ADAPTIVE MULTI-CLUSTER GENETIC ALGORITHM FOR NETWORKED IDENTIFICATION AND CONTROL LABORATORY

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Abstract *¾ The proposed adaptive multi-cluster genetic optimization algorithm may be utilized for setting up research- and education-oriented laboratory stands for adaptive control systems as well as discrete optimization problems. The main purpose of this work was to develop the modified version of the genetic optimization algorithm, which would include parallel processing of several groups of solutions (clusters). The algorithm included some elements of adaptation as the number of clusters as well as the number of each cluster members could be modified as a result of the current optimization process results. It was foreseen that such algorithm would become an effective tool for solving several hard optimization tasks with multiple local minimum points, whereas the needed calculation time would not be prohibitive because of the embedded parallelism. The modified algorithm was included in the proposed laboratory experiment, using networked computers for performing the calculation as well as for accessing the introductory material concerning the laboratory topic and running the experiment.*

Index Terms ¾ Optimization, genetic algorithm, control and identification, virtual laboratories.

INTRODUCTION

In this work the modification possibilities concerning the typical optimization genetic algorithms were considered. The aim was to enhance the standard algorithms in order to make them more efficient when used for optimization tasks including multiple local minima. The basic concept was to work with multiple cluster points in the population of individuals for genetic algorithm and to process such individuals clusters in quasi-parallel structure by means of standard genetic operators. By means of using possibly numerous clusters of individuals during the whole process of optimization it is possible to simulate the multimodal performance index and as a consequence enables to obtain faster genetic optimization algorithm and making the reaching of global minimum of the performance index more probable. With respect to educational purposes it was proposed that the modified genetic algorithm would be used in laboratory exercises concerning such courses as Optimization Methods, Control Systems Programming, Adaptive Techniques, Logic Programming with Constraints. It was also considered to use the modified genetic algorithm in the laboratory being accessed by means of computer network as a tool accompanying the network based delivery of lectures.

The proposed modified genetic algorithm is characterized by its ability to maintain during the whole process of optimization the well established and distinguished groups of individuals concerning which the evolution process is simulated. Such approach to the optimization task enables the natural and fairly simple decomposition into several subtasks, which in turn leads to the numerical decomposition concept and possibly efficient parallel processing. The realization of the proposed genetic optimization algorithm by means of several processing units – possibly several computer stations in the computer network structure – should ensure greater efficiency of the proposed algorithm and enable the reaching better values of the minimized performance index with the same computation time. On the other hand it would be easy to implement the proposed optimization algorithm with the computer aided laboratory exercise site that is enabled for distance access by means of Internet/Intranet facilities. Such concept would enable easy broadening of the potential laboratory exercise users and making the work with proposed laboratory exercises site more flexible. The theoretical introduction concerning the topics covered by the proposed enhancements to the genetic optimization algorithms could be also presented and distributed by means of computer network services, including all standard elements of educational framework.

The author of the paper is involved in the realization of two international collaboration projects in the Socrates/Minerva programme (LINK and LABLINK projects) as well as in Socrates/Thematic Network project called THEIERE. In these projects the partners from several universities worked jointly on the preparation of lectures aimed to be presented to students from the project partner universities by means of internet services. The methodology of preparing and conducting such work with students has been also discussed and developed during this international collaboration. The other project concerned the development of laboratory exercise sites that would be enabled by means of computer network facilities for all partner universities which is in perfect fit with the proposed enhanced genetic optimization algorithm concept.

The software layer concerning the realization of the proposed multi-cluster genetic optimization algorithm as well as the methodological aspects related to its usage for educational purposes were chosen as standard for such

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formulated tasks. The basic multi-cluster genetic optimization algorithm has been developed in the C++ programming language because of its obvious popularity , the possibilities of easy and efficient realization of numerical calculation as well as relatively easy and effective program development cycle for such platform. On the other hand it is reasonable to consider the Java programming language and environment while thinking about enabling the lecture and laboratory exercise materials by means of Internet/Intranet facilities. The author tried to merge both concepts and as a result the basic genetic algorithm has been developed in the C++ programming language whereas the part of the project concerning the presentation of the results of the proposed algorithm and its usage with distant laboratory access facilities was chosen to be programmed with Java programming language.

