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*ambulance travel time prediction,*
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# QUANTUM ROAD TRAFFIC MODEL FOR AMBULANCE TRAVEL TIME ESTIMATION

Efficient management of ambulance utilisation is a vital issue for life saving. Knowledge of the amount of time needed for an ambulance to get to the hospital and when it will be available for a new task, can be estimated using modern Intelligent Transport Systems. Their main feature is an ability to simulate the state of traffic not only in long term, but also the real time events like accidents or high congestion, using microscopic models. The paper introduces usage of Quantum Computing paradigm to propose a quantum model of road traffic, which can track the state of traffic and estimate the travel time of vehicles. Model, if run on quantum computer can simulate the traffic in vast areas in real time. Proposed model was verified against the cellular automata model. Finally, application of quantum microscopic traffic models for ambulance vehicles was taken into consideration.

## 1. INTRODUCTION

Acquiring data on traffic for optimal ambulance fleet control or surveillance is a very complex issue. The ambulances usually have GPS devices and are able to send their positions to the management centre. However, the arrival time differs depend on the current state of traffic. There are several events which are hard to avoid, such as: traffic jams, accidents, weather threats like ice, fog or strong wind.

The paper proposes a real-time solution that aggregates data into a faster than real time model, which can estimate the vehicle travel time. Time is of the essence in case of life saving, therefore authors propose to use Quantum Computing to improve the model performance.

The idea of quantum computing seems very attractive. The quantum effect and possibility of parallel data processing as well as the Quantum Computers prototype, proves that this technology could be used for practical application. In this article the probabilistic feature of quantum computations is used to build the model of the vehicles' movement. The model is based on a known theoretical model for the simulation of freeway and urban traffic – cellular automata model. During the simulation, the vehicles may move with different speed, according to the probability of finding a vehicle in a specific point on the road. Using the quantum model, the vehicle's position can be estimated each step (1 second) or on demand. The model includes methods of vehicle's position correction if during the simulation the vehicles in quantum state occupy the same position on the road or overtake one another.

The remainder of this paper is organized as follows. Related works concerning Quantum Computing, road traffic models and their data sources are thoroughly described in Section 2. Section 3 presents a proposal of a Quantum traffic model. Finally the simulation results are presented in Section 4 with comparison to cellular automata. Section 5 concludes the paper with remarks on possibilities of further development of the model .

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## 2. RELATED WORKS

To predict the time at which the emergency vehicle will reach its destination, precise information about traffic condition must be taken into consideration. The paper connects two main research areas: traffic modelling and quantum computing.

### 2.1. TRAFFIC MODELS

The traffic models are built based on information taken from multiple sources: via video surveillance, VANET or GPS systems[3] [4]. The knowledge of video-detection algorithms is essential to estimate their detection error. The data from various sources are noised [15], however the most precise detection is achieved using virtual detection loops: $\tilde{1}$m accuracy [1]. In case of objects tracking, the accuracy change with distance from the camera and is equal to $(1,\infty)$ meters [7].

Vehicular ad-hoc networks are becoming a more and more reliable tool to exchange data between vehicles. There are many standards and propositions how to store, secure and process the information in vehicular networks [6] [5]. To acquire data for experiments, a VANET simulation model was developed in [2]. Experiments show that the ability to send message to VANET, based on 802.11 standard and at 1200 veh/h traffic volume, is 91%. The obtained information can be used to build and verify the traffic model.

The traffic flow can be modelled in mesoscopic, macroscopic and microscopic scale. The paper focuses on data estimation for particular vehicles, therefore the microscopic model will be considered. There are many traffic models that evaluate the positions and velocity of vehicles. The paper will use the basic kinetic traffic equations and cellular automata to provide data and for verification purposes.

Cellular automata have become a useful tool for microscopic modelling of road traffic processes, due to their low computational complexity and high performance in computer simulations. Cellular models are limited to discrete time, space and state representation. Therefore, despite limitations, a traffic process can be simulated with sufficient precision. The detailed implementations was thoughtfully described in [10] [9]. The model has many applications and extensions for:

- urban road networks [8],
- signalised urban networks [13],
- traffic modelling [13],
- the fuzzy cellular model [12].

