

# SWARM BASED URBAN ROAD MAP UPDATING USING HIGH RESOLUTION SATELLITE IMAGERY

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## Earth Observation for a Changing World

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### ABSTRACT:

Roads are of important elements of urban infrastructure which directly and crucially affect the life of people in cities. The criticality of the roads network in urban areas justifies the efforts made to use remotely sensed data especially High Resolution Satellite Imagery (HRSI) to generate fast and accurate knowledge about road networks and to update road maps. Besides, on the way towards inventing soft computation solutions for geospatial problems, Swarm intelligence approaches such as Ant Colony Optimization are known to be helpful as they hire the emergence from the collective behaviour of social animals to solve combinatorial optimization problems. In this paper ACO solutions are inspected to propose a hand for road map updating using HRSI. First, image and map are overlaid and road elements in the image are extracted. Then, an engine for evaluation of these roads is invented on the basis of supervised classification. To add newly constructed roads to the map, some random seeds in the area are selected and possible candid connections are generated. These candid new roads are heuristically inspected using ACO algorithm and the proposed engine. The results are generated using GeoEye pansharpen images of a sub urban area located in the city of Tehran. Visual investigations show satisfying results and it is presumed to present more accurate results, enhancing ACO optimization, evaluation and extraction procedures.

## 1. INTRODUCTION

Receiving recent and accurate information about roads network is proved to be included among the most prominent requirements to design and implement every systematically planned roadmap towards prosperous developments in social, economical life of residents in urban areas. As urban features such as buildings and roads are consistently constructed and changed specially in developing cities, updating information about urban features is found to be crucially important to receive a comprehensive vision of the current situation, necessities and requirements of the city. On the other hand, roads networks are of prominent elements of urban transportation lifelines which are directly affecting the urban city life. Considering the vitality of road information and the need for constant refresh of urban maps, road map updating using recently generated spatial information as a hot topic in geospatial science is introduced.

Road map updating is defined as the configuration of changes in road elements throughout the city, comparing old maps to newly generated spatial data. Since the advent of High Resolution Satellite Imagery (HRSI) and the spread of commercial image acquisition systems, the use of these highly enriched information sources for map updating tasks, is known to be a major element in many recent researches (Rafieyan, 2008 and Baillioeul, 2002). The ability of providing timely and accurate spatial information has encouraged specialists to invent map updating techniques on the basis of the information derived from satellite images. Besides, along with the process of invention of novel map updating approaches, soft computation techniques are gently injected to cover weak sides in classic solid map updating approaches such as uncertainty, optimization and learning (Samadzadegan et al, 2008). Among

many nominated solutions for such problems, swarm intelligence is supposed to be helpful in many aspects. Swarm intelligence is a type of artificial intelligence based on collective behaviour of decentralized, self-organized systems which is inspired from the strange behaviour of some social creatures, whose unintelligent decentralized activities of each individual result in intelligent outputs (Engelbrecht, 2007). Among many presented approaches in the field of swarm intelligent Ant Colony Optimization (ACO) is inspected to propose a solution to the problem of road map updating.

In this paper, the study of the beneficial aspects of Swarm intelligence approaches especially ACO and implementing map updating on the basis of such aspects are taken into consideration. At the first step reviewing both map updating and swarm intelligence principles, common issues and integration aspects are inspected. Then, generating a road map updating procedure, ACO solutions are purposefully hired to prepare a more efficient solution for this problem. Comparing the results of this experiment the capabilities of this novel approach is inspected.

## 2. LITERATURE REVIEW

### 2.1 Road Map Updating Techniques

Roads are complex in shape and properties. Many different entities in the real world with different properties are entitled as roads when they may differ distinguishably in attribute. Most road map updating solutions are constructed on the basis of some frequently studied topics under the title of road extraction. These approaches are mainly focused on gathering information about road elements using remotely sensed image and object data. Diverse road extraction techniques have been introduced

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since the first appearances of satellite images and direct data acquisition systems such as Radar, SAR and LIDAR (Bajcsy, 1976; Bacher, 2005).

