Міністерство освіти і науки України
Тернопільський національний технічний університет імені Івана Пулюя
(повне найменування вищого навчального закладу)
Факультет комп'ютерно-інформаційних систем і програмної інженерії
(назва факультету)
Кафедра комп'ютерних систем та мереж
(повна назва кафедри)

ПОЯСНЮВАЛЬНА ЗАПИСКА

до дипломної роботи

магістра
(освітній ступінь)

на тему: **МАТЕМАТИЧНЕ ТА ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ КОМП'ЮТЕРНИХ СИСТЕМ КЕРУВАННЯ ТРАНСПОРТНИМ ЗАСОБОМ**

Виконав: студент (ка) 6 курсу, групи СІм-51
спеціальності 123
«Комп'ютерна інженерія»
(шифр і назва спеціальності)
(підпис) Форись Іван Анатолійович
(прізвище та ініціали)

Керівник (підпис) Луцків Андрій Мирославович
(прізвище та ініціали)

Нормоконтроль (підпис) Тиш Євгенія Володимирівна
(прізвище та ініціали)

Рецензент (підпис) Скоренький Юрій Любомирович
(прізвище та ініціали)

м. Тернопіль – 2019

Ternopil Ivan Puluj National Technical University
(full University name)
Faculty of Computer Information Systems and software engineering
(Faculty name)
Chair of Computer Systems and Networks
(full Chair name)

MASTER THESIS

On subject: MATHEMATICAL SUPPORT AND SOFTWARE OF VEHICLE COMPUTER CONTROL SYSTEM

by: student 6th year, group CIm-51
specialty 123
«Computer Engineering»
(code and name of the specialty)

	(signature)	Forys Ivan Anatoliyovych (full name)
Supervisor	(signature)	Lutskiv Andriy Myroslavovych (full name)
Norm control	(signature)	Tysh Evheniia Volodymyrivna (full name)
Reviewer	(signature)	Skorenkyy Yurii Liubomyrovych (full name)

Ternopil – 2019

Міністерство освіти і науки України
Тернопільський національний технічний університет імені Івана Пулюя
(повне найменування вищого навчального закладу)

Факультет ФІС
Кафедра Комп'ютерних систем та мереж
Освітній ступінь Магістр
Напрям підготовки
(шифр і назва)
Спеціальність 123 "Комп'ютерна інженерія"
(шифр і назва)

ЗАТВЕРДЖУЮ
Завідувач кафедри Осухівська Г.М.
«30» 09 2019 р.

З А В Д А Н Н Я
НА ДИПЛОМНУ РОБОТУ СТУДЕНТУ

Фортесю Івану Анатолійовичу
(прізвище, ім'я, по батькові)

1. Тема роботи Математичне та програмне забезпечення комп'ютерних систем керування транспортним засобом

Керівник роботи Луцків Андрій Мирославович, к.т.н., доцент
(прізвище, ім'я, по батькові, науковий ступінь, вчене звання)

Затверджені наказом по університету від «27» вересня 2019 року №4/7-854
2. Термін подання студентом роботи 26 грудня 2019р.
3. Вихідні дані до роботи нейронна мережа, що керує транспортним засобом

4. Зміст розрахунково-пояснювальної записки (перелік питань, які потрібно розробити)
Аналіз предметної області комп'ютерних систем керування транспортним засобом
Аналіз та дослідження комп'ютеризованих систем керування транспортним засобом
Реалізація комп'ютерної програми для комп'ютерної системи керування транспортним засобом

5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень, слайдів)
Тема, мета, актуальність, цілі, висновки, графічне зображення нейронної мережі, модель безрейкового потягу, крива Безьє, зображення можливих траєкторій руху, вхідні дані, основний алгоритм, блок-схема ініціалізації

6. Консультанти розділів роботи

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата: завдання видав	Підпис, дата: завдання прийняв
Економіка	Лесечко О.М., доц.	1.11.19	8.11.19
Обґрунт. екон. ефект.	Ярмак Н.Б.	[illegible]	[illegible]
Безпека в НС	Стручок В.С., ст. викл. кафедри	[illegible]	[illegible]
Охорона праці	[illegible] Т.М.	21.11.19	19.[illegible]

7. Дата видачі завдання 30.09.19

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів дипломної роботи	Термін виконання етапів роботи	Примітка
1.	Отримання завдання	30.09.19	виконано
2.	Аналіз завдання	1.10.19-6.10.19	виконано
3.	Аналіз предметної області комп'ютерних систем керування транспортним засобом	7.10.19 - 12.10.19	виконано
4.	Аналіз і дослідження комп'ютеризованих систем керуванням транспортних засобів	13.10.19 - 1.11.19	виконано
5.	Реалізація комп'ютерної програми для комп'ютерної системи керування транспортним засобом	2.11.19 - 28.11.19	виконано
6.	Обґрунтування економічної ефективності	29.11.19 - 1.12.19	виконано
7.	Охорона праці та безпека в надзвичайних ситуаціях	21.11.19 - 19.12.19	виконано
8.	Економіка	1.11.19 - 8.11.19	виконано
9.	Оформлювання пояснювальної записки	8.12.19 - 16.12.19	виконано
10.	Оформлення графічної частини	17.12.19 - 23.12.19	виконано
11.	Рецензування роботи	23.12.19	виконано
12.	Захист роботи	26.12.19	виконано

Студент ____________ (підпис) Фирсь І.А. (прізвище та ініціали)

Керівник роботи ____________ (підпис) Лупиков А.М. (прізвище та ініціали)

Ternopil Ivan Puluj National Technical University
(full University name)

Faculty Information systems and software engineering
Chair Computer system and network
Degree Master
Specialty Computer Engineering
(code and name)

Approved by
Head of Chair Computer System
Osukhivska H.M.
« 30 » september 2019 y.

TASK

TO MASTER THESIS FOR STUDENT

Forys Ivan Anatoliyovych
(full name)

1. Subject Mathematical support and software of vehicle computer control system

Supervisor Lutskiv Andriy Myroslavovych
(full name, degree)

Approved by university order of «27» september 2019 year № 4/7-854

2. Student submission deadline «26» december 2019 year

3. Output data neural network that controls the behavior of a vehicle

4. Thesis content (a set of questions to be worked out)
Analysis of the subject vehicle computer control system
Analysis and research of vehicle computer steering system
Implementation of computer software for the vehicle computer control system
Rationale of economic efficiency
Occupational safety and health in emergency situation
Ecology

5. Graphic content (with exact indication of mandatory drawings, slides)
Subject, object, purpose, conclusions, goals and relevance, neural network, trackless train model, Bezier curve, Conditional image of possible trajectories, Data lifecycle, main algorythm, init coordinates and trajectory calculation algorithm

6. Section consultants

Section	Full name and position	Signature, date: Give task	Accepted task

7. Date of issue of the assignment 30.09.19

CALENDAR PLAN

№	Name of thesis stages	Term of thesis stages	Note
1.	getting of tasks	30.09.2019	done
2.	analysis of tasks	1.10.19 - 6.10.19	done
3.	analysis of subject vehicle computer control system	7.10.19 - 12.10.19	done
4.	analysis and research of vehicle computer steering system	13.10.19 - 1.11.19	done
5.	Implementation of computer software of vehicle computer steering system	2.11.19 - 28.11.19	done
6.	Rationale of economic efficien	28.11.19 - 1.12.19	done
7.	Occupational health and safety in emergency situations	21.11.19 - 19.12.19	done
8.	Ecology	1.11.19 - 8.11.19	done
9.	Drawing up an explanatory note	8.12.19 - 16.12.19	done
10.	Drawing up a graphic part	17.12.19 - 23.12.19	done
11.	Thesis reviewing	23.12.19	done
12.	Colocvium	26.12.19	done

Student ____________ (signature) Forys Ivan (full name)

Supervisor ____________ (signature) Lutskiv Andriy (full name)

АНОТАЦІЯ

Математичне та програмне забезпечення комп’ютерних систем керування транспортним засобом // Форись Іван Анатолійович // Тернопільський національний технічний університет імені Івана Пулюя, факультет комп’ютерно – інформаційних систем та програмної інженерії, група СІм – 61 // Тернопіль, 2019 // с. – 108, рис. – 35, табл. – 6, аркушів А1 – 10, додат. – 6, бібліогр. – 42.

Ключові слова: НЕЙРОННА МЕРЕЖА, ТРАНСПОРТНИЙ ЗАСІБ, ПОВЕДІНКА, КРИВА БЕЗЬЄ, ТРАЄКТОРІЯ.

Дипломну робота магістра присвячено створенню комп’ютерної системи керування поворотом всіх коліс транспортного засобу, згідно заданої поведінки. Розглянуто комп’ютерні системи автоматизації керування транспортним засобом, рівні автоматизації. Розглянуто і проаналізовано системи задіяні у керуванні поворотом коліс транспортного засобу, а також актуальні транспортні засоби із усіма керованими колесами.

Проаналізовано поведінку транспортних засобів, що рухаються по рейках та звичайних дорожніх автомобілів, автобусів та вантажівок із різною кількістю поворотних осей. Також розглянуто криві Безьє для побудови траєкторії руху транспортного засобу. Розглянуто та проаналізовано апаратне забезпечення нейронних мереж.

Розроблено, проведено навчання та протестовано нейронну мережу, що керує всіма осями транспортного засобу задля реалізації поведінки руху по колії. Також розроблено та описано алгоритм та логіку визначення початкових координат осей та траєкторії руху транспортного засобу.

ANNOTATION

Mathematical support and software of vehicle computer control system // Forys Ivan Anatoliyovych // Ternopil Ivan Puluj National Technical University, Faculty of Computer Information Systems and software engineering, group CIm – 61 // Ternopil, 2019 // p. – 108, fig. – 35, tables – 6, Sheets A1 – 10, Supplement – 6, Ref. – 42.

Key words: NEURAL NETWORK, VEHICLE, BEHAVIOR, BEZIER CURVE, TRAJECTORY.

The Master's Thesis is devoted to the creation of a computer system to control the rotation of all wheels of the vehicle, according to a given behavior. Computer control systems for vehicle control, levels of automation are considered. The systems involved in the steering of the wheels of a vehicle are considered and analyzed as well as the actual vehicles with all the steered wheels.

The behavior of rail vehicles and conventional road vehicles, buses and lorries with different number of axles is analyzed. Bezier curves are also considered to construct the trajectory of the vehicle. The hardware of neural networks is considered and analyzed.

A neural network that manages all axes of the vehicle to implement track behavior has been designed, trained and tested. The algorithm and logic for determining the initial coordinates of the axes and the trajectory of the vehicle are also developed and described.

CONTENT

INTRODUCTION

Relevance of research. Nowadays, one the most important and discussed issues all over the world is the topic of environmental protection in the conditions of climate change and global warming. Currently, people are actively looking for different ways of reducing the level of pollutions in order to prevent possible catastrophic consequences. Among others, one of the best solutions is to focus on the reduction of energy use.

One of the biggest consumers of energy is transportation industry, especially personal transport like cars. According to the study made by the US Department of Transportation "Average occupancy remains unchanged from 2009 to 2017" with an average of 1.54 people staying in one car. At the same time for one route taxi this number varies between 20 and 40 people, for bus it is 30-150 people, for tram it is 30 - 250 people and subway train can contain up to 1000 people at one time. Accordingly, it seems that the best kind of transportation for the city is the subway. However, this is not always the case, because the metro is effective only in big cities of the metropolitan level, and only in conjunction with other modes of public transport. Besides, the construction and operation of metro branches requires large investments, taking into the consideration that the distances between stops should be large enough and finally, only the big city has enough population to fill subway trains. Looking back to the figures mentioned above, it’s obvious that the second-most efficient kind of transportation is tram. Thanks to the rail track, the tram can reach a considerable length, which is not possible for the bus because of the geometric features of the trajectory of turning. However, the construction of tracks and other infrastructure is quite expensive and what is more, during the construction works causes damage both to the city's transportation system and to businesses that are close to construction. Other disadvantages of the tram are the noise and vibrations from its movement as well as its attachment to the infrastructure. Noise and vibration are partially overcome by the rubber inserts in the wheels, but because of the large mass that presses on the small contact area, the rubber quickly wears out and needs replacement. Which in turn complicates and makes more expensive operation. Besides, the mass and small contact area of the wheels have two other disadvantages, such as high road pressure and the inability to climb steep climbs.

Buses and trolleybuses as kinds of public transportation fit good for the small town. But both of them are not capable to provide with high passenger traffic.

With modern computer technology, it is possible to build a hybrid bus and tram. This vehicle will have dimensions, geometric cornering and passenger tram capacity, as well as the flexibility of use, simplicity and cheap operation of the bus. To accomplish this, it is necessary to develop a computer system that controls the angle of rotation of the wheels of each axle of the vehicle to simulate line or rail driving.

The purpose and objectives of the study. The purpose of the study is to develop mathematical approach and respective software for a computer system to control the rotation of all wheels of the vehicle in order to simulate ride on rails.

Achieving this goal requires the following tasks:

- Analyze key inputs for system operation.
- Develop a general scheme of the system.
- Justify the algorithmic support of the system’s operation.
- Investigate performance.
- Develop a prototype system.

The object of study is a neural network that controls the behavior of a vehicle.

The subject of study is the neural network, the behavior of the rail transport, the behavior of the wheel transport, navigation systems, dead reckoning systems, trajectory building.

Scientific novelty of the obtained results:

- The use of a neural network to control the rotation of transport wheels according to a given behavior is analyzed.

The practical significance of the results obtained.

An experienced computerized vehicle control system, after real testing and refinement, involves its continued use in real vehicles.

Testing the results of the thesis.

The results of the master's thesis work were tested at international conferences:

- VIII International Scientific and Technical Conference of Young Scientists and Students "Actual Problems of Modern Technologies"
- VII Scientific and Technical Conference "Information Models, Systems and Technologies"

Structure of work. The work consists of an explanatory note and a graphical part. The explanatory note consists of an introduction, 3 parts, conclusions, a list of references and appendices. Scope of work: explanatory note - 108 sheet. A4 size, graphic part - 10 sheets A1.

CHAPTER 1
ANALYSIS OF THE SUBJECT AREA OF COMPUTERIZED VEHICLE CONTROL SYSTEMS

1.1. Vehicle integrated computer systems

Computer systems have ~~long~~ been integrated into the car and are all designed to make it easier to drive as well as to improve driving safety. The very first computer-assisted driver's system in production cars was an anti-lock system, briefly ABS. Today's vehicles have dozens of systems that are all connected to the onboard computer, for example:

- anti-lock braking system ABS;
- ESP stability system;
- ASR antiskid system;
- park assistance;
- automated parking system;
- adaptive or non-adaptive Cruise Control;
- brake force distribution system;
- downhill assistance systems;
- lifting assist system;
- line-keeping system;
- road sign recognition system;
- emergency braking system;
- oncoming traffic recognition system;
- matrix lights;
- pedestrian recognition system;
- retention system in the strip;
- autopilot and many others.

Also in modern sports cars, as well as in some premium cars, the rear wheel steering system is used. The use of this technology improves the handling of the vehicle and at low speeds it reduces the turning radius while at high speeds it provides better cornering.

1.2. Autonomous and automated driving systems

Autonomous control systems are designed to perform well under significant uncertainties in the system and environment for extended periods of time, and at the same time they must be able to avoid and compensate valid system failures without external intervention. Intelligent autonomous control systems use techniques from the area of artificial intelligent (AI) in order to achieve the autonomy. Such control systems evolve from conventional control systems by adding intelligent components, and their intelligence requires interdisciplinary research. The fundamental issues in autonomous control system modeling and analysis are discussed, with empathies on mathematical modeling [1].

Autonomous systems are systems that are capable of self-government (see Fig. 1.1). A lot of work towards autonomous vehicles was made really about automated control systems. An autonomous control system is the highest level of automation. Vehicle control automation is designed to facilitate routine processes and provide greater road safety [1].

Fig. 1.1. Waymo self-driving car [2]

Levels of driving automation. According to the vehicle control automation, there are 6 levels, from fully mechanical to virtually autonomous.

1.2.1. Level 0. No Automation.

In this case driver should have license and keep full attention and total control. Vehicle has no automation.

Almost every car ever manufactured, from the first Benz Patent-Motorwagen car built in 1885 to the last mass-produced car today, does not have the ability or license to drive itself on public roads. All “Level 0” cars, as the Society of Automobile Engineers classifies them, may have simple intervention or warning intervention systems, but they all require the driver to accelerate, brake, steer, maneuver and park manually.

At level 0, driver has complete control over his car or truck. Car may offer warnings, such as an audio alarm when driver backs up and gets too close to another car, but he must by himself use the brake to avoid hitting the other vehicle.

One of useful zero level technologies is a road signs recognition. This system use pattern recognition to monitor road signs and show driver current speed limit or alarm when he tries drive in wrong way in one-way street [3].

1.2.2. Level 1. Driver Assistance (“hands-on”).

In this level driver requires to have driver license and keep full attention. Vehicle has semi-automated systems, like cruise control.

Level 1 cars have systems that help with steering or speed control, though not both at the same time. The driver must switch from one function to another. Sometimes referred to as the "hands-on" level, since drivers are expected to keep their hands on the steering wheel, this level of automation breaks down vehicle control between the driver and the software. Adaptive cruise control is a typical

Level 1 system for self-driving cars. With adaptive cruise control activated, the vehicle accelerates and decelerates independently while the driver is steering.

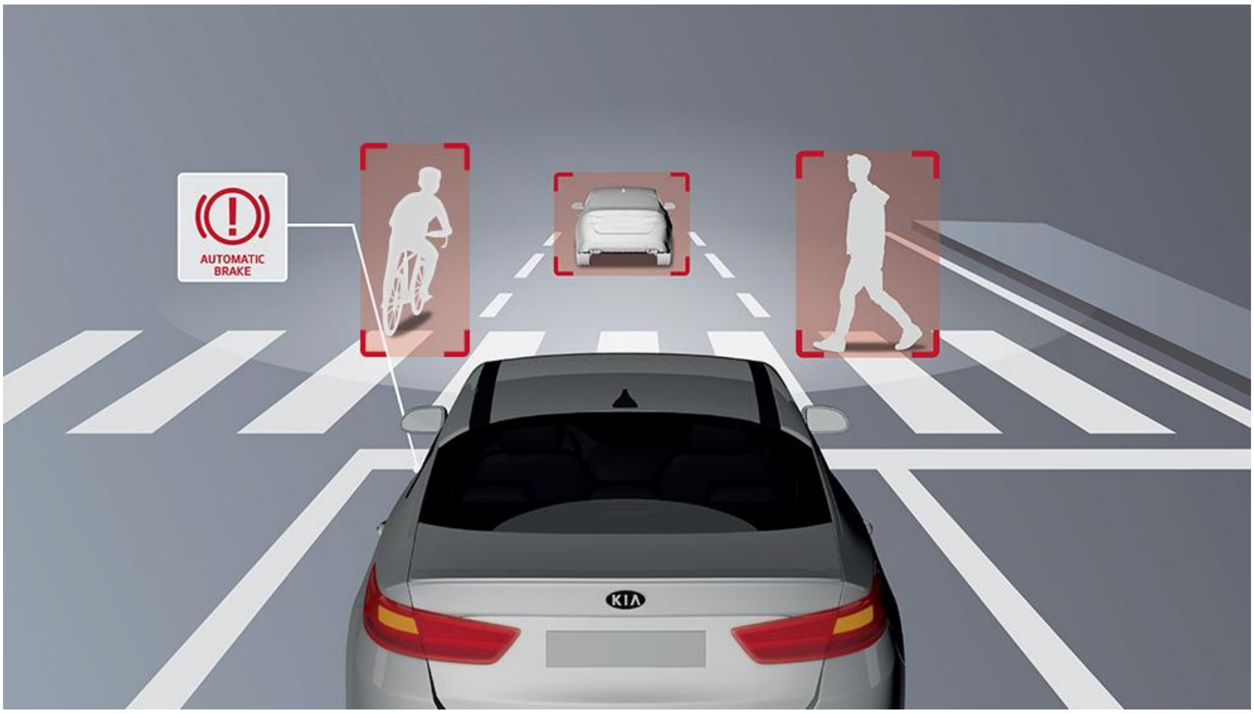

Fig. 1.2. Automatic brake system from KIA Motors [5]

A good example of a Level 1 system is a road marking system that notifies the driver of an unauthorized collision and crossing of the road marking. If necessary, some systems control the car to keep it within the current lane. Automatic emergency braking is also a first-level system that monitors static or slow objects too close to the car. If there is an obstacle or a pedestrian in front of the car, the system notifies the driver. When necessary, an emergency braking automatically applies as well as parking assistance (See Fig. 1.2), which drives the car to check into the parking lot (See Fig. 1.3). At this time the driver must accelerate or brake according to the road situation or the directions or tips of the car [3].

Today, the first level of automation is the most widespread in the world, because most systems have already become a mandatory safety net for new cars in Europe. And this is also the highest level at which manufacturers can enjoy their production of serial cars. Higher levels of automation work only in test mode. Implementing them in production cars is primarily hindered by legislation and not by the perfection of technology.

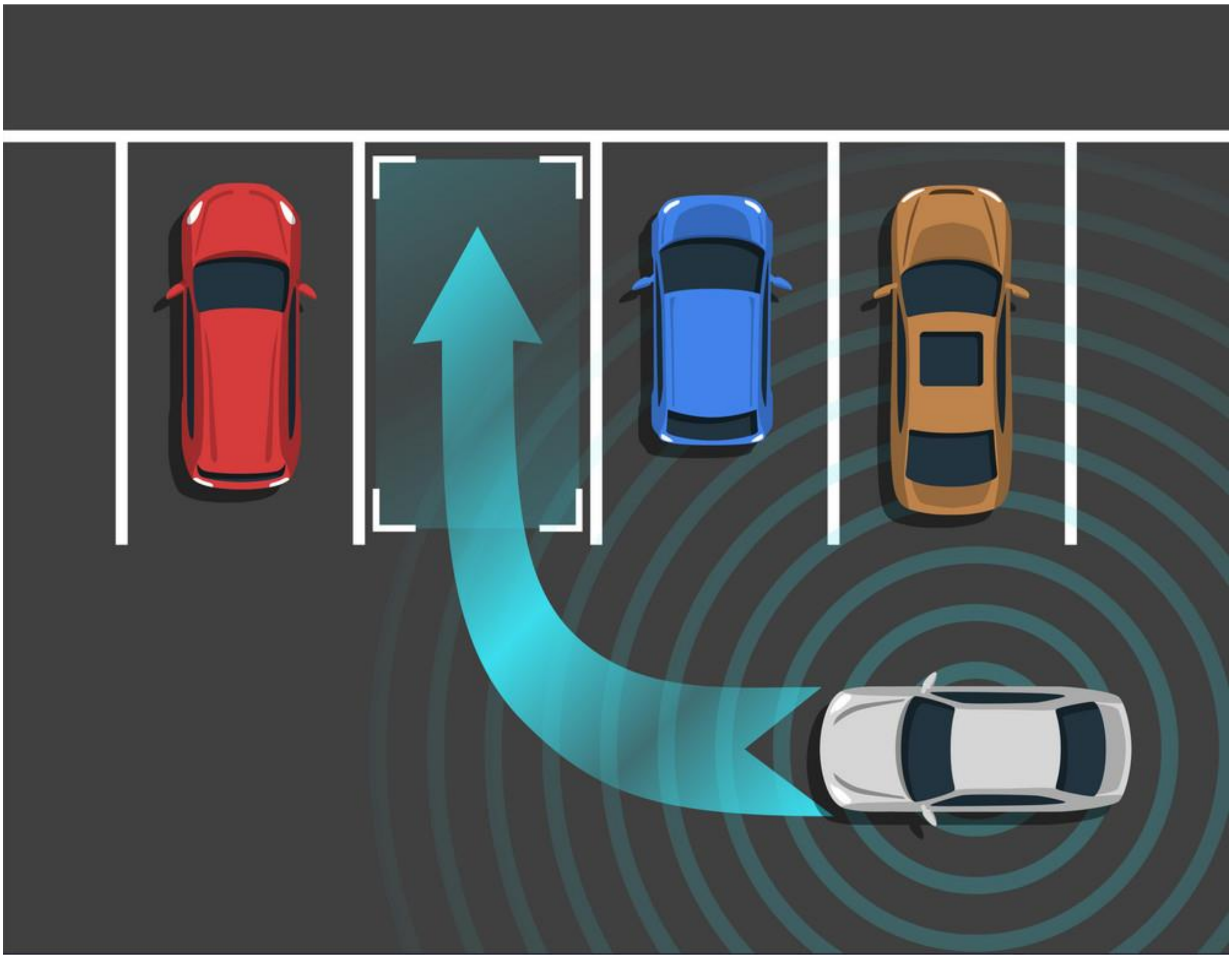

Fig. 1.3. Model of automated car parking system [6]

A lot of Level 1 cars have road edge detection, which tells the driver if they're too close to the side of the road. In Europe, all new sold vehicles must have automatic emergency braking, lane-keeping assistance and road edge detection to qualify for a four-star safety rating or higher.

1.2.3. Level 2 ("hands off").

This automated system takes full control of the car include accelerating, braking, and steering. The driver should monitor the driving process and be prepared to take control at any time if the automated system fails to respond properly. The shorthand "hands off" is not meant to be taken literally. In fact, contact between hand and steering wheel is often mandatory during Society of Automobile Engineers 2 driving, to confirm that the driver in any time is ready to intervene [3]. (See Fig. 1.4)

Currently, this level of automation is the competitive level in which automakers test autopilots. Tests of such vehicles on public roads are being actively conducted in various countries, especially in the US. But it’s important to remember that the driver is still responsible for everything.

Fig. 1.4. Tesla autopilot [4]

1.2.4. Level 3 ("eyes off").

The driver can safely turn his attention away from the driving tasks, for example the driver can text or watch a movie. The vehicle itself handles situations requiring immediate reaction, such as emergency braking. The driver should still be prepared to intervene when called upon by the vehicle. In order to do this, the car will signal sounds or indicators that it does not know how to behave at the current moment [3]. (See Fig. 1.5)

Fig. 1.5. Model of “eyes of” automated driving control system

1.2.5. Level 4 ("mind off").

Everything is pretty similar to level 3, but the driver's attention is no longer needed for safety, for example the driver can sleep peacefully or leave the driver's seat. Self-driving is only supported in certain geofenced or special circumstances. Outside these circumstances or areas, the vehicle must be able to safely interrupt the trip, for example, park the car if the driver does not take control [3].

1.2.6. Level 5 ("steering wheel optional").

No human intervention is required any more. An example would be a robotic taxi. This is the highest level of car driving automation. Only cars of this level can be called autonomous. This vehicle controls the traffic situation itself, decides where to go in accordance with the rules of the road. People are only passengers and all they can do is indicate the destination and purpose of the trip (See Fig. 1.6).

Although this task can be given to the car remotely, which allows him to go to his destination absolutely alone. These vehicles can communication with each other. This option give opportunity to calculate best route, avoiding traffic jams and accidents [3].