### 2.2. QUANTUM COMPUTING

The best known quantum algorithms [16]: Grover's search and Shor's prime factorization, present the power of quantum computations. The great efficiency of quantum computations, comparing it to classical computers, may be obtained because of quantum effect called the entanglement, but also thanks to the ability to perform parallel processing on quantum bits (so-called qubits). On the other hand the quantum effect called decoherence makes it very difficult to construct the quantum computer [17] - it causes the fragility of quantum state containing the quantum information. The influence of any factors from the environment destroys quantum information written in a quantum register, so it is very important to guarantee the high degree of isolation from any external factors during computations. At the same time, after the computation process the results have to be read and the interference with quantum environment is inevitable. In practice it is extremely hard to do the measure properly and guarantee the correct result. The next problem is that the qubits can affect one another when they are isolated from external environment and it is also harmful for quantum information and makes the constructing of quantum computer so difficult.

In spite of all the above mentioned problems quantum computing is intensely developed. Since the 1990s, when scientists were working on i.e. quantum computations with cold trapped ions and with nuclear magnetic resonance, the range of knowledge obtained in the field of quantum computing has expanded significantly. There are achievements especially in quantum teleportation [14], but also this year Google Inc. bought a 512-qubit processor chip (housed inside a cryogenic system) from The Quantum Computing Company for research on machine learning.

## 3. PROPOSITION OF A QUANTUM MODEL

The paper proposes to use quantum computation and cellular automata traffic model to create a simulation environment. The NaSch model is defined by the following steps:

1) Estimate the distance to preceding vehicle (*j*):

$$g_i(t) = s_j(t) - s_i(t) - 1, \tag{1}$$

2) Define the current velocity according to the probabilistic values:

$$v_i(t) \leftarrow \min\{v_i(t-1)+1, g_i(t), vmax\}\ if\ \xi < z\ then\ v_i(t) \leftarrow \max\{0, v_i(t)-1\}, \tag{2}$$

3) Define the position of *i*-th vehicle:

$$s_i(t) \leftarrow s_i(t-1) + v_i(t). \tag{3}$$

where:
*i* – no. of vehicle in time step *t*, *z* – probability threshold (usually set to 0,19), *j* – no. of vehicle in front of vehicle at *i*-th position, *j* is selected basing on evaluated direction from previous frames and velocity, $s_i(t)$ – no. of cell occupied by vehicle *i* at time step *t*, $\xi$– random variable with uniform distribution (values within range [0, 1]).

### 3.1. POSITION DESCRIPTION

In the proposed quantum model the vehicle position is defined as a qubit. A qubit is a vector in two-dimensional Hilbert space $H_2$. According to the Dirac notation the vector h in the Hilbert space will be denoted as |h>. The standard basis is a basis in $H_2$ consisting of two orthonormal vectors: |0> and |1>. The representation of basis vectors from the standard basis is:

$$|\,0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix},\quad |\,1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

The state $|h\rangle \in H_2$ may be expressed as a combination of basis vectors:

$$|h\rangle = \alpha_0\ |0\rangle + \alpha_1\ |1\rangle$$

where the complex numbers $\alpha_0$ and $\alpha_1$are called states' amplitudes and satisfy the normalization condition:

$$|\alpha_0|^2 + |\alpha_1|^2 = 1$$

The state |h> may be denoted as a vector of amplitudes:

$$|\,h\rangle = \begin{bmatrix} \alpha_0 \\ \alpha_1 \end{bmatrix}$$

The quantum n-qubit register is a vector in $2^n$-dimensional Hilbert space $H_{2^n}$ created as a tensor product of n qubits from $H_2$ space.