Standard genetic optimization algorithm may be considered as adaptive algorithm because the individuals comprising the simulated population are constantly modified and replaced. In the proposed multi-cluster genetic optimization algorithm such adaptation feature is further developed because during the optimization algorithm run also the numbers of clusters may change, the number of individuals in each cluster may change and of course the quality of individuals in clusters changes. Moreover the genetic optimization algorithm may be easily used in the control and identification tasks because of its inherent optimization contents and application possibilities. Therefore it was proposed that the new genetic optimization algorithm could be used as part of lectures and laboratory exercises in such courses as Adaptive Techniques, as well as Digital Signal Processing with adaptive filters in mind. This broadened the possible dissemination of the work with respect to the local students audience as well as students from partner universities in the mentioned Socrates/Minerva and Socrates/Thematic Network projects.

MODIFIED GENETIC ALGORITHM DATA

Below the modifications concerning the proposed genetic optimization algorithms for multiple local minima are considered. The essence of the changes is the propagation of the several clusters around the especially well fitted individuals in the population of solutions. Such clusters could of course correspond to local minima and with such structure it is possible to look for the global minimum in a quasi-parallel manner around many or all local minimum points of the optimized performance index.

In the subsequent iterations of the algorithm new individuals are created in the population basically as a result of the cross-over and mutation operations. In the proposed algorithm the decision concerning the acceptance of the newly generated individual as a population member is not automatic but includes the following possible schemes:

- Newly generated individual may be assigned to the existing cluster. In this situation such individual is considered while choosing the group of individuals for such cluster in the next iteration.
- Newly generated individual appears between some existing clusters and in such distance from their central points that it is not reasonable to assign it to any existing cluster. In this situation several test individuals are selected around the new individual in the directions of several neighboring clusters and the mean level of the fit function for such group is compared with the fit function value for neighboring clusters. If such new value of fit function for the selected group is too large the new individual is rejected. If the new value of the fit function is promising when compared with the neighboring clusters the decision to create a new cluster is made.

If as a result of the above described test a new cluster of individuals is generated then in the initial phase several individuals comprising the test group mentioned above become also members of the new cluster. In the standard run of the proposed algorithm it is not allowed to increase the number of individuals in the population, therefore the same number of individuals that appear in the new cluster has to be removed from the existing clusters. In the modified variants of the algorithm it is possible to decide that the number of individuals in the whole population increases if it is justified by the increasing number of clusters.

It is clear from the above description that the proposed algorithm is adaptive in nature from the point of view of the number of clusters as well as the number of individuals in clusters. The number of clusters should generally correspond to the number of local minimum point s of the performance index, which could be assessed in the basis of some kind of identification procedure concerning the possibility of local minimum existence. On the other hand the number of individuals in each cluster should correspond to the value of the performance index in the corresponding local minimum and the rate of change of the performance index value in the vicinity of such point. Generally the greater number of individuals is allowed for clusters with better mean value of the fit function and with smaller changes of the fit function value while deteriorating from the cluster central point.

For each population cluster the age of the cluster – i.e. the iteration in which the cluster was created – is being stored, along with the mean and the best values of the fir function for subsequent iterations. During the aging process of the cluster – i.e. the number of iterations for which the cluster exists – the mean and best values of the fit function are being tracked and if these are not getting better the number of individuals in such cluster is decreased with possibly the whole cluster being removed after several iterations. It is obvious that such cluster and corresponding local minimum could be reactivated in future by means of standard procedure of new clusters generation in the proposed modified genetic optimization algorithm.

In the proposed version of the algorithm it is assumed that most of the cross-over operations takes place locally, i.e. within the same cluster. Such solution makes it possible to faster exploit the possibilities of improving the fit function value of the chosen cluster members and increases considerably the convergence of the algorithm. Of course in order to approach by means of the proposed algorithm the performance index point corresponding to the global minimum it is essential to maintain possibly many clusters as well as the possibility of cross-over operation with respect to individuals belonging to different clusters.

Because most of the calculation in the proposed scheme is performed locally with respect to the current cluster members it is easy to design the operation of the algorithm in such manner that most of the calculation is performed possibly in parallel by different processing unit – maybe different networked computer stations. It is also obvious that in the proposed algorithm run it is necessary to proceed with some calculation involving the members of different clusters and their characteristics – in the phase of inter-cluster cross-over as well as while generating the new cluster among the existing ones. This reason generates the conclusion that the postulated calculation parallelization may be only partial and there is need for some upper layer of the algorithm which would have access to the characteristics of the whole processed population.

Summing up, the characteristic features of the proposed modified genetic optimization algorithm are like follows:

- working with multiple clusters of individuals with prevailing local cross-over operations within the clusters,
- adaptation of the number of clusters and the number of members of each cluster depending on the changes of the mean and best values of the fit function for the chosen cluster,
- possibility of partial parallelization of computation and independent processing with possibly several networked computer stations.