Fig. 1.6. UBER autopilot taxi [7]

1.3. Vehicles computer steering systems

Vehicle steering control systems are a necessary element of automated control systems, ranging from 1-level of automation. These systems are responsible for turning the wheels of the car according to the instructions of the CPU. Although in some modern cars, a computer wheel steering system is an element of first and zero level of automation as well. It is because in some cars, the electric power steering no longer requires direct communication between the steering wheel and the steering rack. Inside the steering wheel there is a rotary sensor or an encoder or stepper motor, which provides information about the angle in electronic form. And further on the steering rack stepper motor is already responsible for turning the wheels. The steering wheel requires a stepper motor to provide feedback.

1.3.1. Car line-control system.

Line control system is a system that is designed to monitor whether a vehicle is moving along one or two lines. This system consists of three components. If drawing an analogy with a person, it is the eyes of the brain and hands. The “eyes” are a separate system that keeps the line. It can be both a set of color sensors perpendicular to the marking line and the system which is equipped with artificial intelligence for the implementation of computer vision, which captures longitudinal lines in the picture. The “brain” of a system is a specific microcontroller or processor that processes information from the "eyes". And “heads” is a system which directly control the steering mechanisms.

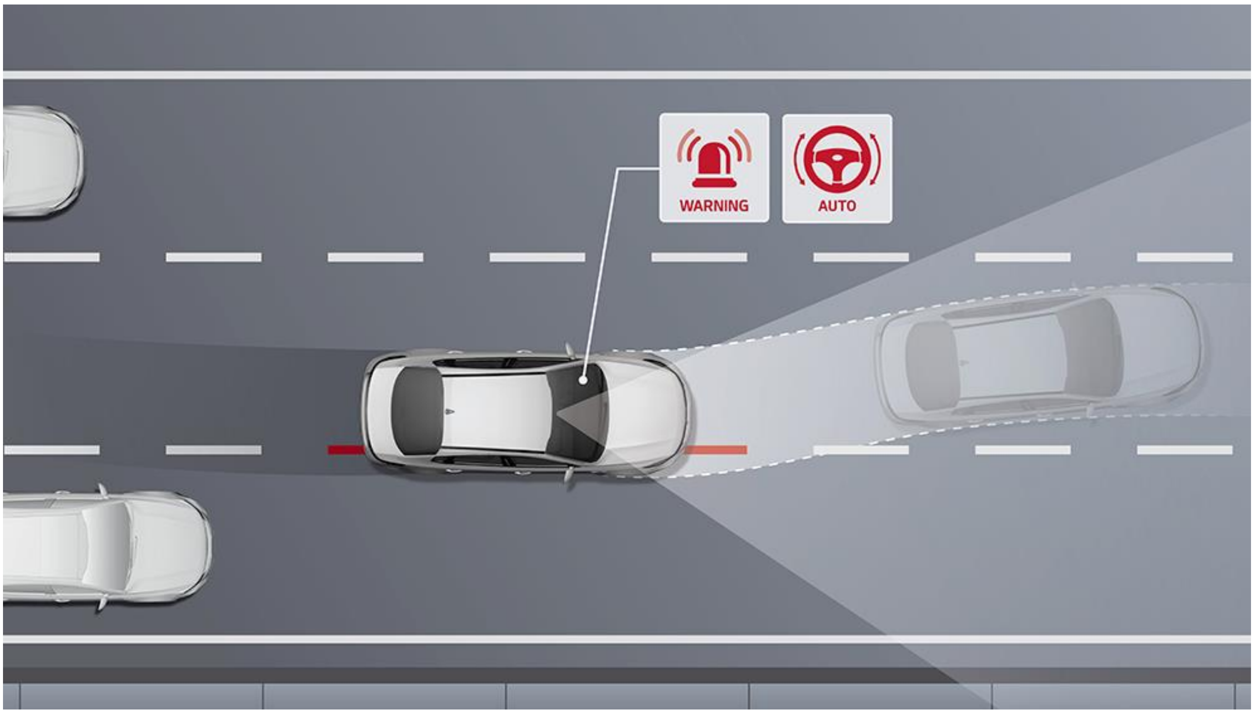

Fig. 1.7. Adaptive cruise control model

This system in addition to adaptive cruise control gives a very simple autopilot. (See Fig. 1.7) Today, all new cars for sale in Europe are equipped with such systems. With a well-marked road and a small intersection, the car can drive safely on its own. But as soon as the markup disappears or there is some unforeseen situation, the car moves helplessly straight and is only able to brake slowly. When drivers began to abuse this system massively, releasing the steering wheel and doing their jobs, and sometimes falling asleep, the manufacturers were forced to add a sensor of hands to the steering wheel.

1.3.2. All wheels steering system.

For better cornering, in some cars, the steering rack is mounted on other axles. In passenger cars, the rear wheels only steer for better maneuverability at low speeds and for better stability at high speeds. The rear wheels in the car turn only at a small angle (<5°), but enough to reach the goal without using a full steering rack, which takes a lot of valuable space. (See Fig. 1.8)

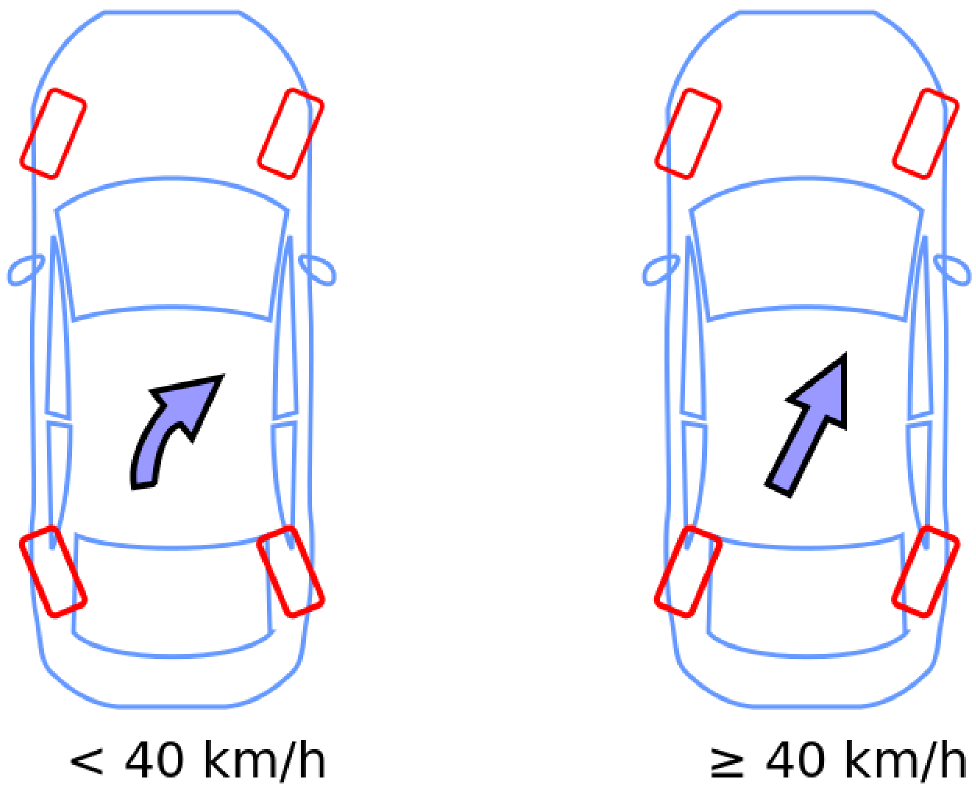

Fig. 1.8. all wheel steering cars model [8]

For long buses and lorries, the steering axle makes it easier to turn. These vehicles already have enough space to install a full steering rack, so the angle of rotation of the wheels may be equal or proportional to the angle of rotation of the front wheels. Particularly, by increasing maneuverability, it is much easier to operate such a vehicle within a city with a large number of cars and narrow turns. (See Fig. 1.9)

Fig. 1.9. Trolleybus with first and rear axle steering [9]

In trucks with many axles, they often use individual wheel steering for each axle, allowing the truck to enter places where the trucker would never be able to enter. An on-board computer is used to control the steering rack of each axle. The driver only chooses how the truck should behave. There are options from simply reducing the turning radius to moving diagonally.

Driven wheels also receive trailers for the transportation of very large loads. The wheels are driven in accordance with the set logic for the purpose of turning. But the operator can also change the logic of the wheel's behavior or take it in its own hands to allow the trailer to travel in inaccessible places. (See Fig. 1.10)

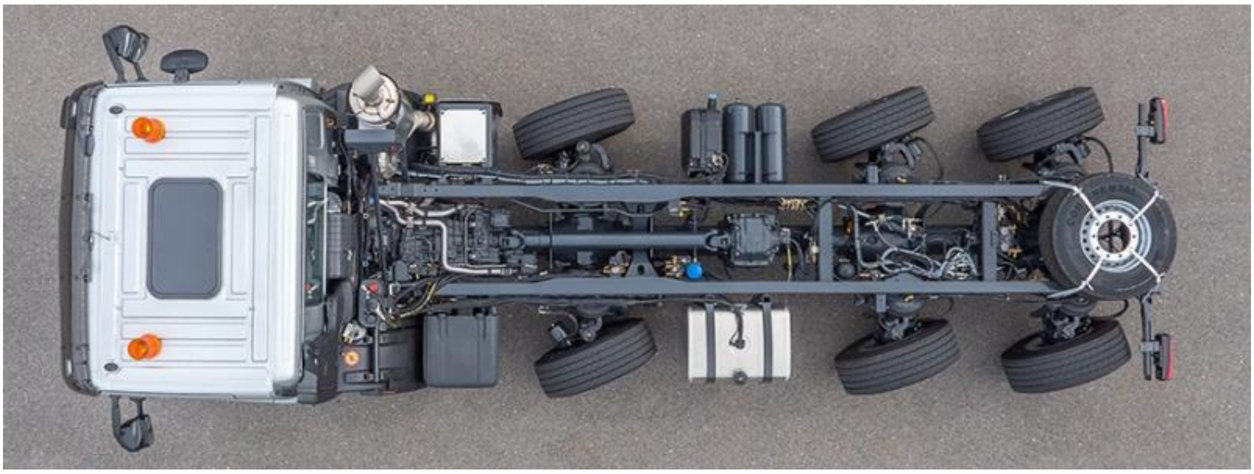

Fig. 1.10. Lorry with all wheel steering system [10]

1.3.3. Trackless train

A multi-unit system by the definition is a way of controlling several units of a vehicle's rolling stock with a central control panel. This system is used in trains, which include several trucks, trams and trolleybuses. In order to make such system able to function, it is necessary that all units under control must be managed through the same individual control systems. The multi-unit system was developed in 1887 by Frank Sprague in Chicago and is actively used today.

Modern multi-section trams also use a multi-unit system, which includes control of the common brake line and traction motors. If each wheel pair make with a rotary mechanism in a tram and operate it according to a particular model, it is possible to realize the movement of such a tram without rails, without changing its behavior. In 1966, Ukrainian engineer Volodymyr Veklych implemented a multi-unit system for Kyiv trolleybus. He coupled the two hard-clutch trolleybuses and combined control of their brakes, engines and steering rails. As a result, he was able to resolve the issue of overloading public transportation in Kyiv. Today, such trolleybuses are supplanted by modern articulated buses and trolleybuses, the so-called "accordions". For busier routes, only those trams are used that can carry a much larger number of passengers [12]. Many major cities have already built tram tracks, but there are still a large number of congested cities. For these cities, the solution may be introduction and exploitation of multi-section buses or trolleybuses, like trams, but capable to move without rails. In order to implement such a vehicle, firstly it is necessary to implement a system capable to control all the axles of rotation according to the specific behavior [12].

Such systems are widely used in factories where multi-section trucks under human control or automatic multi-section trolleys move along a line drawn on the floor. All sections adjust their axes to follow a given trajectory line. But this is all indoors.

1.3.3.1. Chinese high-speed trackless rapid transit. Taking into consideration the rapid development of China's economy and technology as well as its incredibly large population, it is obvious that new solutions are needed in the area of passenger transportation. Chinese cities have now reached the size of small European countries, and in terms of population, one city may be equal to the average European country. The proven solution is the construction of tram tracks, the construction of subway branches and city trains. But all of these options require a change in existing infrastructure and construction. Subway installation requires considerable investment, and where construction work is being done to lay ground, the economic attractiveness of the region is sharply reduced. Although this is only during construction, but in the rapid economic development of China, during the construction period some companies can become bankrupt.

The solution of this problem was the innovative trackless CRRC high-speed tram, the world's largest train manufacturer. Since 2016, this vehicle has been running in the Chinese city of Zhuzhou on an experimental 3.6 km long city branch with 4 stations [11].

This vehicle is a lightweight three section tram-like electric bus. It is powered by rechargeable batteries at the end stations. Controls the trackless rapid transit driver and guides him along the separate lanes of ordinary streets. On these lanes there are two dashed lines, which are guiding trajectories. The trackless rapid transit is equipped with experienced sensors such as those used in factories multi-section trailers moving along the line. All sections of the trackless rapid transit move in focus on these lanes, which prevents the carrying of the body to the adjacent lanes in turns because of the considerable length of the train. These lanes also allow the trackless rapid transit to clearly approach the stop platform, which minimizes the gap between the stop and train platforms and guarantees maximum barrier-free access to transport. As it well known, a barrier-free environment not only facilitates the lives of people with disabilities, but also accelerates the process of boarding and disembarking.

