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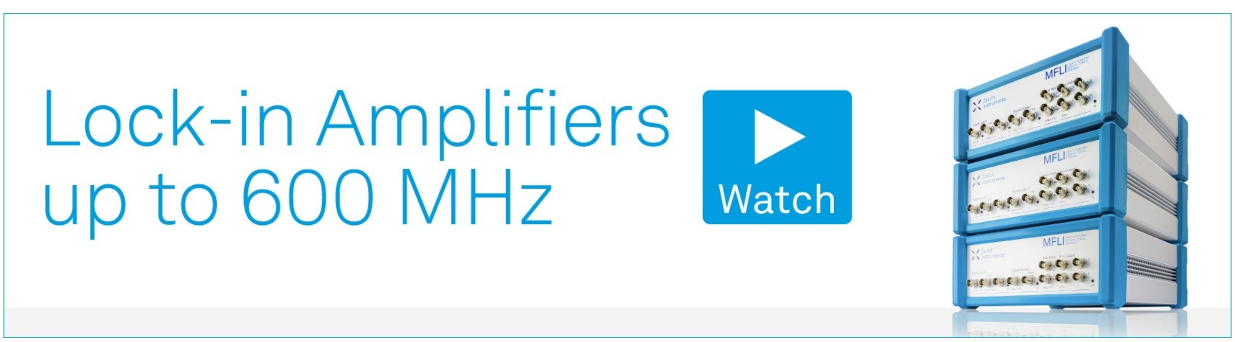

Parallel Optimization Algorithm for Drone Inspection in the Building Industry

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Abstract. In this paper we present an approach for Vehicle Routing Problem with Drones (VRPD) in case of building inspection from the air. In autonomic inspection process there is a need to determine of the optimal route for inspection drone. This is especially important issue because of the very limited flight time of modern multicopters. The method of determining solutions for Traveling Salesman Problem(TSP), described in this paper bases on Parallel Evolutionary Algorithm (ParEA)with cooperative and independent approach for communication between threads. This method described first by Bożejko and Wodecki [1] bases on the observation that if exists some number of elements on certain positions in a number of permutations which are local minima, then those elements will be in the same position in the optimal solution for TSP problem. Numerical experiments were made on BEM computational cluster with using MPI library.

INTRODUCTION

For about one hundred years heavier than air unmanned aircraft are used in military applications. Originally Unmanned Combat Aerial Vehicles (UCAV) was used as flying bombs and flying targets for ground anti-aircraft artillery [2]. Over time, the drones have become extremely dangerous and deadly weapon used in large-scale operations such as Desert Storm. For several years - due to the dynamic development of electronics- we can see considerable interest in UAVs in non-military purposes . Many video feeds of sports competitions uses a camera mounted on board the drone . Also, companies such as Amazon, DHL and Federal Express intensively works on using drones to deliver packages [3].On the other hands UAV's (especially multicopters) are used for technical installations and buildings inspections [4,5,6], such as:

- wind turbines,
- oil and gas pipelines (both offshore and onshore),
- bridges,
- train paths,
- power lines,
- photovoltaic systems,
- thermal analysis with thermal imaging camera.

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(a) (b)

FIGURE 1. Thermal inspection of building with using an UAV. (a) Quadrocopter making a thermal inspection of building with using a thermal camera, (b) view from thermal camera

VEHICLE ROUTING PROBLEM FOR AUTONOMOUS UAV'S

In most of those cases UAV's are remotely controlled by human operator with radio control environment from the ground, but in next few years the civil UAV's become more autonomous and human control will be no more need. This situation requires the development of efficient algorithms which allow for efficient passing obstacles or determination of optimal routes . This is an extremely important issue especially for multirotors whose flight time is limited to tens of minutes. Multirotors becomes a flying platforms with efficient computational environment onboard. For example quadcopter DJI Matrice 100 may be equipped with the computer Manifold which uses a NVIDIA Tegra K1 processor which uses four A15 cores and 192 CUDA capable cores and works under control of the Ubuntu Linux operating system. That solution allows for efficient parallel computing, with 326 GFLOPS computational power.