In the basic version the proposed algorithm has been implemented in the C++ programming language as a straightforward enhancement of existing genetic optimization algorithms code. It is obvious that the part corresponding the choice of the individuals that should survive for the next iteration had to be heavily rewritten, as well as cross-over and mutation operations implementation. As it was mentioned above the software implementing the proposed algorithm will be used with laboratory exercises for several courses and it is supposed to be accessed also in the networked environment and also in the virtual laboratory framework. For demonstration purposes and in order to use the proposed concepts also as part of lecture materials distributed by means of Internet/Intranet services some parts of the algorithm have been programmed also in the Java programming language – in order to make them easily accessible by means of standard web browser, also in the framework of distance learning and virtual laboratories concepts. It is supposed that finally the modified genetic optimization algorithm will be available as an applet written in the Java programming language and accessible by means of computer network environment as well as application written in C++ programming language, possibly also accessible to be run in the networked environment by using typical remote program execution paradigm.

GENETIC ALGORITHMS IN ADAPTIVE CONTROL

It is obvious that in some specific tasks of system identification the usage of genetic algorithms may be justified. The choice of structure of identified multivariable plant model - like the one for active noise/vibration control – seems to be one of such problems, especially if the plant model structure tends to be a complicated one. The other problem which needs some specialized identification and estimation schemes to be used, is the case of some a'priori knowledge concerning the plant model structure and parameters (zeros and poles) location.

The a'priori knowledge of the identified system structure and parameters may be viewed as some constraints imposed on the system parameters values. Some results prove that several complex optimization tasks in the presence of constraints may be solved in an especially efficient way by means of Constraint Logic Programming concepts [2].

Along with enhanced multi-cluster genetic optimization algorithms for identification, several standard estimation schemes were tested while setting up the adaptive control system, including various robustified least squares methods. Main results concerning the genetic and constrained identification in the adaptive control systems were obtained using separate program for genetic optimization with performance index being generated by using the tool as an adaptive control simulation system. This scheme was used in the case of system structure identification experiments, whereas in the case of genetic parameter estimation task in the adaptive control system some parts of specialized environment for genetic optimization and system simulation with constraints evaluation were built and used.

In the case of a'priori knowledge utilization experiments, the appropriate version of genetic algorithms were used – the ones that can handle constraints imposed on independent variables present in the optimization problem formulation. The software enabled also to incorporate the constraints concerning the plant structure and parameters values in the CLP originated framework.

In general, the following identification schemes were proposed and tested as part of the work on genetic and constrained identification in the adaptive control systems:

- Genetic identification of system structure. Genetic algorithms are used off-line for determining the structure of the system to be controlled. The structure of the system includes discrete time delay matrix and degrees of polynomials in SISO and MIMO models of the plant. The proposed combinations of these parameters are evaluated in the simulated control system which may also be adaptive, i.e. the parameters within the proposed structure could be estimated by means of any chosen parameter estimation scheme.

- Single genetic identification of system parameters. It is supposed that the structure of the system to be controlled is known. Genetic algorithms are used for determining the values of the parameters of the plant model which result on the best performance of the resulting control system. The performance index, used as a fitness function in the genetic algorithm, is based on standard control system performance index – preferably sum of squared control errors – and is determined by means of simulation using the chosen system structure and proposed system parameters values
- Genetic identification in adaptive system. In this case it is supposed, that adaptive control system simulation is performed in real time and usually with rather large value of sampling time. Genetic algorithms are used for on line system optimization, i.e. generation of currently the best set of plant model parameters (assuming the proper structure of the system). Performance index used for guiding the genetic optimization algorithm is calculated on the basis of specified number of last measurements by simulating the system with alternative controller parameters sets – proposed within the genetic scheme. It is obvious that some design parameters of the genetic optimization algorithms should be relaxed here, as there exists a constraint of the kind of restricted time of calculation.
- Constrained genetic identification. In this scheme we assume that some parameters of the system to be controlled are known with chosen accuracy. Such a'priori knowledge could also concern the combination of several model parameters values, e.g. the sum of the numerator polynomial coefficients for some transfer function. Such a'priori knowledge could be interpreted as constraints imposed on independent variables – plant model parameters – while determining the parameters values by means of genetic optimization algorithms. Other tools for constrained optimization problem could be used here also – e.g. CLP tools; however, one should build a specialized "evaluation" software in a chosen CLP environment in such case. It should be noted, that the structure identification task is almost always a constrained optimization case, as it is natural to state some a'priori bounds with respect to the discrete time delay value, as well as plant model polynomial degrees.