The state of n-qubit register can be expressed as the superposition of basis states:

$$|h\rangle = \alpha_0|\,0\ldots000\rangle + \alpha_1|\,0\ldots001\rangle + \alpha_2|\,0\ldots010\rangle + \alpha_3|\,0\ldots011\rangle + ... + \alpha_{(2^n-1)}|\,1\ldots111\rangle\,,$$

under the normalization condition:

$$\sum_{i=0}^{2^n-1} |\alpha_i|^2 = 1. \tag{4}$$

The register's state can be changed with use of quantum operator. For n-qubit quantum state the above-mentioned operator can be denoted as a unitary matrix U sized $2^n \times 2^n$. The operation U on state |h> may be shown as the multiplication of matrix U by amplitudes' vector |h>:

$$U\,|h\rangle = \begin{bmatrix} u_{0,0} & u_{0,1} & \cdots & u_{0,(2^n-1)} \\ u_{1,0} & u_{1,1} & \cdots & u_{1,(2^n-1)} \\ \vdots & \vdots & \ddots & \vdots \\ u_{(2^n-1),0} & u_{(2^n-1),1} & \cdots & u_{(2^n-1),(2^n-1)} \end{bmatrix} \cdot \begin{bmatrix} \alpha_0 \\ \alpha_1 \\ \vdots \\ \alpha_{2^n-1} \end{bmatrix} = \begin{bmatrix} \alpha_0^{'} \\ \alpha_1^{'} \\ \vdots \\ \alpha_{2^n-1}^{'} \end{bmatrix} = |h^{'}\rangle$$

where the vector of $\alpha_i^{'}$ amplitudes is a register's state |h'> after the operation U. Because U is a unitary operation the state |h'> satisfies the normalization condition.

The quantum measurement is an irreversible operation, which projects the quantum state into one of the basis vectors. If the n-qubit state is expressed as the superposition of the standard basis states and the measurement is also performed in the standard basis, the probability of finding the state in $|i_{bin}>$ after measurement is $|\alpha_i|^2$ ($i_{bin}$ is an n-bit binary number equal to value i).

The information about every single vehicle's position is kept in another quantum register. Let the number of vehicles/registers be *y*. The simulation of traffic is analysed on the road lane divided into *x* sections – every section may be presented as the amplitude of quantum state. For convenience, let the x = $2^n$, where n denotes the number of qubits in every quantum register. To allow the movements of vehicles, their number have to be lower than the number of road's sections (y < x).

At the beginning of simulation the vehicles take the positions in their registers and they occupy the amplitudes with the lowest numbers.

Example: The number of cars is *y* = 3. The road consists of *x* = 8 sections. There are three 3-qubit registers $R_j$ (j = 1,2,3) needed and the initial state of quantum registers (written as the amplitudes' vectors) at the beginning of the simulation is:

$$R_1 = \begin{bmatrix} 1\\0\\0\\0\\0\\0\\0\\0 \end{bmatrix}, \quad R_2 = \begin{bmatrix} 0\\1\\0\\0\\0\\0\\0\\0 \end{bmatrix}, \quad R_3 = \begin{bmatrix} 0\\0\\1\\0\\0\\0\\0\\0 \end{bmatrix}$$

It means the first vehicle occupies the section of the road no. 0, the second vehicle is in the section no. 1 and the third vehicle – in the section no. 2.

During the simulation, the vehicles move in the direction of amplitudes' growing numbers (in the above example, where amplitudes' vectors are vertical, so the vehicle's movement can be described as "going down"). When the vehicle reaches the last section of the road and the simulation is not over yet, it goes back to the first section (circles around).

## 3.2. THE MOVEMENT MODEL

The speed of a vehicle, in the specified simulation's step is expressed as the number of sections through which the vehicle can ride. The minimal speed is equal to 0 (no movement), the maximal speed is equal to 2 sections, according to the cellular automata model with speed limitation for city traffic.

To make the vehicle start moving, an exemplary operation $M_{2^n \times 2^n}$ may be executed on n-qubit register's state:

$$M = \begin{bmatrix} \sqrt{p0} & 0 & 0 & 0 & 0 & 0 & \dots & \sqrt{p1} \\ \sqrt{p1} & \sqrt{p0} & 0 & 0 & 0 & 0 & \dots & \sqrt{p2} \\ \sqrt{p2} & \sqrt{p1} & \sqrt{p0} & 0 & 0 & 0 & \dots & 0 \\ 0 & \sqrt{p2} & \sqrt{p1} & \sqrt{p0} & 0 & 0 & \dots & 0 \\ 0 & 0 & \sqrt{p2} & \sqrt{p1} & \sqrt{p0} & 0 & \dots & 0 \\ 0 & 0 & 0 & \sqrt{p2} & \sqrt{p1} & \sqrt{p0} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & \sqrt{p2} & \sqrt{p1} & \sqrt{p0} \end{bmatrix}$$

The values p0, p1 and p2 are probabilities of finding a vehicle in one of road's sections in (t+1) step of the simulation:

$p0|s(t+1)=s(t)$, $p1|s(t+1) =s(t)+1$, $p2|s(t+1) =s(t)+2$.

$$p0+p1+p2 = 1$$

The matrix M is not unitary. It only preserves the quantum state if the initial state is the standard basis vector. So after every M operation the quantum measurement in the standard basis has to be performed.

To allow running a few steps of simulation without following them with measurements, the operation $M_E$ was proposed that describe acceleration pattern of the vehicles. $M_E$ is a unitary matrix, calculated with use of evolutionary algorithm. The transformation of the matrix to unitary state is performed by minimizing distortion of the initial probabilities. The mutation within population is performed by performing the subtraction operation according to a diagonal and adding those values to randomly selected diagonal, according to the scheme presented in Fig. 1.

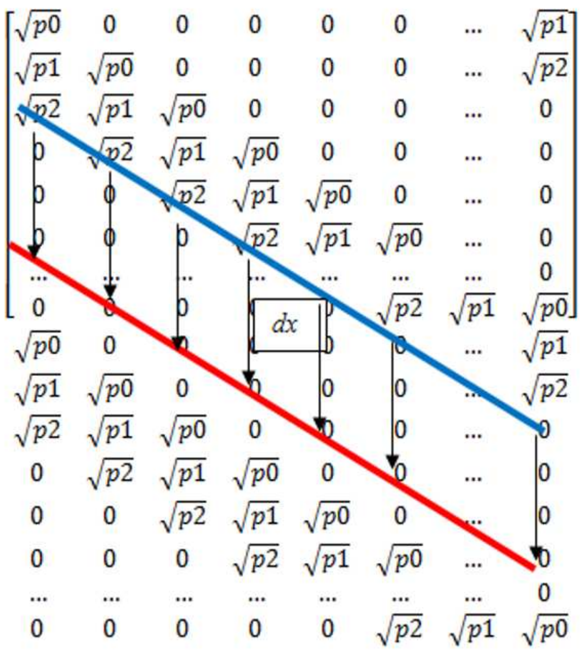


Fig. 1. Normalization scheme.

To maintain the quantum normalization rule (eq. 4), the sum of the square of each pair of modified values are equal to the sum of square of previous values, according to pseudo-code to mutate M matrix to M' matrix according to alg. 1:

1) Generate uniformly distributed values: *i* and *j* value, where $i, j \in [0, 2^n - 1]$and $dx \in (0, 1)$,
2) For each k=0 to $2^n$-1 do

    begin
    m'$_{i+k,k}$= m$_{i+k,k}$ – *dx,*
    m'$_{j+k,k}$= m$_{j+k,k}$ + *dx,*
    s = $(m_{i+k,k})^2$ + $(m_{j+k,k})^2$,
    s' = $(m'_{i+k,k})^2$ + $(m'_{j+k,k})^2$,
    $m''_{i+k,k} = \text{sign}\left(m'_{i+k,k}\right) * \sqrt{\left(m'_{i+k,k}\right)^2 / s' * s}$,
    $m''_{j+k,k} = \text{sign}\left(m'_{j+k,k}\right) * \sqrt{\left(m'_{j+k,k}\right)^2 / s' * s}$,
    end.

The crossover is performed between the two M' matrixes within population averaging values and stabilized according to eq. 4. The fitness function $f_a$ was defined as a sum of two parameters – distance of original matrix M ($f_d$) to its current mutation and as a unification parameter measured as a sum of differences ($f_u$) from the definition: $f_a(M) = f_d(M) + f_u(M)$.