In general, all methods of road extraction could be categorized according to the utilized spatial data, and the algorithms to produce desired results. The spatial data could be in the range of satellite aerial high and low resolution images to LIDAR and digital vector maps. In (Bacher et al, 2005) a method is proposed, using high-resolution multi-spectral IKONOS imagery for extraction of roads on the basis of supervised classification and edge detection techniques. In the method presented in (Baumgartner et al, 1999), road extraction from aerial gray value images, hiring contextual information and Ribbon snake is practiced. In (Hu et al, 2004), fusing satellite and LIDAR data, better results for road extraction in urban area are achieved. Moreover, the proposed method in (Klang, 1998) has hired the information content of digital vector map along with satellite imagery to perform road extraction. On the other hand, various different algorithms have been introduced for the problem of road extraction. Among them, Snakes (Active Contour Models) (Gruen et al, 1997), Hough Transform (Hu et al, 2004), Artificial Neural Networks (Bhattacharya et al, 1997; Valadan Zoej et al, 2004), Dynamic Programming (Gruen et al, 1995) and Multi-Resolution Analysis (Baumgartner et al, 1999; Couloigner et al, 2000) can be referred.

Among these proposed techniques for the problem of road extraction and map updating, soft computation approaches seem to be found interesting by researchers as they offer intelligent solution for problems such as uncertainty learning and optimization. This is why swarm intelligence approaches are studies to be applied on map updating problem.

## 2.2 Swarm Intelligence and ACO

Swarm Intelligence (SI) is a type of artificial intelligence based on collective behaviour of decentralized, self-organized systems. This novel idea is inspired from the strange behaviour of some social creatures, whose unintelligent decentralized activities of each individual result in intelligent outputs (Engelbrecht, 2007). Particle Swarm Optimization (PSO), Bee Colony Optimization (BCO) and Ant Colony Optimization (ACO) are known as most prominent branches of SI. ACO is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs based on the foraging behaviour of ants (Dorigo, 1992). The original idea comes from observing the exploitation of food resources among ants, in which ants' individually limited cognitive abilities have been collectively able to find the shortest path between a food source and the nest (Engelbrecht, 2007). As ants take any random path a kind of chemical substance, known as Pheromone which is detectable by other ants is laid on the trail. As pheromone enjoys the property of being accumulated when a path is used by multiple ants and the property of being evaporated by the time, and furthermore as ants tend to choose the path with higher amount of pheromone, the shortest path is selected.

ACO is a meta-heuristic algorithm to solve combinatorial optimization problems. Assume the problem of finding shortest path in networks of roads to be solved by ant algorithms. In this case the start and destination nodes are considered as nest and food source respectively. At the first step  $k$  ants are deployed from start node to the end node. Ants move throughout the network randomly as no knowledge about the best route

between start destination nodes are available. When all ants reach destination node, an artificial pheromone value is computed for each arc of the network. This value is proportional to the length of the path each ant has passed. It should be considered that as ants choose the path with higher pheromone intensity, the population of ants are conducted towards the arcs with higher pheromone intensities which have higher desirability of being a part of the best route. As pheromones enjoy the property of evaporation the pheromone intensities of abandoned arcs decrease iteration by iteration and the best path is determined. To have a comprehensive vision of ACO the elements of these algorithms should be inspected.

### 2.2.1 Deployment

Deployment is considered as rules to move across network of graphs. This determines if any ant is allowed to move to previously chosen nodes or what to do when reaches a dead-end.

### 2.2.2 Transition Rule

Transition rule determines the possibility of choosing an arc by each ant. There are many variants of transition rules which consider pheromone intensities and also costs such as length. Equation (1) present the probability of choosing arc  $ij$  while  $N_i^k$  is the set of feasible arcs to node  $i$  for ant  $k$  and  $\tau_{ij}$  is pheromone intensity of each arc.

$$p_{ij}^k(t) = \begin{cases} \frac{\tau_{ij}^\alpha(t)}{\sum_{j \in N_i^k} \tau_{ij}^\alpha(t)} & \text{if } j \in N_i^k \\ 0 & \text{if } j \notin N_i^k \end{cases} \quad (1)$$