Features of trackless rapid transit:

- Thanks to a rechargeable power source, there is no need to lay the power line on the road.
- Due to the rubber wheels, there is no need to pave the way, which saves resources and prevents the economic loss of businesses located along the construction site.
- The trackless rapid transit is equipped with a stabilization system that allows for maximum comfort and minimum noise.
- Thanks to the optical system, the trackless rapid transit trajectory can reach a considerable length without loss of geometric indices of turning [11].

The downside of this type of trackless rapid transit is only the need for markup, which is not good in all countries and not always accessible. Also, the train remains tied to the markup and will not always be able to bypass the obstacle or change the route. (See Fig. 1.11)

Fig. 1.11. Trackless Rapid Transit [13]

1.4. Conclusion to the chapter

Modern computer systems involved in vehicle control have been analyzed. Various driver assistance systems have been considered to improve safety and facilitate the routine process. Automation and levels of automation of driving from zero to full were considered. Autonomous vehicle is found to be the car with the highest level of driving automation. Various computerized vehicle steering systems have also been analyzed. An example of the implementation of multi-unit system, with automatic control of the rotation angle of the wheels of all vehicle axles in the form of a trackless tram was presented.

CHAPTER 2
ANALYSIS AND RESEARCH OF VEHICLE COMPUTER STEERING SYSTEMS

2.1. Processing of input data

The data that is needed as input parameters for further computation is the array of coordinates which the system should follow step by step.

The following source of positioning can be used to determine coordinates:

- satellites;
- based on base stations;
- based on special beacons;
- coordinate calculation method;
- using inertial systems.

2.1.1. GPS.

Nowadays, the global positioning is most commonly used when determining the location (shortly speaking GPS), which operates thanks to the American NAVSTAR system or its analogs like Russian GLONASS and European Galileo [14].

Satellite positioning works in the way of receiving information from satellites about the time and current location of the spacecraft, information about the approximate orbits of other satellites of the system and calculating the delay to receive a signal. Minimum ~~of~~ three satellites must be received to calculate the location. Due to the fact that there are at least 24 NAVSTAR satellites in the Earth's orbits, which are located at different altitudes and angles of 60° from one to another orbits, from everywhere on the Earth it is possible to get the signal from at least 4 up to 12 system satellites [14]. (see Fig. 2.1)

The main advantages of such systems are a well-established mechanism of operation, simpleness of obtaining data for determining coordinates and their cheapness.

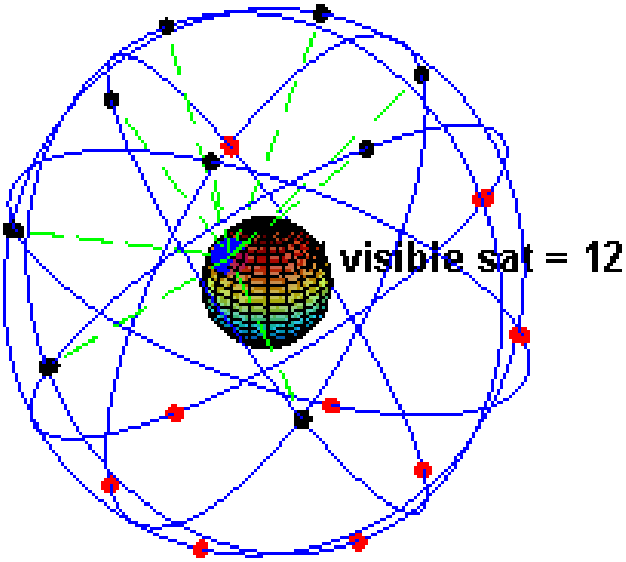

Fig. 2.1. Photo of Satellites on orbit

Accuracy and reach must be evaluated for each specific task. Satellite positioning systems provide location information with a precision of several meters. The signal from the satellite is a radio wave that can refract, reflect, and also ~~it is~~ not able to "break through" thick walls and penetrate underground. Also, when a signal is lost, for further recovery, the system needs some time to search the satellites and calculate new coordinates. The longer the system has been inactive, the more time it takes to recover. If the object is moving at the time of recovery, then the time required to do so will significantly increase. Assisted GPS (A-GPS) is used to speed up this process. The principle of action is to obtain communication of current information on satellites and their orbits through a separate channel. This data is mostly obtained through the Internet.

2.1.2. Location determination through base stations involves.

At least one GSM base station (usually there is several of them) is permanently located within the zone of action of a cellular phone or GSM modem. The location coordinates of these base stations are known. Thanks to numerous navigation services, the application receives information about the base stations visible to the phone and the current position via GSM, and then the application sends this information to the server where the base station coordinate database is accessed, which in turn is freely accessible via API. The command "AT + CREG = 2" is sent to the modem, resulting in receiving the message "+ CREG:" with information about the current connection to the base station "- LAC and CELLID" (respectively, the area code and base station ID). By sending this data to one of the special services, the coordinates of this base station are obtained. Many modems make it possible to obtain a list of visible base stations by indicating their LACs and CELLIDs - it is only possible through databases with the coordinates of the base stations to obtain their coordinates and to determine their approximate location by the triangulation method [15].

The downside is low accuracy, as the base station can be located more than 35 km away from the user, at the same time some base stations are mobile and constantly change their location.

2.1.3. With the help of special beacons.

Navigation can also be performed based on beacons that are specially positioned in the area where the navigation is ~~to~~ taking place. Usually Bluetooth beacons are used for such navigation. Each beacon stands at a pre-specified location and operates in Broadcast mode. The device periodically sends messages with its coordinates. The frequency of sending messages is usually 200 msec, but this value can be adjusted according to the specification. Taking into consideration the coordinates obtained from several beacons and the attenuation level, it is possible to calculate ~~your~~ person's own coordinates. Bluetooth technology belongs to the private-network computer networks, the so-called PAN – Private Area Network. The range of the lighthouse is small, up to 15 meters. Accordingly, with at least three beacons in sight, the accuracy is quite high and the error reaches less than one meter. The main advantages of Bluetooth beacons are the following: the cost of is quite low, and what is more importantly, thanks to Bluetooth Low Energy (BLE) technology, power consumption is also quite low [16]. One beacon has a capability of a CR battery life of up to 2 years. But the downside of technology is the need for a large number of such devices to deploy the network. This technology is well-suited for orientation on the premises, because the premises do not need permission from the relevant structures [16].

2.1.4. Inertial Navigation and Dead Reckoning.

Inertial navigation is used as an aid in case of lost GPS signal and it uses an accelerometer, gyroscope and magnetometer. This method continues to search for a location based on the last known coordinates and already given motion parameters of the object. And with the help of sensors, adjustments are made to the trajectory of motion. This method is only suitable as ancillary, because in the process it accumulates error and with the time the number of errors is constantly growing. This may result in the placement of data which are out of date.

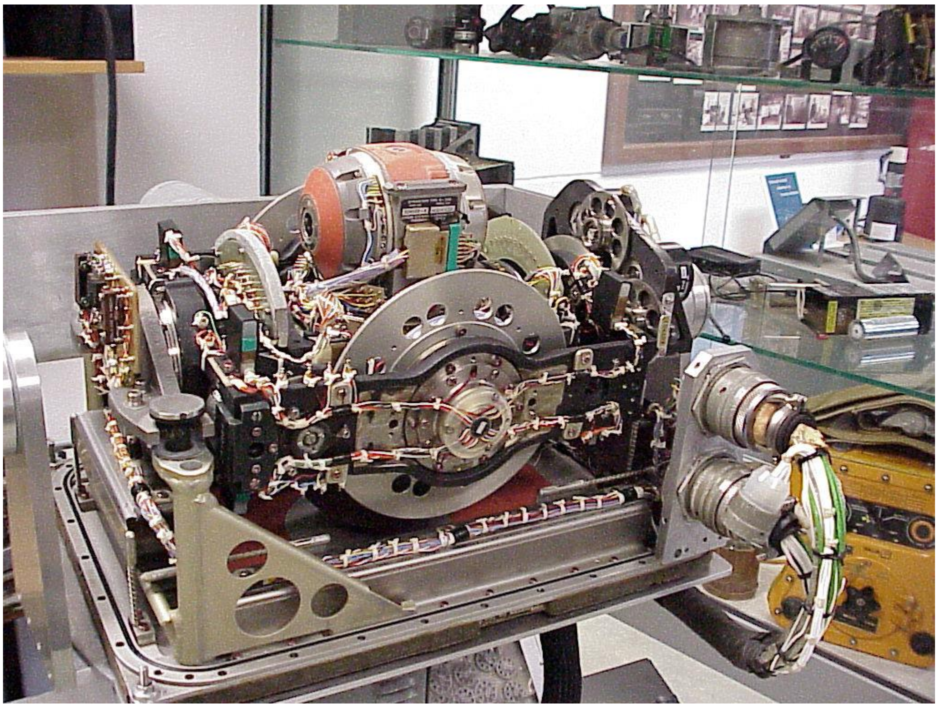

Fig. 2.2. Mechanical Gyroscope and Accelerometer [17]

Such systems are still used in aviation and navy as a fallback. Quite often the sensors are mechanical for greater electromagnetic and mechanical reliability, but they are also duplicated by a computer too. (see Fig. 2.2) If such technology is used, the error is corrected by known benchmarks if we have them [17].

Read reckoning is a method of determining the relative location to the last known point using a variety of motion and direction sensors. In contrast to the inertial system, the reference point can be both the last known coordinate and a certain conditional point in space, with respect to which orientation is possible. To determine new coordinates, it is necessary to capture the direction and speed of the object. It is also necessary to take care of timeframe. Measurements can be done over certain equal lengths of time or record time with each change in trajectory or speed. Modern devices can easily measure with the speed of several tens of times per second. To eliminate the noise, it is needed to set a lower sensitivity threshold so that only useful changes can be made. However, even better yet to make firstly a Fourier transformation for the signal, and then filter it.

The basic formula for determining a new coordinate is the following:

$$X = L * \cos(\varphi)\,,\ Y = L * \sin(\varphi), \qquad (2.1)$$

where:

$$L = v * T,$$

where L is the distance traveled by body, v is the speed of body, T is the time from last count, and φ is the angle at which the trajectory is relative to a given axis. Most often, this axis is the direction to the magnetic north.

In the case of this project, it is not necessary to know the global coordinates or coordinates relative to other objects. The system may function based on its own relative coordinate system, the center of which may be the first axis of the vehicle.

Basically, there are two counting options:

- The center of the coordinate axis is fixed at the moment of initialization of the system. The vehicle starts moving along the X-axis.
- The center of the coordinate axis moves together with the first axis, which is always directed along the X-axis.

In the first case, a trajectory of movement for a vehicle is projected. In the second case, only the relative location of each axis to the first is formed.

2.2. Neural networks.

Neural networks by definition are computing structures that model simple biological processes which are associated with human brain processes. They are systems capable of learning through the analysis of positive and negative impacts. The elemental converter in these networks is an artificial neuron or simply a neuron, named by analogy with a biological prototype [18].

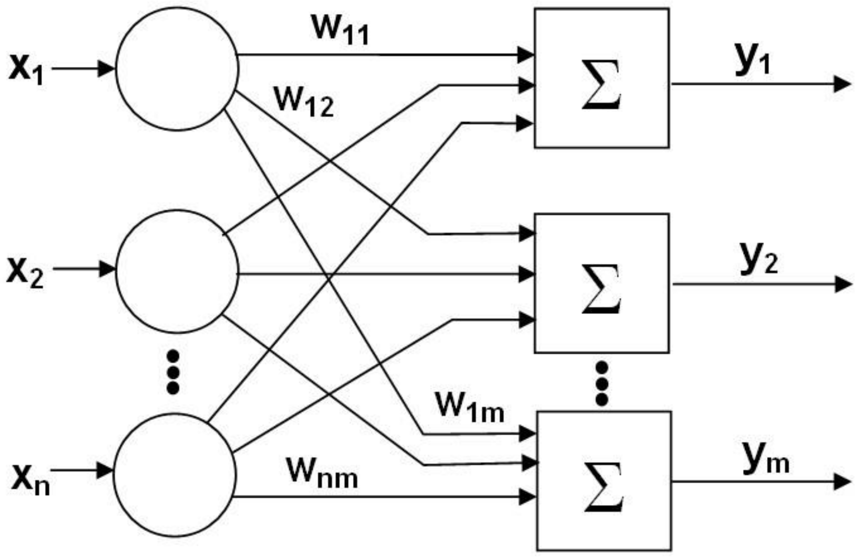

Fig. 2.3. One-layer neural network

The prototype for the creation of a neuron was a biological brain neuron. A biological neuron has a body (a set of processes – dendrites), through which the neuron receives input signals and axons which transmit the output signals of neurons to other cells. The connection point of the dendrite and the axon is called a synapse. Simplified functioning of the neuron can be represented as follows:

- The neuron receives from the dendrites a set (vector) of input signals.

- The total value of the input signals is estimated in the body of the neuron. However, the inputs of the neuron are ambiguous. Each input is characterized by some weight factor that determines the importance of the information transmitted by it. Thus, the neuron not only sums up the values of the input signals, but calculates the scalar product of the vector of the input signals and the vector of the weights [19].

- The neuron generates an output signal whose intensity depends on the value of the calculated scalar multiplication. If it does not exceed a certain threshold, then the output signal is not formed at all - the neuron "does not work".

- The output signal is supplied to the axon and transmitted to the dendrites of other neurons.

The most important feature of neural networks is their ability to learn from environmental data and, as a result, to increase their productivity. Performance increases over time according to certain rules. The training of the neural network is performed with the help of an interactive process of synaptic weights and thresholds correction. Ideally, the neural network receives knowledge of the environment at each iteration of the learning process [20].