The genetic algorithm stops if the maximal number of epochs is reached or $\min_M f_a(M) < \alpha$. The $\alpha$ value is estimated empirically according to the reading operation in s-th step. If reading operation is performed at each simulation step $\alpha =$ . According to research, $\alpha < 3$ gives correct results for performing the reading every 5 steps (r=5). Lane length is defined as $2^n$cells, where $n \in \mathbf{N}$.

The unified matrix M$_e$ is used for simulation according to alg. 2:

1) Set I to 0,
2) Evaluate quantum position of a vehicle: $U\left|h\right\rangle = \mathrm{MeR} = \mathrm{R}' = \left|h'\right\rangle$,
3) For each k=1 to $2^n$-1 do
   If $r_{i,k}^2 + r_{i+1,k}^2 > 1$ perform matrix operation: $r_i$=DIFF*$r_i$,
4) If I%s=0 read vehicle position,
5) If number of steps I is not maximal, return to 2.

The DIFF procedure aims to move the NivenGubit value to the left using DIFF matrix. The Matrix is constructed dynamically according to n parameter:

1) Define DIFF Matrix with dimension $x = n * n;;$
2) For each a=0 to a<x do
   For each b=0 to b<x do
   DIFF[a,b]=0;
1) For each b=1 to b<x do
   DIFF[b-1,b]=1;

## 3.3. ESTIMATING POSITION OF A VEHICLE

Reading of the quantum position is estimated based on probability of the qubit vector R. Next, the boundary conditions are checked. The positions with negative value are estimated as probability equals 0. Two heuristic constraints for traffic were created:

1) If the vehicle overtakes the vehicle in front of it, set its position behind this vehicle.
2) If the vehicle's position decreased since the previous reading, return it to previous position.

## 4. MODEL EVALUATION

The cellular automata model [10] was used in order to verify the proposed approach. The model was defined for 16, 32 and 64 cells, which corresponds to a road lane length of 100, 200 and 400 meters.

The model was verified in urban traffic. The cellular automata model was calibrated with n=2, and $z$ value equals 0.19, which corresponds to traffic with maximal velocity of 50 km/h. To adapt the proposed quantum model to urban traffic characteristics, the probability values were defined as $p0$=0.01, $p1$=0.05 and $p2$=0.94. The traffic flow was defined within three classes: low traffic 100 veh/h, medium traffic 500 veh/h and high traffic 1000 veh/h. To verify results, the simulation tool was implemented with both models. The quantum simulation was implemented with the following additional possibilities:

1) unification of $M_e$ matrix within defined threshold,
2) setting read process every $n^{th}$ step,
3) definition of the quantity of simulation steps,
4) allow to overtake vehicles in case of ambulance scenario (cancel 1 boundary rule for ambulance only).

Based on the estimated probabilities the initial matrix was built (Fig. 2a). The matrix undergoes the unification process, using genetic algorithm, if vehicle position is not estimated in every step. The unification process generates negative values, which are accepted as quantum model. Additionally, unitary matrix generates new probable positions, when the quantum reading process is not executed every step.

Based on *Me* matrix the position of the vehicles in next step is estimated. After the reading procedure the estimated position of vehicle is given.

The 20 simulation, with 3600 steps (1 hour), for every traffic density was performed. The obtained results for quantum model and cellular model were consistent in average velocity, travel time and traffic density. The difference between measured values did not exceed 3%.
The calibrated model was used to estimate the ambulance travel time. Based on the introductory observation the overtaking rule for ambulances was turned on. In this case the quantum jumps observed in the model allowed to simulate the ambulance overtaking manoeuvre on narrow lanes. As a field test, a road near the hospital was selected, where the density of ambulances is high. Passage of 25 ambulances was registered.

The model was calibrated according to 20 ambulances passes divided into three classes by traffic flow value: low, medium and high. Then the model was verified using 5 ambulances passes treated as a test vector. Travel time of ambulances varied from 28 up to 50 seconds on a distance of 0.5 kilometer. The model estimated travel time on average with 4 seconds accuracy. The travel time in a simulation could be predicted with 10% accuracy. Unfortunately, the relatively low prediction precision is caused by a human factor and small data sample. Further research will be focused on increasing the simulation area and improving its precision.

