Ben-Gurion University of the Negev
Faculty of Engineering Science
School of Electrical and Computer Engineering
Dept. of Communication Systems Engineering

Fourth Year Engineering Project

PDR

Autonomous Driving using Swarms

Project Number:	p-2023-003
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I. Abstract

1. Abstract (English):

Autonomous Driving using Swarms

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The future of transportation depends on development of autonomous vehicles that are required to function in real-time and make decisions according to traffic conditions, when contacting an external factor may take valuable time and cause accidents in cases of a communication failure. The goal of the project is to develop an algorithm that creates swarms of vehicles with peer-to-peer (P2P) communication in a decentralized manner. Each swarm is a group of vehicles moving together as one, according to their destination and the vehicle's location on the road in real-time. The algorithm must organize the vehicles with a minimal number of steps until the swarms are stabilized.

The concept of communication without an external server is innovative in the context of autonomous vehicles. Beyond the idea of communication without a human factor, the idea of swarms can improve the decision-making of a vehicle.

The method will include a fixed number of vehicles on a road with more than one lane, each vehicle having a color according to its destination. Each car can communicate with vehicles up to 100 meters, to identify its swarm mates. After dealing with this, edge cases will be considered to improve the algorithm and adapt it to reality. In the end, the expectation is to develop a single initial algorithm that could be installed on all autonomous vehicle systems and will organize the moving vehicles into swarms in a minimum time.

Keywords – Innovative transportation, Autonomic cars, Autonomous Driving, Distributed algorithms, P2P, Swarms, real-time, SUMO (vehicle simulation software).

2. Abstract (Hebrew):

<u>נהיגה אוטונומית בעזרת להקות</u>

שמות הסטודנטים: בן-גל מעיין, אלה נוי

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עתיד התחבורה תלוי בפיתוח רכבים אוטונומיים הנדרשים לתפקד ולקבל החלטות בזמן-אמת בהתאם לתנאי התנועה והשטח, כאשר יצירת קשר עם גורם חיצוני כגון חדר בקרה עלול לגזול זמן יקר ולגרום לתאונות במקרה של נפילת תקשורת.

מטרת הפרויקט לפתח אלגוריתם המייצר להקות רכבים הנעים בכביש בעזרת תקשורת עמית לעמית (P2P) באופן מבוזר. כל להקה היא קבוצת רכבים הנעה יחד כרכב אחד, על פי יעד הנסיעה בהתאם לרכבים הממוקמים על הכביש בזמן אמת. על האלגוריתם לארגן את הרכבים כך שכמות השלבים עד להתייצבות הלהקות בכביש תהיה מינימלית.

הרעיון של תקשורת ללא שרת חיצוני הוא חדשני בהקשר של רכבים אוטונומיים. מעבר לרעיון התקשורת ללא גורם אנושי, רעיון הלהקות יכול לשפר משמעותית את תהליך קבלת ההחלטות של הרכב.

שיטת העבודה תכלול מספר קבוע של רכבים על כביש בעל למעלה מנתיב אחד, כאשר לכל רכב יש צבע על פי יעדו הסופי. לכל מכונית ישנה יכולת לתקשר עם רכבים עד 100 מטר, על מנת לזהות את חבריו העתידיים ללהקה. לאחר התמודדות עם מצב זה נוסיף מקרי קצה במטרה לשפר את האלגוריתם ולהתאימו למציאות. בסיום הפרויקט הצפי הוא לפתח אלגוריתם ראשוני יחיד שיותקן על כל מערכות הרכבים האוטונומיים וייבצע את ארגון הרכבים הנעים ללהקות בזמן מינימלי.

<u>מילות מפתח</u>: תחבורה חדשנית, רכבים אוטונומיים, נהיגה אוטונומית, אלגוריתמים מבוזרים, P2P, להקות, זמן אמת, SUMO (תוכנת סימולציית רכבים).

II. Research Proposal

Autonomous Driving using Swarms

1. The Essence of the Project:

The goal of the project is to develop an algorithm that maps autonomic cars to swarms using peer-to-peer communication in real-time with minimal steps until the stabilization of the swarms. The idea is to sort the cars by their destination by marking every car with color and creating a swarm from all the cars with the same color on the road, this way every swarm can move and be referred to as a single car. The swarm has inner communication between the cars, and outer communication via the gateway car which reduces the number of messages