Many concepts are associated with the concept of learning, so it is difficult to give a clear definition of this process. Moreover, the learning process depends on it. This makes it virtually impossible for any precise definition of this concept to emerge. For example, the process of learning from the perspective of a psychologist is fundamentally different from learning process from the perspective of a school teacher. From a neural network standpoint, it can be probably used the following definition: Learning is a process, in which free neural network settings are tuned by modeling the environment in which that network is embedded [19].

The type of training is determined by how to adjust these parameters. This definition of the learning process of the neural network involves the following sequence of events:

1. The neural network receives stimuli from the external environment.

2. As a result of the implementation of the first paragraph, the free parameters of the neural network are changed.

3. After changing the internal structure, the neural network responds to penalties in another way.

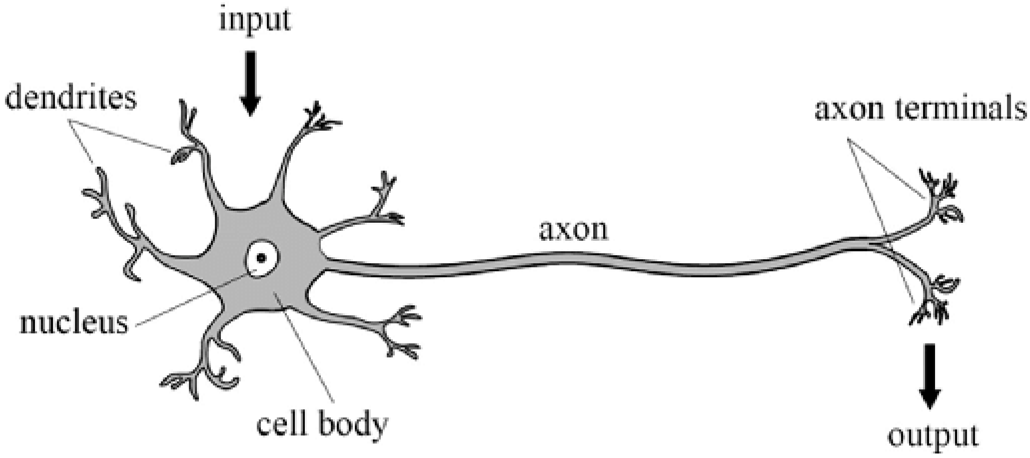

Fig. 2.4. Biological neuron [21]

The mentioned above list of clear rules for solving the neural network learning problem is called the learning algorithm. There is no one-size-fits-all learning algorithm for all neural network architectures. There is only a set of tools represented by many learning algorithms, each with its own advantages. Learning algorithms differ from each other in the way in which synaptic neuron weights are adjusted. Another great feature is the way the neural network is trained to connect with the outside world. In this context, it’s about the learning paradigm associated with the model of the environment in which this neural network operates. There are three ways of learning: with a teacher, without a teacher and mixed [21].

Neural network training with the teacher assumes that for each input vector of the training set there is a necessary value of the output vector, so-called target. These vectors form a training pair. The network weights are varied until an acceptable level of deviation of the original vector from the target is obtained for each input vector. The neural network has the correct answers (network outputs) to each input example. The scales are adjusted so that the network produces the answers as close as possible to the already known correct answers. The enhanced version of teacher training suggests that only the critical assessment of the neural network output is known, but not the correct output values themselves [22].

Teacher-free neural network training is a much more plausible model of learning from the biological roots of artificial neural networks. The training set consists only of input vectors. The neural network learning algorithm adjusts the network weights in the way that consistent output vectors are obtained, in other words, the presentation of sufficiently close input vectors yields the same outputs. Teacher-free learning does not require to know the correct answers to each example of training sample. In this case, the internal data structure or correlations between the samples in the data system is revealed, which allows the samples to be divided into categories. In mixed learning, part of the scales is determined by training with the teacher, while the other is obtained through self-study.

Classification of images. The task is to specify whether an input image (such as a speech signal or handwriting symbol) is represented by a feature vector to one or more predefined classes. For example, letter recognition, language recognition, electrocardiogram signal classification, blood cell classification.

Clustering (categorization). There is no training sample with class labels when solving the problem of clustering, which is also known as the "non-teacher" image classification. The clustering algorithm is based on image similarity and places close images in one cluster. There are known cases of using clustering with a purpose of data compression and exploration of data properties.

Function approximation. Let’s assume that there is a training sample (input-output data pairs) that are generated by an unknown noise-distorted function F(x). The approximation problem is to find the estimation of the unknown function F(x).

Function approximation is required when solving numerous engineering and scientific modeling problems.

Prognostication. The task is to predict some values at some point of time in future. Predictions have a significant impact on decision-making process in business, science and technology. Stock market pricing and weather forecasting are typical forecasting programs [23].

Optimization. Numerous problems in mathematics, statistics, technology, science, medicine and economics can be considered as optimization problems. The goal of the optimization algorithm is to find a solution that satisfies the constraints of the system and maximizes or minimizes the objective function. The salesman's task is a classic example of an optimization problem.

Content-addressed memory. In the Neumann computation model, memory access is available only through an address which is independent of memory content. Moreover, if there is an error in the calculation of the address, then completely different information can be found. Associative memory or memory that is addressed by content, is available at the specified content. The contents of the memory can be called even by partial input. Associative memory is extremely effective when creating multimedia information databases.

Neural-based software products are used to control water quality and can detect plastic bombs in the baggage of air travelers. Investment bank specialists make short-term forecasts of currency fluctuations using a software package.

Adaptation to environmental changes. Neural networks have the ability to adapt to environmental changes. In particular, neural networks trained to operate in a certain environment can be easily retrained to operate in conditions of slight fluctuations in environmental parameters. Moreover, in order to work in a dynamic environment (where statistics change over the time, such as stock quotes) some neural networks can be created, which are re-trained in real time. The higher is the adaptive capacity of the system, the more stable it will be in a dynamic environment. It should be stated that adaptability does not always lead to sustainability; sometimes it results in quite the opposite. For example, an adaptive system with rapidly changing parameters can also quickly respond to third-party disturbances, which will cause productivity loss. In order to take full advantage of adaptability, the basic parameters of the system must be on the one hand, sufficiently stable in order to avoid considering external interference and on the other hand, flexible enough to respond to significant changes in the environment.

High speed of calculations. Neural networks have the potential for high-speed performance through the usage of mass parallel processing of information.

Neural networks are potentially fault-resistant in hardware implementation. This means that under unfavorable conditions their productivity drops slightly. For example, if a neuron or its connections are damaged, retrieving process of stored information is getting complicated. However, taking into consideration the distributed nature of the storage of information in the neural network, it can be stated that only serious damages to the structure of the neural network will significantly affect its performance.

2.3. Vehicle behavior

Study of the trajectory of turn. Usually the vehicle has a first rotary axle and all subsequent other ones are static. This configuration gives maximum stability on the road at any speed. In slow-moving vehicles that require maximum maneuverability, such as forklifts, agricultural combines, some types of tractors and excavators, the rear axle is used as a swivel axle and the front axle is static. Also, during reversing a classic car has great maneuverability which allows, for example, to perform parallel parking in a narrow parking space. At the same time while gaining a certain speed by reversing, one sloppy motion of the wheel leads to a reversal. The explanation for this is simple: the front axle "pulls" a car and the rear "pushes".

In large buses as well as trucks or trailers with three or more axles, the rear axle also has a rotary mechanism. The angle of rotation of the wheels will be opposite to the angle of the front axle, but proportionally smaller. This arrangement a little bit reduces the turning radius of the long vehicle and prevents the tire from being erased prematurely when turning at low speeds at low speeds.

Let’s consider the trajectory of rotation of different arrangements.

2.3.1. Only the first axis rotates.

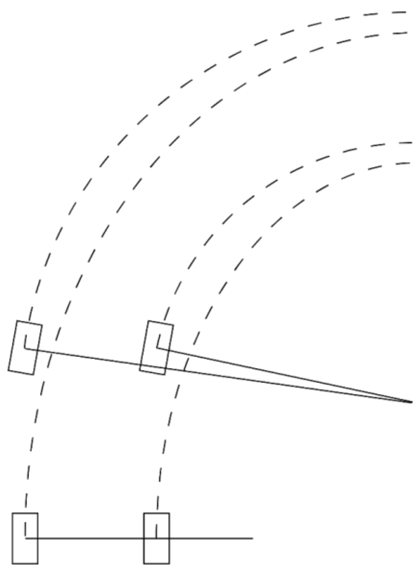

Fig. 2.5. Vehicle behavior with first axis rotation

As can be seen in Fig. 2.5, the trajectory of the rear wheels has a larger radius than the front wheels and "cuts off" the turn. Therefore, the trajectory of the rear wheels must be taken into account for turning, that is, to start turning a little later. With multiple sections connected, these trajectories become multiple and the overall turning radius increases significantly. An example of this is a semi-trailer truck.

2.3.2. Only rear axle swivel.

When rear wheels are positioned, the trajectory of movement of the latter begins to deviate significantly from the axis of motion. Turning smoothly, this deviation is not significant, but it should not be forgotten, because the rear of the car can easily take to the oncoming lane or the roadside.

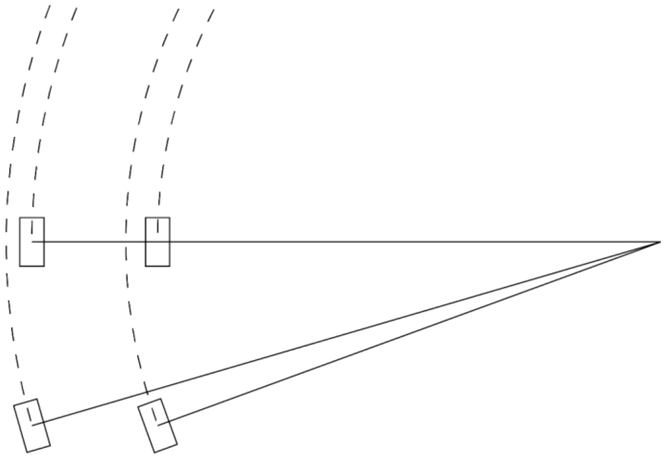

Fig. 2.6. Vehicle behavior with rear axis rotation

2.3.3. Rotary first and last axles in a vehicle with three axles.

As can see in Fig. 2.7, when the last axle is steered it helps to rotate with a smaller radius. In this configuration, the rear axle wheels are rotated at an angle proportionally smaller than the first axle wheels in proportion to the axial distance.

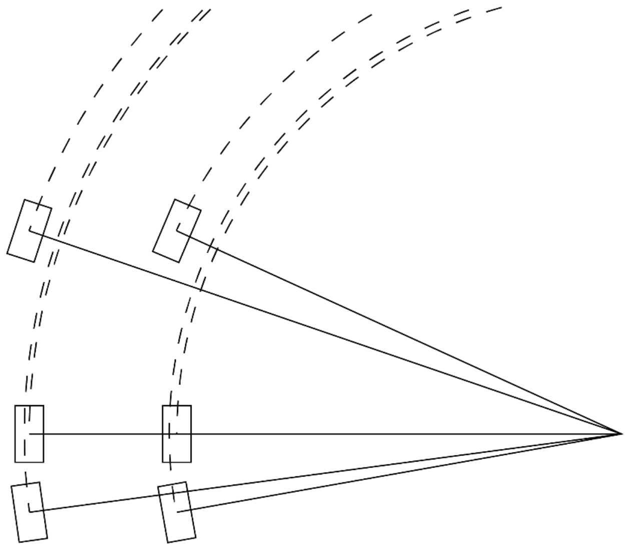

Fig. 2.7. Vehicle behavior with first and last axis rotation

2.3.4. Turning "on rails".

The configuration in which the wheels of all axles can rotate freely allows you to implement the behavior of the movement on the rails. The rear axle follows the same trajectory as the front axle. With the correct adjustment of the steering system of these axles, it is possible to make a multi-section vehicle, all axles of which will rotate along the same trajectory as the first axle. (see Fig. 2.8)

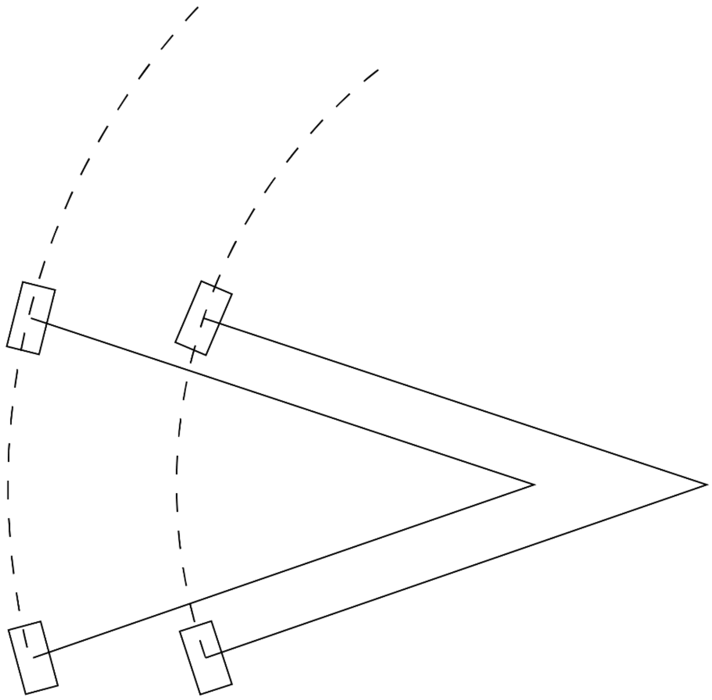

Fig. 2.8. Vehicle behavior like on rail

2.4. The Bezier curve is used to calculate the trajectory.

Vector images consist of contours, which in turn consist of segments bounded by nodes. Having several such segments any figure can be made up. Vector graphics programs use parametric polynomial curves designed by French mathematician Pierre Beziers to describe the outlines (see Fig. 2.9). Today, Bezier curves are widely used in computer graphics, automated production management systems, etc. and fit perfectly for our task [24].