## 5. SUMMARY

The obtained results are encouraging, however further research is needed. The proposed model was verified against cellular automata model giving comparable results. The model was also used to simulate the travel time of an ambulance. The obtained results proved on real world data that the proposed quantum model can be used to simulate the real traffic on urban roads and estimate travel time. The advantage of the proposed model is possibility to skip the reading procedure and obtain the probability distribution after several simulation steps if no data from video-detection can be acquired in that time. Furthermore, the quantum model, if applied on quantum computer, could give the results in an instant, overtaking the fuzzy and uncertainty solutions.

The drawback of the solution is time-consuming generation of $M_e$ matrix and its unification. The further research will focus on finding a heuristic to generate the unified matrix in a faster and more efficient way. Furthermore the model will be enhanced with the intersection rules.

## BIBLIOGRAPHY


[1] BERNAŚ M., Objects detection and tracking in highly congested trac using compressed video sequences, ICCVG 2012, Lecture Notes in Computer Science, vol. 7594, pp. 296-303.

[2] BERNAŚ M., VANETs as a part of weather warning systems, CCIS Computer Network,2012, Vol. 291, pp. 459-466.

[3] BHAKTHAVATHSALAM R., NAYAK S., Operational inferences on VANETs in 802.16e and 802.11p with improved performance by Congestion Alert, Consumer Communications and Networking Conference (CCNC),2011, pp. 467 - 471.

[4] BOUKERCHE A., OLIVEIRA H., NAKAMURA E., LOUREIRO A., Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems, Journal of Computer Communications, 2008, Vol. 31, Issue 12, pp. 2838-2849.

[5] FESTAG A., Global standardisation of network and transport protocols for ITS with 5 GHz radio technologies, Proceedings of the ETSI TC ITS workshop, Sophia Antipolis, 2009, pp. 197-212.

[6] HARSCH C., FESTAG A., PAPADIMITRATOS P., Secure position-based routing for VANETs. Proceedings of IEEE66th vehicular technology conference (VTC-2007), 2007, pp. 26-30.

[7] JAYABALAN E., KRISHNAN A., Detection and Tracking of Moving Object in Compressed Videos. Communications in Computer and Information Science, 2011, Vol. 142, part 1, pp. 39-43.

[8] KYUNGNAM K., HARWOOD D., DAVIS L., Real-time foreground-background segmentation using codebook model. Real-Time Imaging Journal, 2005, Vol. 11, Issue 3, pp. 7-21.

[9] LO S.C., HSUC. H., Cellular automata simulation for mixed manual and automated control traffic, Mathematical and Computer Modelling, 2010, vol. 51, pp. 1000–1007.

[10] MAERIVOET S., DE MOOR B., Cellular automata models of road traffic. Physics Reports 419, 2005, pp. 1-64.

[11] PŁACZEK B., A real time vehicles detection algorithm for vision based sensors, ICCVG 2010, Part II. Lecture Notes in Computer Science, 2010, vol. 6375, pp. 211-218.

[12] PŁACZEK B., Fuzzy cellular model for on-line traffic simulation, Lecture Notes in Computer Science, 2010, vol. 6068, pp. 553-560.

[13] SCHADSCHNEIDER A., CHOWDHURYD E., A new cellular automata model for city traffic, Traffic and Granular Flow ’99: Social, Traffic, and Granular Dynamics, Springer, Berlin, 2000.

[14] XIAO-HUI B., XIAO-FAN X., CHE-MING L., ZHEN-SHENG Y., CHAO-YANG L., JIAN-WEI P.: Quantum teleportation between remote atomic-ensemblequantum memories, arXiv:1211.2892v1 , 2012.

[15] YILMAZ A., JAVED O., SHAH M., Object Tracking: A Survey. ACM Computing Surveys, 2008, Vol. 38, no. 4, art. 13.

[16] WIŚNIEWSKA J., Fast method of calculating unitary matrix for quantum decision algorithm, Polish Journal Of Environmental Studies, 2009, Vol. 18, pp. 381-385.

[17] WIŚNIEWSKA J., Quantum Computer Network Model for a Decision Making Algorithm, Communications In Computer And Information Science, 2012, Vol. 291, pp. 73-81.