2. Technologies and Methodologies that Will be used in the Project:

- Communication protocols – The cars use peer-to-peer communication when there is a difference between inter-swarm and intra-swarm communication. The car can communicate by broadcasting messages to all the cars around her, and unicast messages. Broadcast messages are required to find close cars with the same color, and the unicast messages are requiring communicating with a specific car to become a swarm or communicate directly to the swarm leader or use algorithms to decide the leader along with the swarm.
- Physical conditions – Our algorithm must depend on a few physical conditions like the roadway, the number of lanes in the road, the different cars or traffic around each car, the communication ability of the cars, and even the speed limit. All these physical conditions are important and need to be considered in the protocols and the algorithm. The initial physical conditions are an infinite road with 2 lanes and no speed limit, the cars can send a message up to 100 meters radius.
- Simulation of Urban Mobility (SUMO) – SUMO is an open-source, microscopic, multi-modal traffic simulation. [2] SUMO can simulate large traffic and network features, it can be used in Python. This package is the way the algorithm simulation tool will be used to simulate different states and edge cases. [3]
- Driving Protocols – – The cars are autonomic, which means they need to know how to drive, the cars must know simple driving protocols – such as speeding up, slowing down, passing other cars by speeding in another lane, stopping at a red light.[4]

3. Work Plan:

- Create a basic algorithm that handles with only two swarms on 2 lanes infinite road.
- Simulate the algorithm and check simple edge cases and check the algorithm performance.
- Develop the algorithm for more than two swarms and more than two lanes, check if the way of decision-making is more efficient and if the traffic can be stabilized into swarms with minimal steps.
- Simulate and check the efficiency in cases when a new car enters the road or leaves the road along with other simple edge cases.
- Formulate the protocol that should be coded on every single car.
- Try to formulate a protocol that can be used on autonomic cars and semi-autonomic cars as well, define protocols dealing with complicated human-dependent edge cases, and create a simulation with randomly generated traffic to test it.

4. Applications for the Project:

The project's algorithm's purpose is to create a program based on the algorithm that will be compatible with all types of autonomous vehicles. The project will reduce the need for vehicles to communicate with an external server in real-time and even avoid problems arising from server crashes or communication fails. In the future, the goal is that it will even be possible to apply the algorithm to semi-autonomous cars and make the project more relevant to what exists on the markets today.

5. System Performance Spec:

The algorithm can change the way autonomic cars are perceived, get a better way of monitoring the autonomic traffic and lower the risks around real-time decisions of autonomic individual cars. The algorithm allows the cars to lower the dependence on navigating systems and lower the risks around other cars' decisions – when the cars drive as a swarm there is a lower risk of a car interrupting the traffic unexpectedly and making the other cars react and decide in real-time with higher risk for accidents.

6. General Scheme:

- The current state of the system built last year:

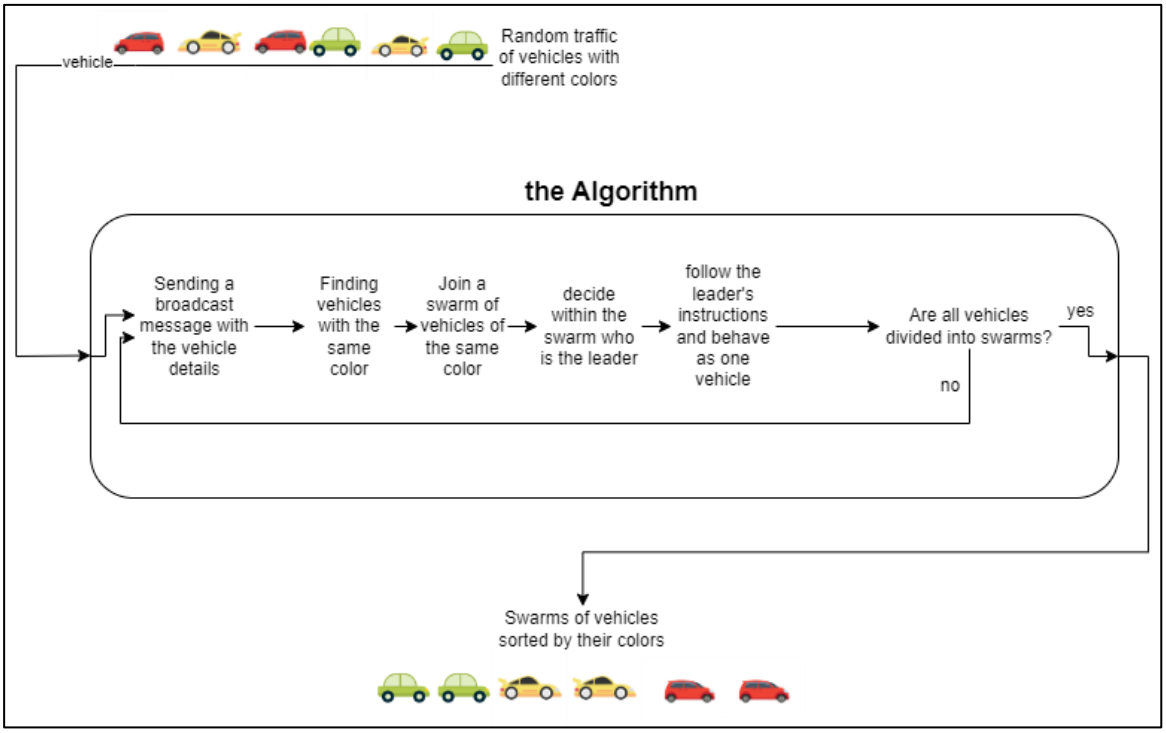

Figure 1: General diagram of the algorithm's flow.