By specifying an array of vertices:

$$P = \{P_0, P_1, P_2 \dots P_n\},$$

the Bezier curve will be determined by the formula:

$$R(t) = \sum_{i=0}^{n} B_i^n(t) P_i, \tag{2.2}$$

where $t\epsilon[0,1]$,

where:

$$B_i^n(t) = C_n^i t^i (1-t)^{n-1}\ , \tag{2.3}$$

The basis functions of the Bezier curve, also called the Berstein polynomials:

$$C_n^i = \frac{n!}{i!\,(n-i)!},$$

where:

$$P_i = \binom{x_i}{y_i}.$$

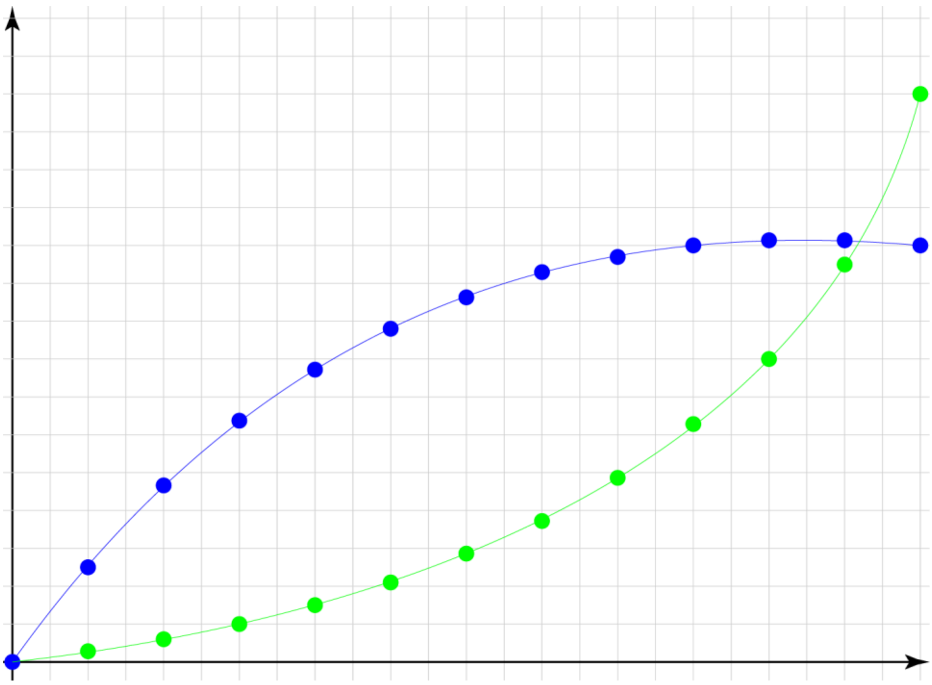

Fig. 2.9. Two Bezier curves

Note: Some of the properties of the Berstein polynomials significantly affect the behavior of the Bezier curves. The main ones are the following: Bernstein polynomials acquire non-negative values; in the sum of polynomials of Berstein give 1, in other words, for them the following condition is satisfied:

$$\sum_{i=0}^{m} B_i^n(t) = 1$$

The Berstein polynomials do not depend on the vertices of the array, but depend only on the number of points in it [24].

In scalar form, equation (2.2) is written in the following form:

$$x(t) = \sum_{i=0}^{n} C_n^i t^i (1-t)^{n-i} x_i;$$

$$y(t) = \sum_{i=0}^{n} C_n^i t^i (1-t)^{n-i} y_i \,,$$

where the points P_0 and P_n are called end points and the points $P_1, P_2, P_3, \ldots P_{n-1}$ are control points. The polygon $P_0 P_1, P_2, \ldots P_n$ in this case is called control or supporting [24].

The Bezier curves have a number of interesting properties, making them widely used in practice. The main ones are the following:

- The degree of a polynomial $R(t)$ defining a Bezier curve is one unit less than the number of points contained in an array P, meaning that a Bezier curve constructed on $(n + 1)$- the point and with a polynomial of degree n.

- The order of points in the array P significantly affects the appearance of the curve. The shape of the Bezier curve repeats the course of the polygon $P_0P_1, P_2, \dots P_n$. When you change the order of the points, the shape of the curve changes completely.

- The first and last points of the curve coincide with the corresponding points of the array P , that is $R(0) = P_0$ and $R(1) = P_n$.

- Since $R(0) = n\,(P_1 - P_0)$ and $R(1) = n(P_n - P_{n-1})$, the vectors tangent at the ends of the Bezier curve in the direction completely coincide with the first and last links of the reference polygon [24].

The Bezier curve is a smooth curve. In particular, the first derivative of the radius vector $R(t)$ can be written as:

$$R(t) = n \sum_{i=0}^{n-1} (P_{i+1} - P_i) B_i^{n-1}(t)$$

Since for the coefficients of the linear combination of the points of the array P the condition (11) is satisfied, the Bezier curve lies in the convex shell of the vertices of the array [24].

The Bezier curve is invariant under affine transformations. In other words, by constructing a Bezier curve, it is possible to perform affine transformations over it and the other way around - first to perform affine transformations over support vertices and then to construct a curve on new vertices. If the results are the same, it can be concluded that the curve is invariant under this affine transformation. It is easy to notice, for example, that the rotation of the reference vertices and the subsequent construction of the curve takes less time than the rotation of the curve itself. And it’s important to keep in mind that affine transformations include rotation, stretching, compression, parallel transfer, and their possible combinations [24].

If at least one vertex is added to the array, then the parametric equations of the Bezier curve must be completely recalculated.

Changing at least one point in an array P causes a noticeable change in the entire Bezier curve (see Fig. 2.10).

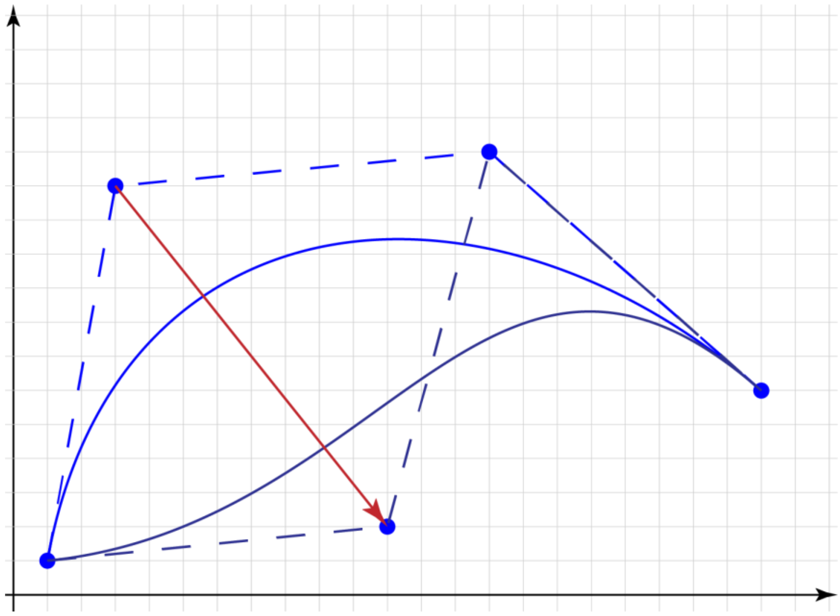

Fig. 2.10. Changing the Bezier curve with one point

There are no free parameters in the formula describing the Bezier elementary curve which means that the given array uniquely defines the Bezier curve and there is no way to influence its shape in any way.

The last disadvantage can be eliminated by introducing the rational Bezier curves defined by the formula:

$$R(t) = \frac{\sum_{i=0}^{m} \omega_i B_i^n(t) P_i}{\sum_{i=0}^{n} \omega_i B_i^n(t)}, t \in [0,1], \quad (2.4)$$

where, $\omega_i \geq 0$ weighting factors, the sum of which is strictly positive.

By changing the parameters ω_i, it is possible to control the shape of the rational Bezier curves. If the value ω_i is very big, then the curve $R(t)$ extends close to the point P_i; if ω_i is small, then $R(t)$ extends beyond the point P_i. If all ω_i are equal, then the usual Bezier curve is obtained.

2.4.1. The example of construction of the Bezier curve.

Construct a third-order Bezier curve which has already known the following reference and control points: $P_0(2{,}3), P_1(0{,}5), P_2(-1,-2), P_3(2{,}1)$.

In order to do this, on the first step, according to Bezier curve formula, it's necessary to write an equation describing the Bezier curve, which is determined by four points:

$$R(t) = (1-t)^3 P_0 + 3t(1-t)^2 P_1 + 3t^2(1-t)P_2 + t^3 P_3, t \in [0,1]$$

After that, writing down the last expression in scalar form and substituting the corresponding coordinates of control and anchor points instead of unknowns, it's possible to get the formulas for calculating the values and the Cubic Bezier curve will be obtained:

$$x(t) = 2 \cdot (1-t)^3 + 5 \cdot 3 \cdot t(1-t)^2 + (-2) \cdot 3 \cdot t^2(1-t) + 2 \cdot t^3;$$
$$y(t) = 3 \cdot (1-t)^3 + 0 \cdot 3 \cdot t(1-t)^2 + (-1) \cdot 3 \cdot t^2(1-t) + 1 \cdot t^3,$$
$$x(t) = 3t^3 + 3t^2 - 6t + 2;$$
$$y(t) = 19t^3 - 27t^2 - 6t + 3$$

And in the last iteration, moving with some step, for example Δt = 0.1, each time the value of $x(t)$ and $y(t)$ are recalculated, and thus the next segment of the curve is determined and drawn. The Bezier curve that will be obtained as a result of these actions is shown on the Fig. 2.11.

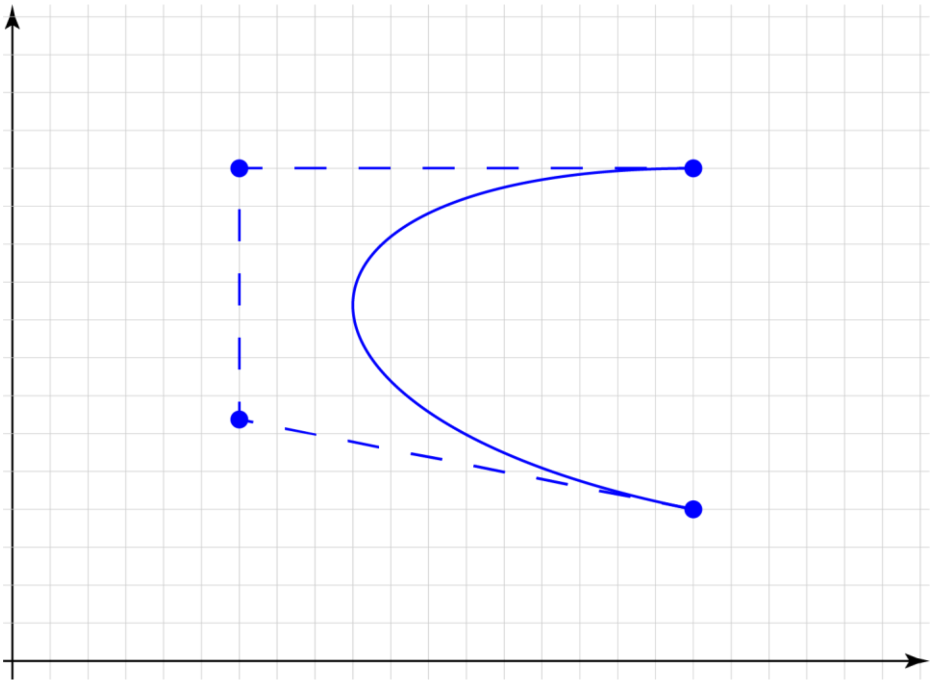

Fig. 2.11. Third-order Bezier curve

In order to construct a trajectory through known points and to pass it through these points, it is necessary to divide the trajectory into several curves. Knowing the angle of rotation of the wheels, it is possible to add two points at intervals between the axes at certain distances from the axis. We set this distance as a constant, and choose for it the diameter of the wheel. Each segment will have four points, which will serve as the basis for the construction of the Bezier curve of the 3rd degree.

2.5. Analysis of the hardware of a computer neural network vehicle control system

2.3.1. Tensor processor.

The Tensor Processor (TPU) is a Specific Application Integrated Circuit (ASIC) (see Fig. 2.12), developed by Google and designed to accelerate calculations for artificial intelligence tasks [25].

The tensor processor was named TensorFlow. Because TPU's purpose is to accelerate artificial intelligence algorithms using free software libraries.

