteria values is not changed. Given results are provide that parallel-sequential method is preferable within strong and very strong restrictions zones for control algorithms with any vertices count and S.I. Baranov method – within weak restrictions zone. An interesting feature [17] is that observed nearly linear growth of $\mathcal{T}(H)$ criteria value as well as growth of difference $\Delta \mathcal{T}(H) = \mathcal{T}_{PSM}(H) - \mathcal{T}_{Bar}(H)$ during increasing average control algorithm size. Difference $\Delta \mathcal{T}(H)$ is can be up to 6.5% of total blocks count (modules in LCS).

Experiment 5 is carried out for the purpose of time cost investigation during increasing average control algorithms size. Given empirical function dependencies for all methods was approximated with least-squares method using polynomials with power one (for S.I. Baranov method) and three (for A.D. Zakrevsky and parallel-sequential methods):

\[
\begin{align*}
    t_{Bar}(N) &= -1.064 + 9.698 \times 10^{-2} N, \\
    t_{Zak}(N) &= -6.756 + 1.143 N - 4.524 \times 10^{-2} N^2 + 6.326 \times 10^{-4} N^3, \\
    t_{PSM}(N) &= -15.475 + 3.143 N + 0.146 N^2 + 2.809 \times 10^{-3} N^3. 
\end{align*}
\]

(4)

Given functional dependencies for S.I. Baranov and A.D. Zakrevsky methods don’t include time cost for building relation matrix [1, 5, 18]. Functional dependencies (4) can be extrapolated to algorithms with a significant more vertices. For example, synthesis of separations of control algorithms with $N = 10000$ vertices will need one second for S.I. Baranov method, one week for A.D. Zakrevsky method and over one month for parallel-sequential method (in a best way). I.e. synthesis LCS with real complexity will need to be satisfied with low quality of S.I. Baranov separations or need to realize optimization/parallelization of program realization of parallel-sequential method and/or replace most time cost operations for its hardware-level analogues by working out specialized device (accelerator). Analogous hardware-level tasks are described in [19]. Synthesis of hardware-level accelerator is offered as most perspective way and actively evaluated at present time [20-22].

6. CONCLUSION

1. A number of zones within ranges of values of technological restrictions is discovered.
2. Field of application of parallel-sequential method is strong and very strong restrictions zones (practice case).
3. Field of application of S.I. Baranov method is weak restrictions zone (ideal case).
4. A.D. Zakrevsky method (at least in realization [14]) don’t support technological restrictions and provide most low quality separations.
5. Correlation between quality criteria values is indifferent during increasing control algorithms size. This allow to extrapolate given above recommendations to the control algorithms with any size.
6. High-quality synthesis of separations of parallel logic control algorithms with real complexity (10000 vertices and higher) will need some months of computing time. That is obstacle to operative change-over of LCS.
7. Requirement of synthesis of separations of logic control algorithms with a big size is bring to be satisfied with low quality of S.I. Baranov separations or need to optimization, parallelization of program realization of parallel-sequential method or replace some steps of method with its hardware-level analogs.

7. REFERENCES