ALGORITHMS IMPLEMENTATION DETAILS

The starting point of the multi-cluster genetic optimization algorithm is to choose/generate the initial population of N individuals for subsequent evolution simulation. These individuals are grouped into clusters on the basis of their mutual distances, it is possible to use a typical clusterization algorithm in this phase of the enhanced algorithm. It is supposed that a small number of initial groups/clusters would be chosen – e.g.3 or 4, and the algorithm would start with finding the mutually most distant 2-4 individuals in the initial population and forming groups/clusters around such points.

With such most distant initial individuals the initial clusters are formed around them on the basis of the nearest distance of each individual to one of the most distant corners. After generating the initial clusters in this way one should find the best fitted individuals among each cluster members and replace the cluster points of the clusters with these best fitted individuals. After choosing these new cluster centers the assignment to clusters is reconsidered and all clusters are recalculated from the point of view of their membership

At this point the genetic optimization phase begins. During the genetic optimization the cross-over operations take place with dominating probability within the formed clusters, with small probability it is possible that the cross-over operation would involve partners from different, drawn clusters. The same rules concern the mutation operation.

The next phase in every simulated evolution iteration includes some typical form of clusterization with respect to the newly generated individuals. The following specific rules should be observed:

- If the newly generated individual does not belong with some specified accuracy to any of the existing clusters and the fit function value corresponding to such individual is greater than 125% of the minimum value of the fit function for the neighboring clusters then such individual is rejected.
- If the fit function value for the new individual is between 105% and 125% of the best fit function value for the nearest cluster then the new individual survives and is assigned to this cluster for the next iteration.
- If the fit function value for the new individual is lower than 105% of the best fit function value for the nearest cluster then a new cluster is built. In one iteration only one new cluster may be generated in the neighborhood of any clusters if the new cluster generation fit function value is greater than 100% of the existing one.
- If the fit function value for the new individuals are lower than 100% of the best fit function value for the nearest cluster then multiple new clusters may be generated provided that new central clusters points are distant enough one from the other.
- During subsequent iterations if the best fit function value has not decreased then the number of cluster members is decreased by one per iteration with some minimum number of members specified, if the best fit function value has decreased then the number of members in the cluster is increased by one.

- If for some cluster the number of members is minimum for some iterations (e.g. 5 iterations) and the best fit function value is the worst among all clusters and greater than the 125% of the next worst cluster then such cluster is canceled provided that the number of remaining clusters would be at least 4.
- After every iteration the cluster central points are recalculated.
- If a new cluster is created then new members of such cluster are being generated by means of restricted mutation in order to reach the minimum number of cluster members.
- Every 5 to 10 iterations after recalculating the cluster central points the full reassignment of all individuals takes place.

The open question remains if the best individuals in clusters should be replicated.

CONTROL AND IDENTIFICATION TASK

The proposed genetic optimization algorithm has been developed with the advanced control and identification tasks in mind. At the Institute of Automation, Silesian Technical University, one of the most challenging laboratory experiment include the active noise and vibration control problems. These tasks are theoretically and numerically involved and include by far nontrivial hardware problems concerning the noise measurement and anti-noise generation. In particular the creation of 3-dimensional zones of quiet is the filed of current interest and is one of the more difficult tasks from the point of view of the adaptive control algorithm design and implementation. On the other hand the creation of such zones is of great potential application as it could concern the vehicles interior but also offices, shops, industrial buildings as well as concert halls.

The creation of 3-dimensional zones of quiet is investigated in the Laboratory of Active Noise and Vibration Control which is equipped with basic hardware concerning noise measurement and anti-noise generation including measurement microphones, sound-level meters, signal analyzers and generators, amplifiers, mixers and loud-speakers. Additional and very important hardware components include special anti-aliasing filters as well as forming filters used for precise anti-noise signal generation. Obviously the laboratory is heavily computerized and the laboratory sites under discussion include fast computers equipped with specialized signal processing cards and input/output interfaces as well as additional sound measurement equipment. The noise is generated by means of loud-speakers driven by sound generators and is measured by means of several measurement microphones placed in a special way in the 3-dimensional measurement space. On the basis of this multidimensional measurement process the anti-noise signal is on-line calculated and generated by means of precise signal generators and several loud-speakers specially placed in the 3-dimensional anti-noise generation space. However, the basic problems attacked in the laboratory concern the algorithms used for identification, recursive estimation, filtering and adaptive control of the zone of quiet control task. These problems are difficult because the acoustic object is very difficult to model, it is impossible to bound the control scene, several signals have to be involved in the control scenario calculation and all this has to be performed on-line and very fast which usually leads to simplified control identification algorithms and much trouble with the most possible efficient coding of such algorithms.