In Equation (2) and Equation (3) the transition rules consider a priori effectiveness of the move from  $i$  to  $j$  ( $\eta_{ij}$ ) as cost which can be simply translate to length of each arc. In equation three another fomulation of idea is presented.  $\alpha$  and  $\beta$  are tuning parameters.

$$p_{ij}^k(t) = \begin{cases} \frac{\tau_{ij}^\alpha(t) \eta_{ij}^\beta(t)}{\sum_{u \in N_i^k(t)} \tau_{iu}^\alpha(t) \eta_{iu}^\beta(t)} & \text{if } j \in N_i^k(t) \\ 0 & \text{if } j \notin N_i^k(t) \end{cases} \quad (2)$$

$$p_{ij}^k(t) = \begin{cases} \frac{\alpha \tau_{ij}(t) + (1-\alpha) \eta_{ij}}{\sum_{u \in N_i^k(t)} (\alpha \tau_{iu}(t) + (1-\alpha) \eta_{iu})} & \text{if } j \in N_i^k(t) \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

In the other transition rule in Equation (4), if the random value of  $r$  is higher than  $r_0$ , ant chooses the path according to the a probability function such as Equation (1), Equation (2) and Equation (3). If not, ant chooses the path with higher pheromone intensity deterministically. This transition rule is called pseudo-random-proportional action rule.

$$j = \begin{cases} \arg \max_{u \in N_i^k(t)} \{ \tau_{iu}(t) \eta_{iu}^\beta(t) \} & \text{if } r \leq r_0 \\ J & \text{if } r > r_0 \end{cases} \quad (4)$$

### 2.2.3 Pheromone Updating and Evaporation Rules

Choosing an appropriate updating and evaporation rule directly influences the pace of reaching optimum solution and also the

probability of early stagnation. Consider  $f(x^k(t))$  is the desirability of the route passed by ant  $k$  at  $t^{\text{th}}$  iteration and  $d_{ij}$  is the length of each arc.  $Q$  is a constant. Three variants of updating rules known as Ant-Cycle, Ant-Density and Ant-Quantity are presented in Equation (5), Equation (6) and Equation (7) respectively (Engelbrecht, 2007).

$$\Delta\tau_{ij}^k(t) = \begin{cases} \frac{Q}{f(x^k(t))} & \text{if link } (i, j) \text{ occurs in path } x^k(t) \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

$$\Delta\tau_{ij}^k(t) = \begin{cases} Q & \text{if link } (i, j) \text{ occurs in path } x^k(t) \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

$$\Delta\tau_{ij}^k(t) = \begin{cases} \frac{Q}{d_{ij}} & \text{if link } (i, j) \text{ occurs in path } x^k(t) \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

### 2.2.4 Stoppage Criterion

It decides when the heuristic investigations are enough so, ants iterative trips are halted. Algorithms are usually stopped when most ants take the same route.

### 2.2.5 Applications

ACO has been practiced in many recent fields of interest to provide solutions for computation optimization problems. Travelling salesman problem was a turning point in coinciding ants' theory with optimization problems (Manfrin et al., 2006). Vehicle routing problem is also discussed and practiced to be solved through ACO (Baran, 2003).

The idea of the effectiveness of ACO to the problem of roadmap updating arises from the conformity of ACO structure to the problem instructions. Since every optimization problem to be solved via ACO needs to be translated to a network of solutions, the problem of map updating might seem to be solvable when the initial network of road to be updated is already constructed. On the other hand, the use of information derived from HRSI is simply facilitated as desirability of the path to be considered as an extracted updated road feature is assignable considering pheromones and other tuning parameters. Furthermore, as Ants also enjoy properties of autonomous agents, they are capable of perceiving context and having a spatial component to their properties and functions. Regarding to these phenomenal capabilities offered to map updating by ACO, the idea of a Swarm based map updating technique is developed.