As described in Fig. 1, the algorithm input is random traffic of vehicles with different destinations as we mark by different colors. Each vehicle goes through the steps of the algorithm and each swarm is perceived as one vehicle instructed by the swarm's leader. Every round the algorithm will ask if all the cars are divided into swarms, if so it would get the wanted output of swarms of cars sorted by destination, else it would repeat the steps as shown.

III. Design Approach

1. Different Approaches for the Problem Presented

- One approach is developing an algorithm that creates the swarms according to physical geographical proximity of the vehicles in real time**.** That is, the cars on the road will communicate and connect to a collective according to their position on the road at a minimum distance. In prof. Michael Segal article [1] a D-Cut algorithm is presented that generates clusters of vehicles according to their position on the road and chooses a temporary leader for the swarm each time. The advantage of this approach is that the swarm creation and stabilization time is fast. Another advantage is that there is a limit on the number of vehicles in each cluster, which gives a simple

intra-swarm communication protocol. A disadvantage of this approach is the instability of the swarm in a situation where a vehicle leaves the group when it reaches its destination. Since the vehicles in the swarm do not necessarily reach the same destination, the group will not remain intact throughout the route.

2. Our Approach:

The algorithm developed in our project is an algorithm for creating swarms of autonomous cars organized according to their destination. In the initial state there will be a finite number of autonomous vehicles with different initial speeds on a straight endless road with several lanes. Each vehicle has a color that represents the destination it wants to reach, and the ability to communicate with the other cars on the road within a hundred-meter radius. Each car in a distributed manner will send broadcast messages to the cars in its range with the required information and checking the cars around it. If there is a car in range that has the same color as the car above, it will send a direct message back confirming that they match in color and should join in a swarm. When there is an agreement, the cars can catch up with each other when the cars behind must advance to the car in front and not the other way around. It can overtake other cars in the bypass lane. When the two cars are adjacent, they announce the establishment of a swarm in their color and choose a leader for the swarm arbitrarily (by tossing a coin, for example). When the cars have formed into a swarm, they move on the road as one car at a constant speed and broadcast messages again to cars in their range. The algorithm converges when all the autonomous cars on the road are arranged in swarms according to their color.

- **Project Limitations**
  - The project is limited to the conditions of the simulator and if we want to test a function that does not exist in it, we will not be able to test it reliably.
  - There is not currently a way to examine our algorithm in real-life traffic conditions.
- **Project Assumptions**
  - The assumptions regarding the road conditions are that the road is endlessly straight without interchanges or exits and without bumps in the road that could cause accidents.
  - The number of cars on the road and their colors at any moment is fixed and cars do not leave or enter the road.

IV. Bibliography

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[2] SUMO wikipidia. https://en.wikipedia.org/wiki/Simulation_of_Urban_MObility

[3] SUMO Overview. https://www.eclipse.org/sumo/

[4] Yadhu Prakash et al. “Incorporation of Swarm Intelligence in Autonomous Cars”. In: 2014

[5] Y. Anand and R. Ajithkumar, "Autonomous Car With Swarm Intelligence," 2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT), 2019, pp. 1659-1662

[6] https://carbiketech.com/swarm-intelligence-automated-driving/

V. Appendix: PDR Evaluation

הערכה לשיחת סקר תכנון ראשוני (PDR)

<u>אם יש צורך, לכל סטודנט/ית בנפרד</u>

מספר הפרויקט: p-2023-003

שם הפרויקט: נהיגה אוטונומית בעזרת להקות.

שם המנחה מהמחלקה: פרופסור מיכאל סגל.

שם הסטודנטית: נוי אלה ת.ז.: 312252257

שם הסטודנטית: מעיין בן גל ת.ז.: 311438733

%	מהות	ציון	הערות
10	שיחה + דו"ח - הבנת הנושא ומהות העשייה, הבנת הצורך, סביבת היישום, הגדרת מדדים, מקורות ועבודות דומות. הצגת התקצירים, מפרט טכני/הצעת מחקר והצעת תכנון מפורטים.		
	ציון סופי		

הערות: