Logistics Application of Military Land Robotic

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ABSTRACT

The ground military robotic (UGV) domain is evolving for more than two decades and contemporary technological advances within this area are slowly approaching the operational maturity stage. We could expect that level of automation touching the future military operations will be dramatic and military logistics will not stay apart. The trend of military personnel replacement by robotic systems is apparent in routine and dangerous tasks with a focus on mission performance of robotic systems, which could benefit from a very low sensor and processing latencies. This aspect could not be beaten by contemporary human capabilities and it creates key fundaments for future visions of the military battlefield.

1.0 INTRODUCTION

One of the decisive components of the future military robots is operational decision-making capability, adapting each course of action within actual or estimated common operations picture, in real-time, and with available assets. The paper is focused on operational logistics adaptive planning, where a UGV swarm is applied to establish a supply delivery chain in the complex operational environment. The task is mathematically modelled as operational research (multi-criteria) and intelligence analyses problem, where discreet modelling and simulation for close future estimation are applied.
Within a military area of autonomous systems application, we are at the beginning of the understanding of this problem. It is apparent, that the complexity of this field is very high and dispersed in several layers. If there should be a quick reaction to the operation picture update, there is a strong assumption, that the high-level data analytical process (based on the dataset linked with C4ISTAR Sytems) has to be automated.

2.0 RESEARCH GOAL AND SELECTED APPROACH TO THE SOLUTION

Based on the previous information mentioned in the introduction, there are several incrementally rising complexity phases of the solution and in this paper, we will dedicate the solution effort to the first one, which is defined as follows:

> *In the operation area, there are numbers (N) of UGVs with certain manoeuvre capability and resistance to the enemy fire, there are also a number (M) of destination points for the supply delivery. The UGVs are deployed in an operational area and a „tactical manoeuvre“ respecting the operational criteria and UGVs capability is required. As destination points, we select a shooting/combat post, which has to reflect good visibility to the destination area and visibility of the UGVs manoeuvre is taken into the account within the manoeuvre criteria.*

Remark: In this starting case, we approximate or simplify the problem to avoid some particular details, vital for the final solution (such as a size of a particular supply, weight, particular request of each combat post, and load capacity of UGVs), but complicate the initial solution. There is only one type of supply (ammunition) and there is no strict limit on the UGV number employment, in the other words, even one UGV could satisfy the destination points if necessary (if other vehicles are too far, for instance).

Desired state: Based on the request from the destination points (combat/shooting posts) for the „ammunition“ supply, there is intent to satisfy this request by the available number of UGVs as soon as possible and under the operational conditions and priorities set on the tactical maneuver, balancing the risk of speed and safety, we are minimizing a total „tactical“ cost.

Mission Total “Tactical” Cost $\rightarrow min \sum_{i=1}^{N} TSP(UGVi)\,; \rightarrow min \sum_{i=1}^{N} TSP(UGVi)\,;$ (1)

Where: i – index
TSP – Traveling Salesman Problem solution within the graph of all nodes to visit, each node has to be visited once by any vehicle.
UGVi – Particular Unmanned Ground Vehicle

For this initial solution we developed an approach, which could be characterized by six conceptual steps:

1) Selection of operating (source) area and enemy (destination) area, which has to be covered by observation (fire).

2) Operational analyses and shooting/combat post-deployment.

3) Selection of UGVs positions

4) Selection of tactical criteria and capability for each UGV. It has a decisive impact on the „tactical“ manoeuvrability graph arrangement.

5) Calculation of the „tactical“ manoeuvrability graph for each UGV, the graph is composed of nodes and weighted connections. Nodes represent every observation position and initial UGV location, nodes are interconnected by weights representing the „cost“ of the „tactical“ path between each node.

6) Solution of the asymmetric „traveling salesman problem“ (TSP) on the „tactical“ maneuverability graph with 3 UGVs.

3.0 ANALYTICAL PART

In this chapter, we would like to describe the solution in-depth, for which we developed a software application (C++) solving mentioned problem and utilizing various raster and vector type datasets as a descriptor of the operational area. Actually, this conceptual approach could serve as a “high level” decision support, for any similar logistic problem/mission.

1.1 Selection of operating and enemy area

Selection of the operating (source) and enemy (destination) area is done in 2D on a digital map with 3D view overlook.

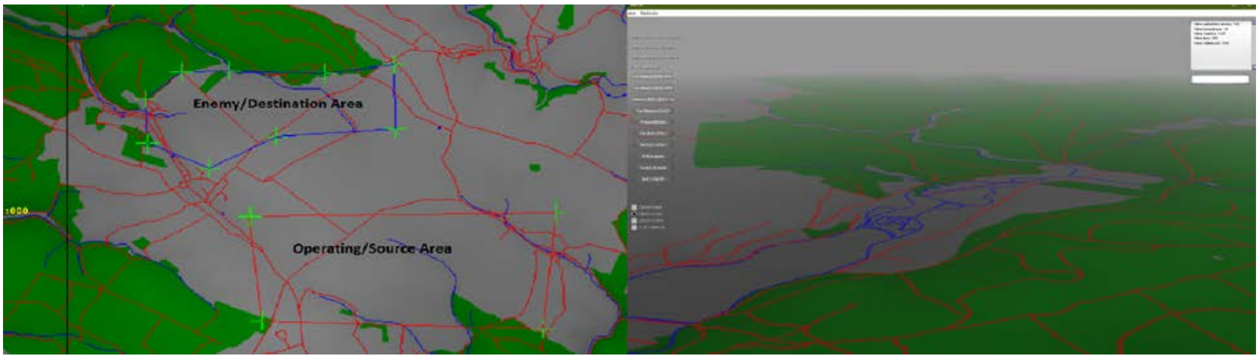

Figure 1: Area selection and 3D view.

1.2 Defense positions deployment

Because the defensive position should fulfil a set of criteria, which could be specific for every type of the mission, in any case, the observation ability of the enemy/destination area is always essential. So we simplify the problem in this case as centralized around the visibility issue only [1]. The aim of the problem solution is defined as a search of such observation points (from the source area), from which we have a maximal observation coverage of the destination area and the number of these points is low as possible (minimum).

The best case, where we could find a one-observation point from which we could see the whole destination area is usually a very rare occasion. So we need to apply other methods to find these points, if they exist, what is actually the first test before the start of another process of solution, so if:

$$\forall\, n \in N, \bigcup_{1}^{n} V_n \neq D;$$

Where: D – point set of the destination are
Vn – point set, $V_n \in D, V_n \in D,$ visible from n, n $\in N, \in N,$
N – point set of the source area
n – particular point from N

There does not exist any set of potential observation points from the source area to observe the complete destination area. In this case, there are just two options, select another source area (for instance scale it down to the set of k points, where...) or scale down the D:

$$\forall\, n \in N, \qquad D = \bigcup_{1}^{n} V_n; \tag{3}$$

What is the case used in the further approach. The problem is defined as:

$$\bigcup_{1}^{n} V_n = \bigcup_{1}^{m} V_m ; n \in N, m \in M;\ M \subset N, \min \to m \tag{4}$$

Or, usually we could accept the case:

$$\bigcup_{1}^{n} V_n \approx \bigcup_{1}^{m} V_m ; n \in N, m \in M;\ M \subset N, \min \to m \tag{5}$$

Where: V_n $-V_n$ – point set, $V_n \in D, V_n \in D,$ visible from n, n $\in N, \in N,$
V_m $-V_m$ – point set, $V_m \in D, V_m \in D,$ visible from m, m $\in N, \in N,$
N $-N$ – point set of the source area
M $-M$ – point subset of the source area
n $-n$ – particular point from N
m $-m$ – particular point from M

Especially, when the “approximate” solution (m) generates seriously lower numbers than the “original one”. In any case, a further solution we attempt to calculate is [3], the [4] needs additional analyses and could be easily derived from the solution of [3]. Regarding the problem described by [3], as usually, there could exist theoretically more approaches. In any case, one of them, generating a mathematically optimal solution is based on an iterative search of all combinations of the observation points on N and checking if a particular combination fulfils the solution [3]. The following pictures show the results of this solution:

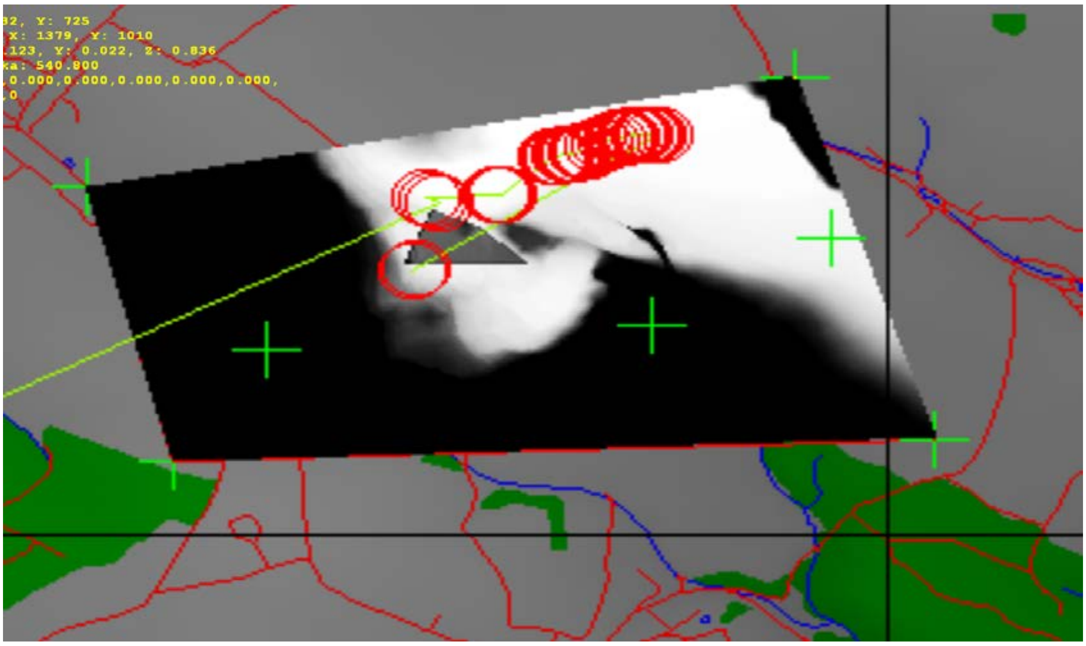

Figure 2: Visibility map (perceptual visibility of the destination area, <0,1> as <black, white> greyscale) and calculation results of the best observation points to watch the destination area – red circles.

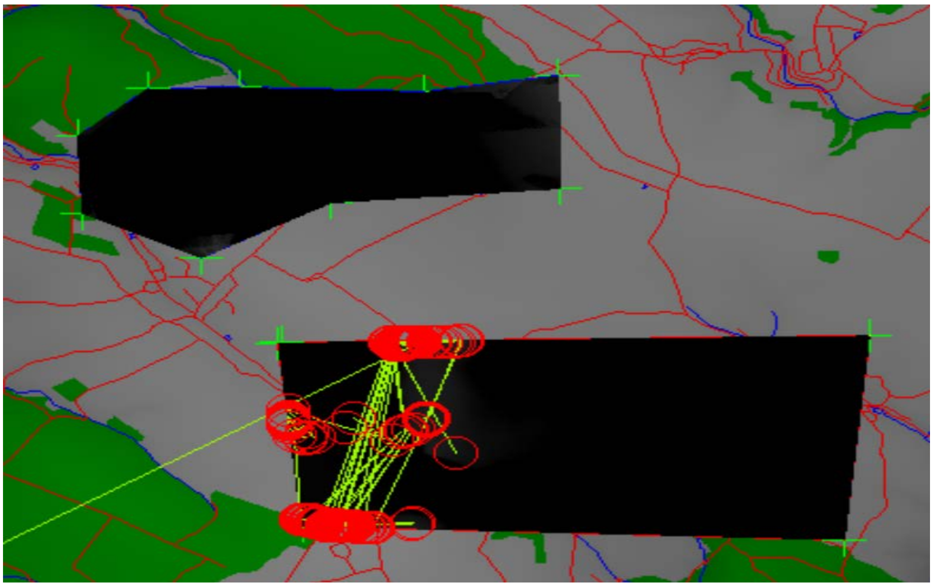

Figure 3: Another area - visibility map (perceptual visibility of the destination area, <0,1> as <black, white> greyscale) and calculation results of the best observation points to watch the destination area – red circles.

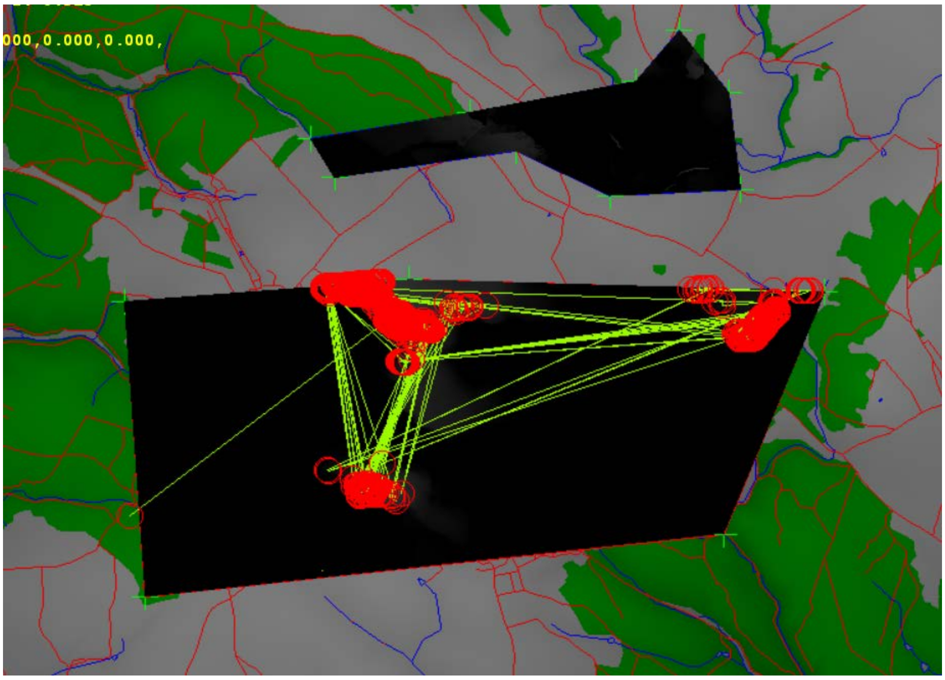

Figure 4: Another area - visibility map (perceptual visibility of the destination area, <0,1> as <black, white> greyscale) and calculation results of the best observation points to watch the destination area – red circles, sometimes the operating area is not convenient to effective observation.

1.3 Selection of UGVs positions

Selection of UGV positions could be done anytime until the optimal manoeuvre solution starts, sometimes are vital to see the results of the defensive position deployment and source area visibility map. For this example we select just 3 UGVs because computational complexity rises significantly with each UGV, so the result was available within 30 minutes, in any case, the solution is independent of any number of UGVs.

1.4 Selection of tactical criteria and capability for each UGV

As was mentioned before, each UGV could be characterized by a specific manoeuvre and transportation capability with different security constraints. So the multi-criteria table is generated by the user as a weight imposing a selected cost on the terrain point/area with particular attributes.

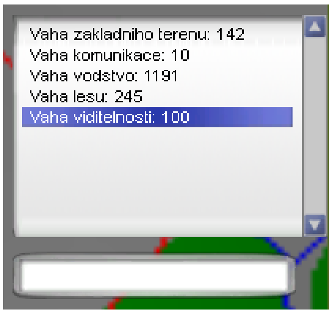

Figure 5: An example of selected criteria and corresponding weights, in this particular case it has the cost for the: terrain, roads, water, woods, and enemy visibility. Calculation of the „tactical“ manoeuvrability graph for each UGV

A tactical manoeuvrability graph is a mathematical graph filled with the minimal path cost to every node from the initial node, especially the defence positions. The manoeuvrability graph could be calculated by Dijskra or similar from this class (A-Star) of algorithms. Our optimized version uses specific weight limitation constraints but is relatively fast. Even though the solution is computationally intensive and results are delivered within tens of minutes for the three UGVs. The decisive impact on the calculation time in this regard is the dimension of the source and destination area. An example of the one version of the manoeuvrability graph is in the following image.

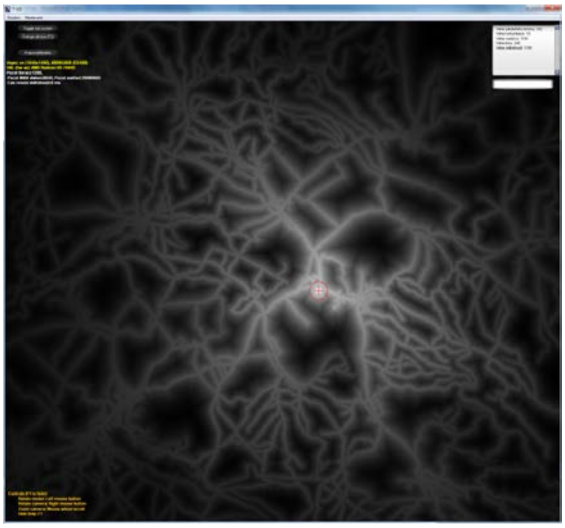

Figure 6: An example of manoeuvrability graph from initial position – red circle.

1.5 Solution of the asymmetric „traveling salesman problem“ (TSP)

The solution of mentioned (and in our case „simplified“) problem is based on the TSP algorithm, and there are many potential approaches or algorithm classes like „Lin Kernigen“, Ant Colony Optimization, Nearest Neighbour, GRASP, and others. Because transformation to the „Tactical Domain“ (manoeuvrability graph containing just tactical coefficients coming from the multi-criteria evaluation) is relatively „tricky“ and thus perfect mathematical (optimal) solution could not perform in reality better than other close optimal solution, we chose for simplicity and initial demonstration just a „nearest neighbour“

adjusted to any number of UGVs. Algorithm search for the total shortest path of all vehicles vising the destination points. Destination point has to be visited just once by any vehicle, thus there could appear a situation when only some vehicles are employed, when some vehicle is too far and other vehicles fulfil the task until this vehicle could visit any target point, this vehicle is left apart. The solution to the problem is illustrated in the following picture.

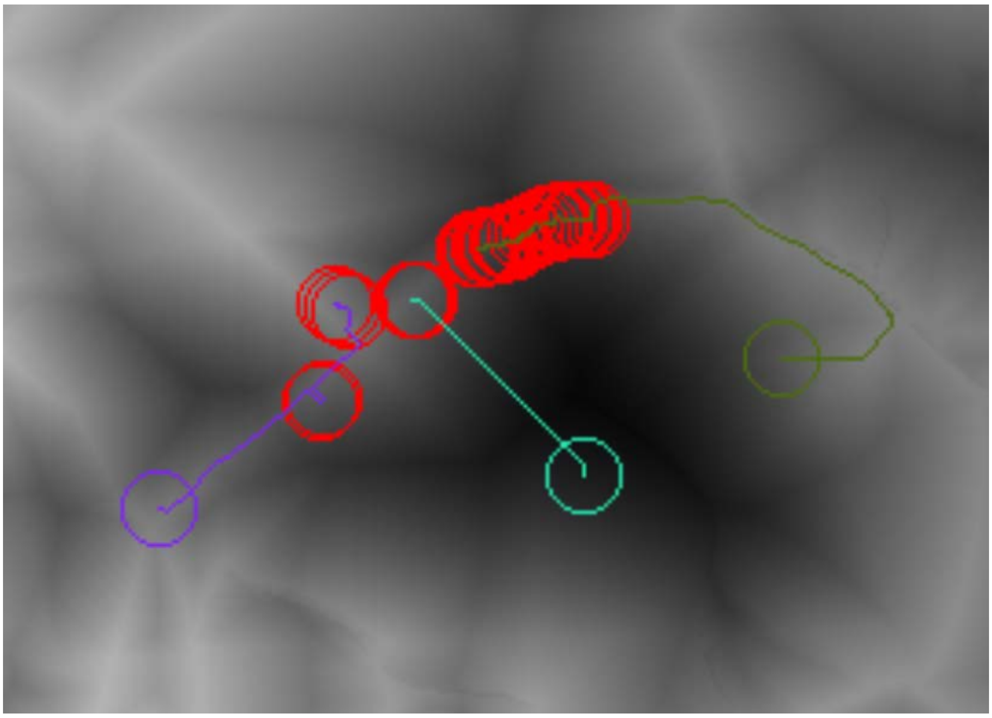

Figure 7: An example of the final solution from Figure 2 on the manoeuvrability graph (from the first UGV_1 position to any point of the area) as a background.

4.0 CONCLUSION AND DISCUSSION

Based on contemporary needs and close future prognosis of a dramatic increase of robotic applications in military operations we develop a relatively "simple" operational problem linked with military logistics in operations, but even though, the initial solution (which is usually easiest and approximate) is relatively computationally expensive and takes a long time (many minutes) to compute. Based on the state-of-the-art analyses and other sources [2-8], we do not see many similar publications dedicated to military ground robotics and thus the research activities in this field are actual. We believe that wider recognition of operational problems initiates a broader interest in the "solution infrastructure" and cohesion of the operational and research/technical community. It is also apparent, that the future battlefield will require full automation of combat activities, where "high level" operational problems play the decisive role. In this regard, it is a very poorly "harvested" area, containing a huge potential for military advancement.

Way forward:
In the conceptual approach, we developed an (initial) algorithm, which could solve the problem at a certain level of performance. It has to be evaluated in practice and incrementally risen the level of

complexity meeting the operational needs and situational reality like load limit per vehicle, asset type-specific delivery, de tailed 3d model of the operational environment, interoperability with C4ISTAR systems, supply issuing points incorporated within the path calculation and many other.

5.0 LIST OF REFERENCES

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