## 3. PROPOSED METHOD

In this paper the design and development of a swarm based road map updating technique using HRSI is inspected. Similar to many map updating approaches, road map updating is implemented in two major branches of Evaluation and Extraction. Evaluation process starts with the projection of registered map onto the satellite image and determination of each road element in the dataset to be inspected. At the end of this procedure, it is decided whether the target road segment is same or removed. The Extraction process is established through localizing places which can be categorized as new road regions. Considering these new road seeds and the direction they are supposed to lie towards, the process of road extraction is performed. As a result, some road elements are extracted which

should be put together with evaluated road elements to generate a graph of the updated map.

The result of map updating procedure is supposed to include the evaluated roads in the old map plus newly generated road elements. Therefore, the updated network and the generated roads should be joined using edges connecting nodes from evaluated map and extracted road regions. Then, candid connections are generated to be evaluated to generate the updated map. The optimization of the network is performed according to ants' capabilities in finding best route between food source and nest on the basis of stigmergic communication protocol. On the basis of collaboration of ants, the algorithm is conducted towards inspecting edges with higher probability of being considered as road element. The flowchart of the proposed algorithm is illustrated in Figure 1.

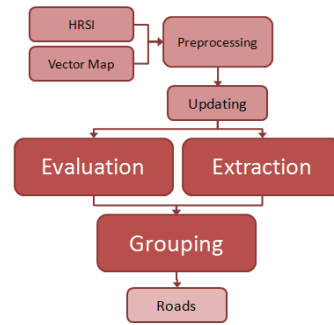


Figure 1. The flowchart of the proposed method.

### 3.1 Evaluation

In Evaluation procedure where existing roads in the vector data set are inspected, a road could be categorized in one of the following classes. A large group of road entities are supposed to remain unchanged as in urban areas it is deserved to observe rare major changes to the streets. These categories are titled as same road class. The other class of evaluated road entities refers to the road segments which are completely removed. This situation is deserved to take place seldom as it is not predicted to happen frequently in urban areas.

To evaluate existing roads, digital vector map of the area is overlaid upon satellite imagery. Then, extracting information about shape and attribute, the corresponding pixels of each road element in the vector dataset is extracted. This simply reduces data redundancy in the process of road map evaluation. Then, recognizing objects at the extracted region the road current situation is maintained. To do so, an engine is designed to be applicable on each road segment derived from data set. The engine uses supervised classification to extract road building vegetation shade trees and other presumable objects at the scene. Comparing the results of classification the road element is provided with the pheromone intensity which indicates the desirability of any arc to be considered as road element. Since this procedure is performed on arcs separately, all existing road elements in the vector dataset are extracted and evaluated and the desirability of each road is maintained. In Figure 2 the process of evaluation is depicted.

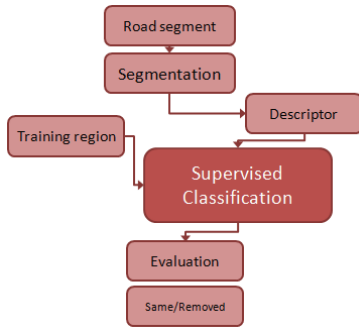


Figure 2: The process of road evaluation

### 3.2 Extraction

The Extraction process is established through localizing places which can be categorized as new road regions. These regions could be considered as presumable choices for initiating new road features. Considering these new road seeds and the direction they are supposed to lie towards, the process of road extraction is performed. This process starts with finding best seed points to be considered as new road regions to generate roads. Two prominent techniques can be applied to the purpose. In the first technique, using conventional road extraction algorithms such as Snakes, road regions are extracted and seed points are derived. On the basis of this procedure some nodes which are likely to be considered as road regions are extracted. In the second technique, random seeds with specific density are selected to be evaluated. In this technique, the evaluation of seeds is performed during grouping procedure considering collaborative behaviour of ants. To have knowledge about seed nodes quality, they are simply evaluated using the spatial position and the result of evaluation is introduces to the pheromone intensities of arcs which are connected to the seed. In summary the second algorithm entrusts the extraction of new roads to the grouping procedure which is determined to merge results of evaluation and extraction. The flowchart of this extraction algorithm is depicted in Figure 3.

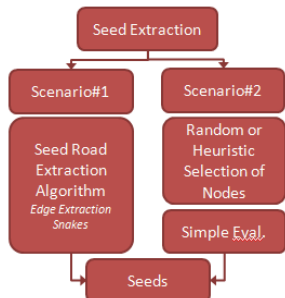


Figure 3: Seed extraction scenarios

### 3.3 Grouping

To regenerate the updated map two processes of Evaluation and Extraction are merged. Therefore, candid connections are generated to be evaluated to result in updated map. Within the deployment of ants across the network and inspecting candid edges the updated road network is extracted. Through this procedure, a framework for determination of best structure for the network can be presented and the updated road map is generated.

At the first step of grouping procedure all possible connections between evaluated network and seeds are constructed. Therefore the evaluated network should be changed in the way that the possible junctions are available. Then connections between these points and seeds provide all candid road elements. As the quantity of all these possible arcs increases, the process of examining all these arcs does not seem to be practical due to huge dataset and computational restrictions. So, ant algorithms are proposed to conduct processing engines towards arcs with higher possibility of being road entities.

At the second step, each arc of the candid network of road is provided with a value which literally describes the desirability of the arc to be supposed as road element. This value is computed by averaging the desirability of both ends of seeds computed in extraction process. This is considered as initial pheromone intensity to be sensed and followed by ants. The previously evaluated network which is also a part of this huge candid network is marked in the way that its elements are not subject to such processes.

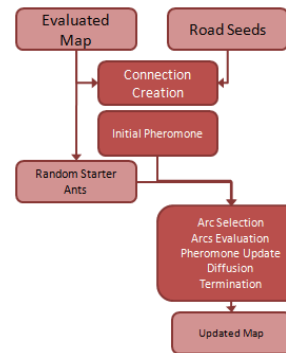


Figure 4: the Grouping procedure

At the last step, ants are deployed throughout network. According to the literature ants tend to choose the arc with higher pheromone intensity. Any chosen arc is evaluated through the proposed engine and new pheromone intensity is assigned. Ants choose the next node following the same process. When a candid road is evaluated and confirmed as new road element using previously mentioned engine, due to the assignment of high pheromone intensity, the ants are guided to search the arcs in the neighbourhood of the new road. On the other hand, when the algorithm finds the selected arc as a false road element, assignment of low pheromone intensity, decreases the desirability of arc to be chosen so the arcs which are connected to this road element will be less intensely inspected.

## 4. EXPERIMENT & RESULTS

To inspect the capability of this technique, it is evaluated and tested using GeoEye pansharpen imagery. The data is collected from an urban area placed in the city of Tehran, Iran. The vector and raster data are illustrated in Figure 5. To inspect results regionally, a subset of the main dataset is extracted and utilized.



Figure 5. GeoEye1 image and overlaid map of the test area.

According to the proposed method the first step towards map updating is to evaluate existing road element. In this case road elements are extracted, segmented and evaluated using supervised classification techniques to provide a comprehensive knowledge about objects on the surface of the road. Six classes of objects are extracted which include, Road, Building, Bareland, Car, Vegetation and Shade. The overall desirability of the road is computed directly from the results of supervised classification. The computation is handles by counting pixels in each region. If the ratio of the number of road pixels to all pixels is higher than 0.3 the area is considered as road. If not, the road element is rejected. As this decision suffers from the ambiguity from it is recommended to use fuzzy engines to compute the similarity of the region to the road. The results of evaluation to some road elements are presented in Figure 6.

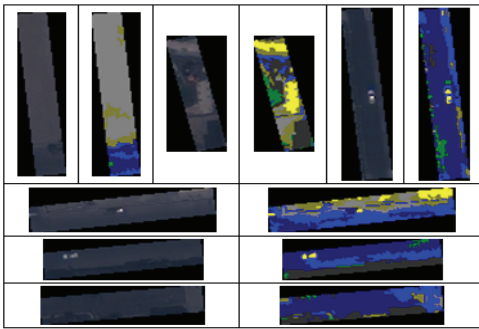


Figure 6. The results of evaluation of a road element. Blue regions show the surface of the road.