The control and identification algorithms are calculated mainly by means of specialized DSP hardware plugged into PC computer used also for data input, resulting data analysis and control and identification results visualization. The equipment used for calculation has to ensure the satisfactory computation speed because of the natural demand to work with short sampling period in such control system. One should realize that in the adaptive control system – such as the generation of the 3-dimensional zones of quiet – it is necessary to realize both identification/estimation and control calculation which heavily increases the needed computation power. The control algorithms proposed for the zone of quiet generation control task include several modern and advanced control, filtering and identification algorithms like poles/zeros placement control approach, adaptive feed-forward filters, phase-shifts algorithms, minimum-variance control and adaptation in the frequency domain. It is difficult to include the genetic optimization algorithms in standard way for the identification task in such system because of the calculation time problem. On the other hand the identification/optimization task includes non-trivial performance index to be minimized and good identification algorithms is of much importance. Therefore the work towards more efficient identification/optimization algorithms like the multiple cluster one described in this paper is important for the efficient run of the algorithms in the active noise/vibration control systems. The parallelized genetic optimization algorithm described above is a straightforward candidate for efficient optimization/ identification procedure for complex multimodal performance index – as the one for the acoustic plant – with constraints for needed calculation time.

Another aspect of using the enhanced multi-cluster genetic optimization algorithm described in this paper concerns the setup of laboratory site to be used in virtual manner by students from possibly other universities, and countries. This concept was developed in the Institute of Automation, Silesian University of Technology as part of the international collaboration based on the participation in Socrates/Minerva programme in the framework of LABLINK project. Within LABLINK project framework it is proposed that laboratory experiments will be exchanged between universities in a virtual way. By using the internet, distant students are going to have access to laboratory experiments which could be called tele-laboratories. The experiments could include image and sound transmission which is especially well suited to the active noise and vibration control experiments described above.

The main goal of the first phase of the LABLINK project was to develop the methodology of organizing remote laboratory experiments and simulations. The target group consisted of undergraduate university students in a technical study programme. The project dissemination phase would include the methods developed can be transposed to postgraduate students or doctoral students, and even to adults who are trained on-the-job (in companies).

The Institute of Automation, Silesian University of Technology, has chosen the laboratories for Active Noise/Vibration Control, as well as Adaptive Control laboratories to be included in LABLINK. The general field of study covered by the Institute of Automation staff is Electrical Engineering, the direction is Automation and Robotics and specialization is Computer Controlled Systems. The target group was composed of students from the 4th and 5th year of studying. The target laboratory experiment included the above mentioned active noise control experiment with producing 3-dimensional zones of quiet as well as active vibration control with magnetic bearings system. Both experiments include elements of adaptive control theory and important implementational issues. Both experiments pose heavy demands concerning the computational power and the optimization of multimodal performance index which makes it reasonable to try the enhanced multi-cluster genetic optimization algorithm for identification/estimation purposes in the adaptive control system. The general laboratory concept included the computer assisted experiments with real and simulated plants that could be accessed from outside by means of computer internetworks and IP protocol. Such experiments may be accompanied by some kind of tele-control.

CONCLUSIONS

The general concept of the work included the usage of multiple attraction points within the genetic algorithm population and quasi-parallel processing of such members clusters by means of standard genetic algorithm operators. Working with several member attraction points should result in faster optimization and enables the simulation of multimodal performance indices, which should also result in greater probability of reaching the globally optimum point. From the engineering education point of view it was proposed that the modified algorithm would be used while teaching such courses as Adaptive Control, Control Systems Programming and Constraint Logic Programming. Because of optimization-oriented nature of genetic algorithms they are easily incorporated into the identification and adaptive control tasks, in addition – the proposed algorithm enables the numerical decomposition of such identification and control problem to several subtasks and parallel processing. All this makes it natural to use the proposed algorithm in networked computers laboratory stand for efficient solving of complex adaptive control tasks.

The proposed algorithm could be also easily used as part of the computer laboratory stand enabled to the students by means of Internet/Intranet protocols. Such concept – closed to the virtual laboratory idea – would significantly broaden the audience with respect to students testing the proposed algorithm. When accompanied with the Internet based lecture and laboratory exercise notes delivery the laboratory stand would become the fully equipped element of distance/e-learning course on advanced adaptive control.

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