The problem of routing of the drone may be modeled as a *Traveling Salesman Problem with inspection times and due dates*(*TSP_ITDD*).It means, than in each inspection point i a processing time p_i is needed (for example thermal control of the building must be done without sun). Additionally, due dates d_i are given for each inspection point i, which means that the inspection should be finished be before d_i.If not, a penalty is given as a weighted tardiness $w_i T_i$, where w_i is a weight connected with inspection point i and $T_i = max\,\{0, C_i - d_i)$ is a tardiness, where C_i given by the formula:

$$C_{\delta(i)} = s_{0,\delta(i)} + \sum_{j=1}^{i-1}(p_{\delta(j)} + t_{\delta(j),\delta(j+1)}) + p_{\delta(i)}, \qquad (1)$$

where $t_{i,j}$ denote a flight time from point inspection point i to inspection point j. In case of flight at a constant height in windless weather, with a constant speed of drone there is a linear relationship between time of flight and the distance from the points of inspection. The problem is to determine the sequence of the inspection points which minimizes the sum of tardiness costs. The solution of this problem is to determine an optimal element from all permutations. That element should minimizes the goal function value. This problem had a NP hard nature and is extensively described in the literature (see [6]).

PARALLEL EVOLUTIONARY ALGORITHM FOR TRAVELING SALESMAN PROBLEM

In this section we propose to apply a parallel evolutionary algorithm designed for solving Traveling Salesman Problem (see Bożejko and Wodecki [1]). The algorithm provides very good solutions for VRPD because of its speed, performance and parallel nature. This natural parallelism can be easily applied in multirotors as flying platforms with efficient computational environment onboard with possibility to run parallel programs [7]. The PEA_TSP algorithm can be described by the following list of steps (executed on each processing unit):

1. Start with initial, random generated population,
2. Apply 2-opt algorithm for each individual, which allows to determine local minimum.
3. Previous step allow us to obtain a set of local minima. If there is a number of elements in the same positions in the (fixed) number of permutations we lock (freeze) these elements in the permutation.
4. Generate next population by changing the unlocked elements (frozen elements are still at the same positions).
5. Increase the number of the locked elements in next iterations, but free the oldest frozen elements (to avoid the possibility of block of the algorithm after a certain number of iterations, when all the positions are locked).

The PEA_TSP_IPDD (inspection points due dates) algorithm can be considered for two models of communication:

First one bases on set of the independent populations. For each process evolutionary algorithms described above is running For each of the processes the algorithm described above, is executed independently (on different starting populations for each process). This approach allows you to search a broader solution space. At the end the best of solutions is chosen.

Second approach bases on cooperation model. In this model each process works independently with using evolutionary algorithm but in every population the same elements are frozen.

COMPUTIONAL EXPERIMENTS

Multirotors became a flying platforms with efficient computational environment onboard. Computational experiments were made with using BEM cluster [8,9]. This supercomputer has Linpack Performance (Rmax) 695.59 TFlop/s, Theoretical Peak (Rpeak) 859.546 TFlop/s, 22656 cores (Xeon E5-2670v3 12C 2.3GHz processors) and 70656 GB memory works under Scientific Linux Operating System. Presented computational experiments were made with node which use2, 4, 8 and 16 processors and 100MB for each process. In Table 1 the results for Average Percentage Relative Deviation (APRD) [10] parameter as a function of processors for cooperative PEA_TSP_IPDD algorithm are presented. The average value of APRD parameter in this case is -3,99%.

TABLE 1. APRD values for cooperative PEA_TSP_IPDD algorithm for various number of processors

Number of processors	APRD (%)
2	-2,19
4	-3,57
8	-4,59
16	-5,62

In Table 2 the results for Average Percentage Relative Deviation (APRD) [10] parameter as a function of processors for PEA_TSP_IPDD algorithm with independent communication model are presented. The average value of APRD parameter in this case is -3,71%.

TABLE 2. APRD values for independent PEA_TSP_IPDD algorithm for various number of processors

Number of processors	APRD (%)
2	-1,81
4	-3,21
8	-4,61
16	-5,24

The results (in average) for cooperative model of PEA_TSP_IPDD are better than for PEA_TSP_IPDD with independent version of communication.

CONCLUSION

In this paper we presented and tested approach based on Parallel Evolutionary algorithm for Traveling Salesman Problem with inspection times and due dates on example of multi objects inspection with using multirotor flying platforms. We implemented and tested numerically algorithm that may be used for Vehicle Routing Problem for Drone. We compared the two versions of the algorithm, cooperative and independent. The average score for the cooperative algorithm is better than algorithm independent. In our deliberations we adopted the following assumptions: Drone make inspection at the same height (rises and falls only once), there are any winds therefore considered problem has symmetric character TSP. The speed of drone during inspection is constant. As the future work one can try to use energy consumption in cost function and various wind conditions.

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