The extraction of new roads should be performed by extracting seeds to represent nodes of the new road elements. As previously discussed, this procedure is performed by random selection of these seeds and applying a simple evaluation so the desirability of the seed to be considered as node is maintained. 4000 random seeds are extracted and evaluated in two aspects. Firstly they should not be closer than 10 meters which reflects the mean road width to any nodes and secondly a 5x5 window of pixels around the seed is evaluated to determine the desirability of the seed to be considered as a node.

To generate all possible connection map arcs are broken into smaller steps to have the ability of being connected to the seeds from many positions along the path. To have to most optimum number of sub nodes along each arc they are chopped each 15

meters to make a 1.5 ratio with 10 meter road width. Then all possible connections between all nodes which lie in the 10 to 50 meter distance to the neighbouring nodes are constructed. This range is decided as minimum length of nodes to prevent detection of double edges for one road and to reduce the redundancy. The connections and seeds in the area are depicted in Figure 7.



Figure 7. Left: the results of evaluation Green: evaluated roads. Red: rejected roads. Right: Seeds and all possible connections.

As in can be perceived from Figure 7, possible connections between nodes and seeds are enormously outnumbered. This jeopardizes the idea of evaluating each connection separately to find new roads. This is where ACO is hired to propose a meta-heuristic solution. Ants are deployed randomly on some nodes which are considered as nest and the new roads are considered as food source. Any ant takes a path according to the initial pheromone intensity from both ends of the arc. The chosen arc is evaluated using previously described engine and the pheromone intensity is updated as well with respect to the evaluation results. If the evaluation value is high which is equal to finding a new road, other ants are indirectly swarmed towards this region and neighbouring arcs. In contrary, if the candid arc is rejected the pheromone is declined to restrict the search area heuristically. After some iterations the extracted road are marked and the same idea of finding seeds are and making connection is applied. Figure 8 shows final results. The deployment rule is considered to be random which decreased the amount of computation. The transition rule is set to choose arcs according to the pheromone intensity only according to Equation (1).

The idea proposed in this paper is the first of its own in this field. Therefore it enjoys many novel states of art as it suffers from some shortcomings. The following lines describe these states of arts and shortcomings. In general ACO is proved to be helpful for searching through graphs and this is counted as a special offer of this paper to reduce searches for finding new roads. This method seems to have the minimum human supervision as it only needs human supervision to determine training regions. Regardless of this, finding new roads is facilitated by the collaborative behavior of artificial ants. Hence, Visual inspection of the results shows that the algorithm is almost successful in map updating but the quality of the new roads is somehow weak as the engine is not distinguishing enough due to simplicity. Furthermore, contextual information is indirectly used as ants find the context of new road regions and focus investigations on those areas. But it is not appropriately developed in the field of evaluating engine. Moreover, seeds are chosen randomly in this algorithm. But it is highly recommended to use heuristic search algorithm to find best seed to reduce redundancy and to avoid huge candid networks. More importantly, shape properties are not included

which could help the process of evaluation and extraction of roads with respect to the road's specific shape signature. Extraction of edges along with Snakes can be generally recommended.

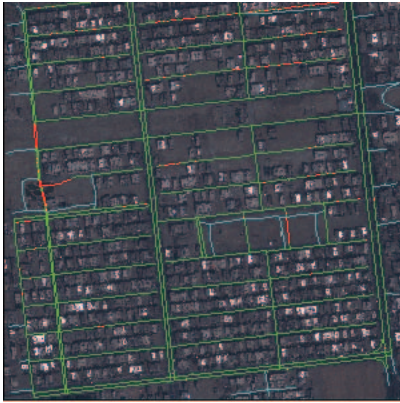


Figure 8. Final results of map updating Green: evaluated roads; Red: rejected Roads, Cyan: Extracted roads.

## 5. CONCLUSIONS

The cardinal goal of this paper is to present a road map updating algorithm using mega heuristic search and optimization algorithm known as swarm intelligence. This paper is the first endeavor to facilitate the problem of road map updating with Swarm intelligence approaches. Regarding to the need for investigating more comprehensive algorithm for better map updating and also considering the capabilities of ACO for this specific problem, more prosperous approaches are predicted in the prospect.

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