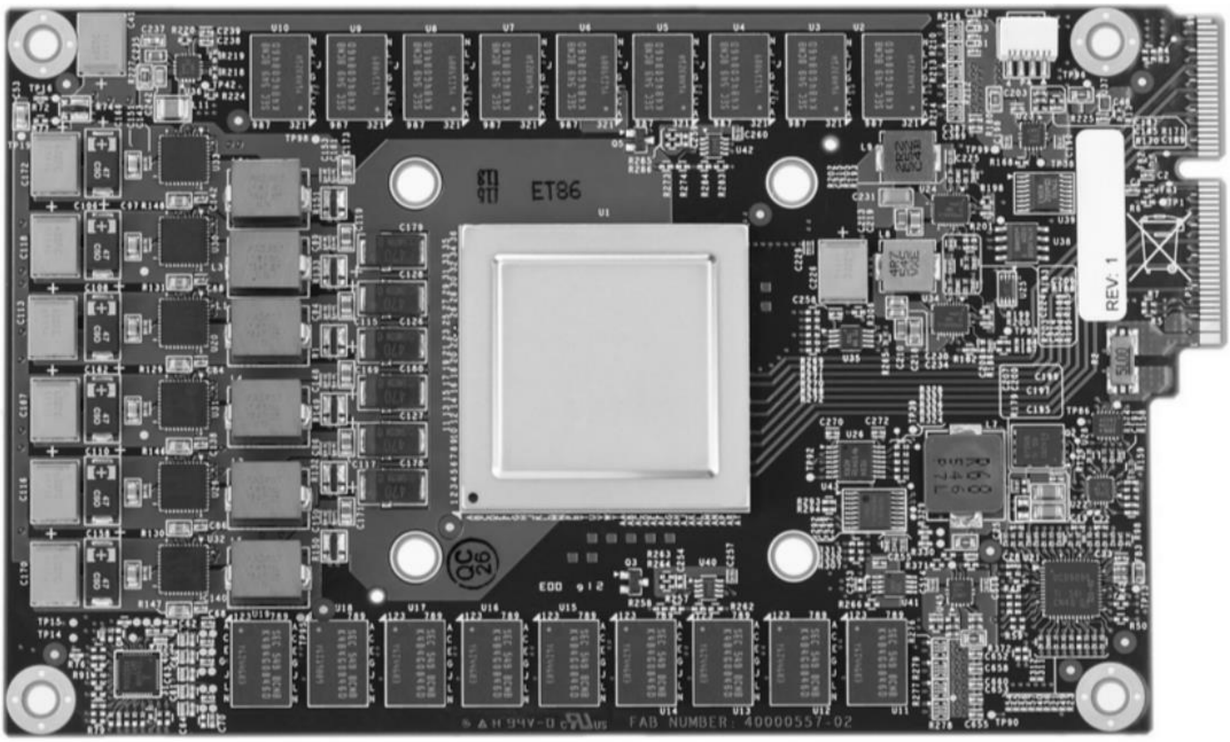

Fig. 2.12. General view of the TPU PCB

Google's artificial intelligence has reached significant heights. And one of the factors behind this success is that Google has developed specialized hardware that works with neural networks much more efficiently than traditional CPUs and GPUs.

On average, the tensor processor performs 15-30 times faster calculations, compared to traditional server CPUs and GPUs. Performance per watt in TPU is 25-80 times higher than that of central and graphics chips [26].

2.3.2. Structure of the tensor processor.

TPU ASIC is built on 28 nm process, operates at 700 MHz and consumes 40 watts during operation. The processor is presented as an external acceleration card that is placed in the SATA hard drive slot for installation. The TPU is connected to its host via the PCIe Gen3 x16 bus, which provides an effective bandwidth of 12.5 GB/s.

Programmability was another important design goal for TPU. The TPU is not designed to run only one type of neural network model. Instead, it is designed to be flexible enough to accelerate the computations required to run many different neural network models.

Most modern CPUs are built using the Reduced Instruction Set Computer (RISC) architecture. RISC focuses on identifying simple instructions (such as downloads, storage, adding and multiplication) that are commonly used by most applications and then executing these instructions as quickly as possible. The Complex Instruction Set Computer (CISC) architecture was selected as the basis for the TPU instruction set. The CISC architecture focuses on implementing high-level instructions that perform more complex tasks (such as multiplication and addition calculations) with each instruction.

The TPU includes the following computing resources:

- Matrix Multiplier (MXU): 65,536 8-bit multiplication and addition units for matrix operations;

- single buffer (UB): 24 MB SRAMs that work as registers;

- Activation unit (AU): activation functions [121, 122].

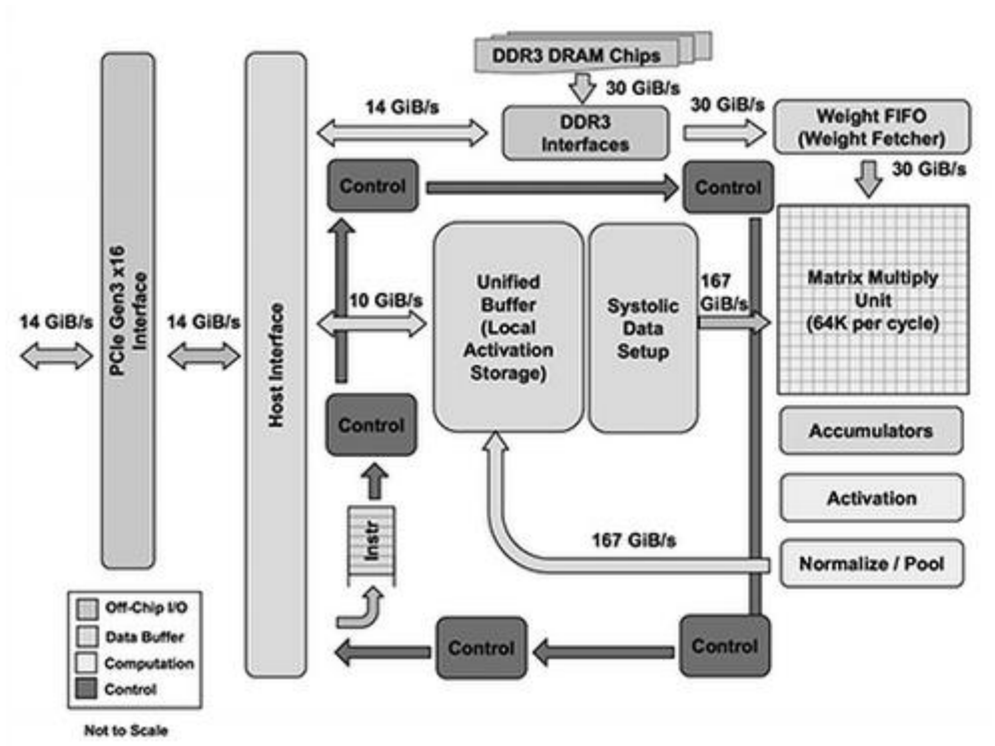

Fig. 2.13. Block diagram TPU

Typical RISC processors provide instructions for simple calculations, such as multiplication or addition of numbers. These are the so-called scalar processors because they process one operation (scalar operation) with each instruction.

Even though processors are clocked in GHz, it can take a long time to perform large matrix operations using scalar operations. One effective and well-known way to improve the performance of such large matrix operations is vector processing, where the same operation is performed simultaneously with a large number of data elements. Multiprocessor (SM) streaming graphics processors are efficient vector processors. Vector-processing machines can handle hundreds to thousands of operations in one cycle.

In the case of TPU, Google has developed its MXU matrix processor that processes hundreds of thousands of operations (matrix operations) in a single clock cycle.

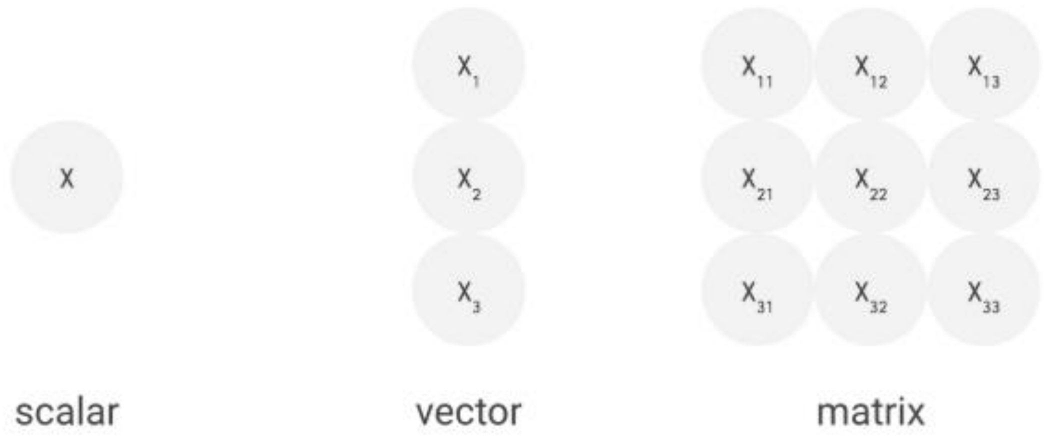

Fig. 2.14. Comparison of scalar, vector and matrix operations

To implement such a large-scale array processor, the MXU has a different architecture than typical central and GPUs, called the systolic array. These processors are designed to perform virtually any calculation. These are general purpose computers. To implement this property, processors store values in registers, and the program tells arithmetic logical units (ALUs) which registers to read, which operation to perform (eg, addition, multiplication) and the register in which to put the result. The program consists of a sequence of read / work / write operations. All of these community-enabled features (registers, ALUs, and programmed controls) have lower power costs.

For MXU, matrix multiplication reuses both inputs many times as part of the output. We can read each input value once, but use it for many different operations without saving it back to the register. ALUs only perform multiplications and additions in fixed models, which simplifies their design.

The special type of systolic array in the MXU is optimized when performing matrix multiplication, and is not well suited for general purpose calculations. This makes an engineering compromise: limiting registers, controls, and operating flexibility in exchange for efficiency and a much higher density of operation [26].

The TPU multiplication module has a systolic array mechanism that contains 256 × 256 = 65,536 ALUs. This means that the TPU can handle 65,536 multiplication and addition operations for 8-bit integers each cycle. Because the TPU is clocked at 700 MHz, the TPU can calculate 65536 × 700000000 = 46 × 1012 multiplication and addition operations, or 92 TeraOps per second (92 × 1012) in the matrix block.

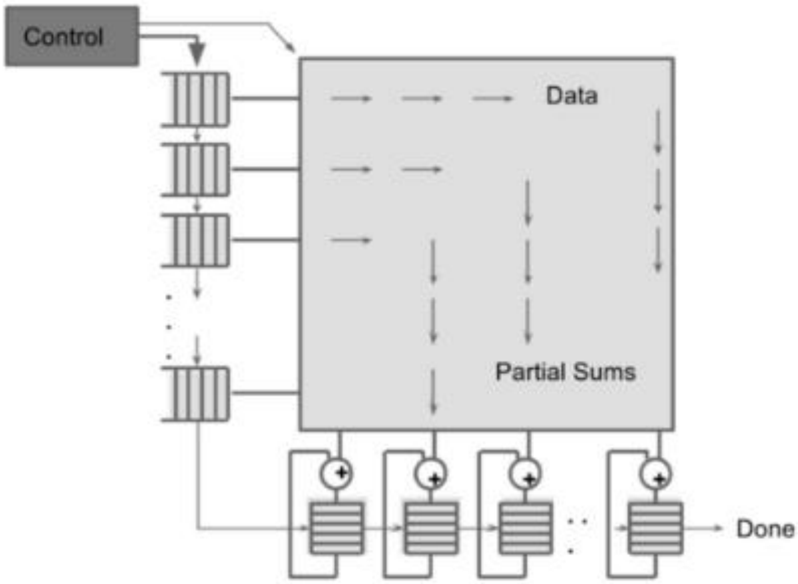

Fig. 2.15. Matrix Multiplier Unit (MXU) TPU

For comparison, a typical RISC processor without a vector extension can only perform one or two arithmetic operations per instruction, and GPUs can perform thousands of operations per instruction. With a TPU, a single MatrixMultiply instruction cycle can cause hundreds of thousands of operations.

During MXU run, all intermediate results are transmitted between 64K ALUs without any memory access, significantly reducing power consumption and increasing bandwidth. As a result, the design of CISC-based matrix processors delivers a performance-per-watt ratio: the TPU delivers 80 times the ratio of today's CPUs and 29 times the ratio of today's GPUs (see Fig. 2.16).

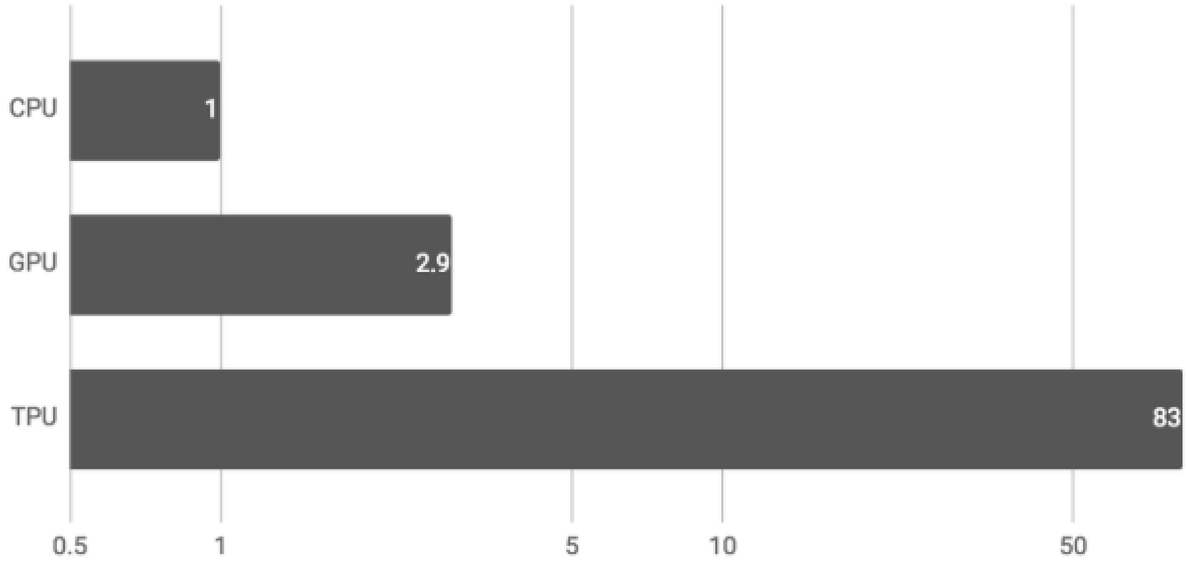

Fig. 2.16. Comparison of performance per watt of CPU, GPU, and TPU power consumption

Since general-purpose processors such as CPUs and GPUs need to deliver good performance across a wide range of applications, they have many sophisticated, performance-oriented mechanisms. As a side effect, the behavior of these processors can be difficult to predict, which complicates the guarantee of a certain limitation of latency for neural network processing. In contrast, TPU design is strictly minimal and deterministic, as it only has to perform one task at a time: neural network prediction.

Despite the fact that the CPU and GPU have much more arithmetic units and a large amount of RAM, the TPU chip is half the size of other chips.

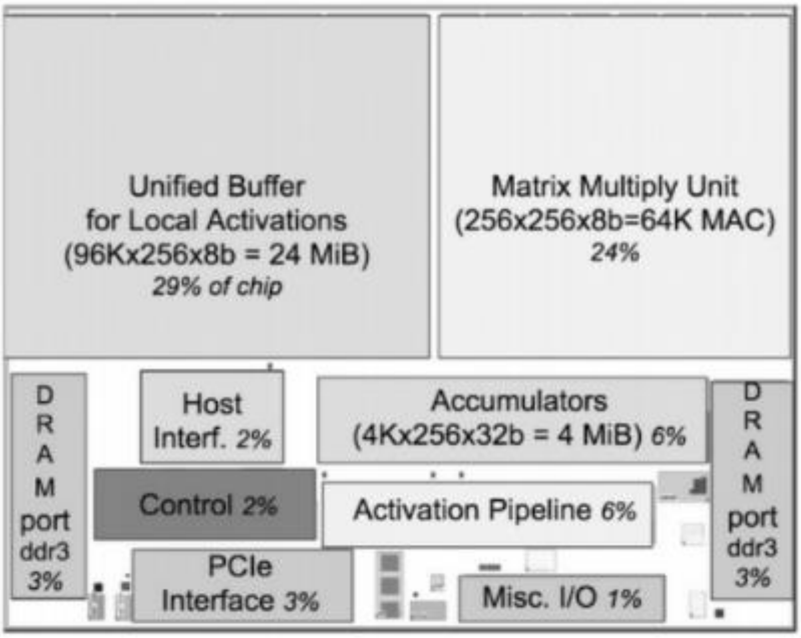

Fig. 2.17. TPU elements placement

With TPU, we can easily estimate how long it takes to run a neural network and forecast. This allows to work with the maximum bandwidth of the chip [26].

2.6. Conclusion to the chapter

This chapter discusses how to obtain location information and how to process it. Neural networks, perceptron and their application in the task were also considered. The behavior of the vehicle under different rotary axle configurations was investigated.

Natural language processing hardware using neural networks has been analyzed. Efficiency of use of tensor processors in comparison with traditional server CPUs and GPU was investigated. Also, the structure of the tensor processor which is intended for the training tasks of neural networks, was considered.

CHAPTER 3
IMPLEMENTATION OF COMPUTER SOFTWARE FOR THE VEHICLE COMPUTER STEERING SYSTEMS

3.1. Main Algorithm

As with any algorithm, everything starts with initializing all the necessary components and gathering the necessary initial information. Then, in a continuous cycle the input is read and processed and the results obtained forms output. There are also exceptions, foreseeable and unforeseen situations that can cause damage to the system. When any non-standard situation occurs, the system exits the loop until the situation is resolved. Due to testing, most of such cases are stopped and the program resolves such situations. In such a system, redundancy and redundancy are also important, which are designed to continue the system's performance when one or more elements fail.

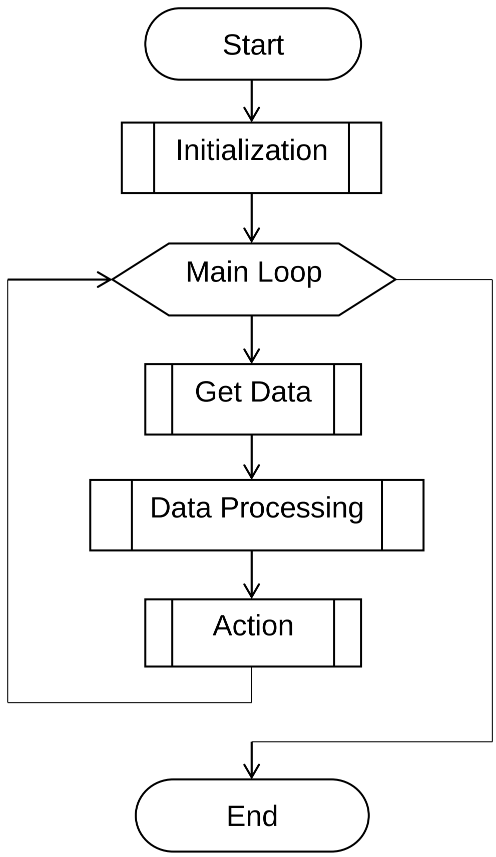

Fig. 3.1. Main block algorithm

3.1.1. Algorithmic solution of the problem.

An algorithm that runs at a frequency enough to adequately respond to a situation. Assuming that the speed of the vehicle will not exceed 50 kilometers per hour (which is respectively 14 meters per second) and that the diameter of the wheel does not exceed 1 meter, it is possible to take the frequency of the algorithm of 50 times per second.

The principle of the algorithm is to calculate the angle of motion vector change.

As a result of initialization process there is an array of coordinates that reflect the trajectory of the wheel at the current moment. Moreover, each axis has its initial coordinates, at the current moment, as well as the current angle of rotation of the wheels and accordingly the current motion vector. At the moment of starting of the movement, the further coordinates of the first axis of the vehicle are calculated. However, in order to avoid overflow, the calculation takes place in a relative coordinate system. The first axis always has coordinates (0; 0) and the movement is directed along the X axis in the negative direction. Accordingly, in most working hours, all subsequent axes will have a positive abscissa. So, with the beginning of the movement the recalculation process of all the coordinates of the array takes place. The current coordinate and the previous coordinate in the array based on which the vector of the desired motion is constructed are taken into account:

$$\overline{x_{cur}x_{des}, y_{cur}y_{des}},$$

$$x_{cur}x_{des} = x_{des} - x_{cur},$$

$$y_{cur}y_{des} = y_{des} - y_{cur},$$

where $x_{cur}, x_{des}, y_{cur}, y_{des}$ are coordinates of current and desired points [27].

Then, the angle between the current motion vector and the required is determined in the following way:

$$\alpha = \mathrm{acos}\left(\frac{\bar{a}\cdot\bar{b}}{|\bar{a}|\cdot|\bar{b}|}\right),$$

where α is an angle between two vectors, $\bar{a}$ is current motion vector and $\bar{b}$ is desired motion vector [27].

According to this angle, there is a rotation of the wheels, after which the trajectory of motion is again calculated.

3.1.2. Initialization.

During the process of initializing, it's important to keep in mind that the vehicle will almost never stand in a straight line. Therefore, at the first start it is necessary to determine the initial coordinates of each axis. In order to do this, it's necessary to know the relative position of each wagon relatively to the others and the length between the axles.

Simple geometric formulas must be used to determine the initial coordinates of each axis:

$$x_{01} = 0;$$

$$y_{01} = 0;$$

$$x_{02} = l_{02};$$

$$y_{02} = 0;$$

$$x_{11} = l_0 + l_{11}\cdot\cos\beta_1\,;$$

$$y_{11} = l_0 + l_{11}\cdot\sin\beta_1\,;$$

$$x_{12} = l_0 + (l_{11} + l_{12})\cos\beta_1\,;$$

$$y_{12} = l_0 + (l_{11} + l_{12})\sin\beta_1\,;$$

$$x_{21} = l_0 + l_1\cos\beta_1 + l_{21}cos\beta_2;$$

$$y_{21} = l_0 + l_1 \sin\beta_1 + l_{21} sin\beta_2;$$

$$x_{22} = l_0 + l_1 \cos\beta_1 + (l_{21} + l_{22}) cos\beta_2;$$

$$y_{22} = l_0 + l_1 \sin\beta_1 + (l_{21} + l_{22}) sin\beta_2;$$

where l_{xx} are distances between axles, l_x length of section, l_0 distance between first and second axles of first section, β_{x} is an angle between two sections (see Fig. 3.2).

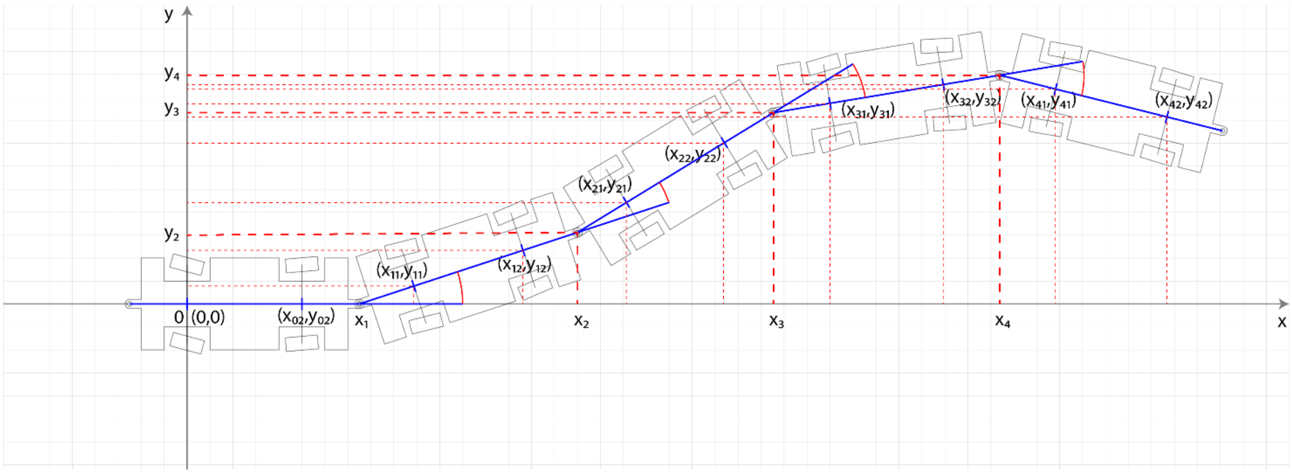

Fig. 3.2. Train axle position

Initialization may also have some modifications depending on the type of connection of the vehicle sections. The sample above shows an easy way to connect wagons moving relative to each other, having one common contact point. Such a connection is easy to implement and has additional difficulty in turning. The axles in the middle of the vehicle will have to deviate somewhat from the trajectory given by the driving axle, due to geometric features. The option is when the flexible hinge is connected not to the ends of the wagons, but to the beams which are rigidly connected to the axles and rotated to the angle corresponding to the wheels. This option is more fitting for trains with twin trolleys that co-rotate about the wagon. For the bus it is possible to use a rigid clutch of cars with two swivel joints. This method allows the ends of the wagons to deviate independently from the trajectory, which allows the axes to follow the latter better. With this arrangement, two encoders are needed, one for each hinge, which adds another row to the initial coordinates.

When the initial coordinates are known, the Bezier curve is constructed through them taking into account the current wheel rotation. Separate curve is constructed for each pair of adjacent axles.

3.1.3. The main cycle.

After initialization, the vehicle is ready to start moving. According to the information from the encoder on the first axis and the speedometer, a new coordinate is calculated, which is written in a new row in the coordinate table. Each subsequent axis has accordingly moved to a new coordinate in the table. But since there are errors in the real model, most likely the axis is in the vicinity of the required coordinate. For this purpose, a neural network was developed to help navigate this situation. It adjusts the angle of rotation of the wheels to follow a given trajectory. After one cycle of the program, the vehicle has moved a certain distance, a new trajectory calculation with Bezier curves and all goes continuous.

3.2. Behavior of moving like rails.

One of the tasks is to study the behavior of a vehicle that moves like rails. In order to understand how the axles of the vehicle should behave, it is necessary to simulate the appropriate situation. Matlab development environment will be used for modeling [28].

Firstly, it is necessary to calculate the trajectory and simulate the rails. For this task can be used the Bezier quadratic curves. The number of curves will be equal the number the axial distances. The first and last points of the input array are the coordinates of the contact points of the wheels of the adjacent axes, between which the curve is calculated. Taking into consideration the scale of the study, there is no need to construct the trajectory of both rails. A single line passing through the center of each axis is sufficient. The other two points of the input array will be calculated by the angle of rotation of the wheels, as well as the distance at which these points will be taken into account from the axis. This distance will correspond to the diameter of the wheel.

By depicting the trajectory, the vehicle itself can be simulated. In this simulation, it will be a straight line that reflects its length. This segment will pass through the coordinates of the axles of the vehicle. The angle between the ground and the vehicle in the coordinate of the axis ~~and~~ will reflect the angle of rotation of the wheels of the corresponding axis.

Having done the appropriate simulation, it is possible to see how change the angle of wheels' rotation when passing a certain trajectory.

For one-section vehicles, both synchronous rotation of the axle wheels and with a certain delay are possible. And when the vehicle is made up of several sections, the delay between wheel turns must be taken into account. Consider a similar model of the vehicle trajectory, only this time the machine will have two sections and a total of 4 axles.

It is necessary to calculate 3 Bezier curves between each adjacent axes. In further calculations, it is enough to consider the angle of rotation of the wheels of the first section and the next section will follow the coordinates of the first.

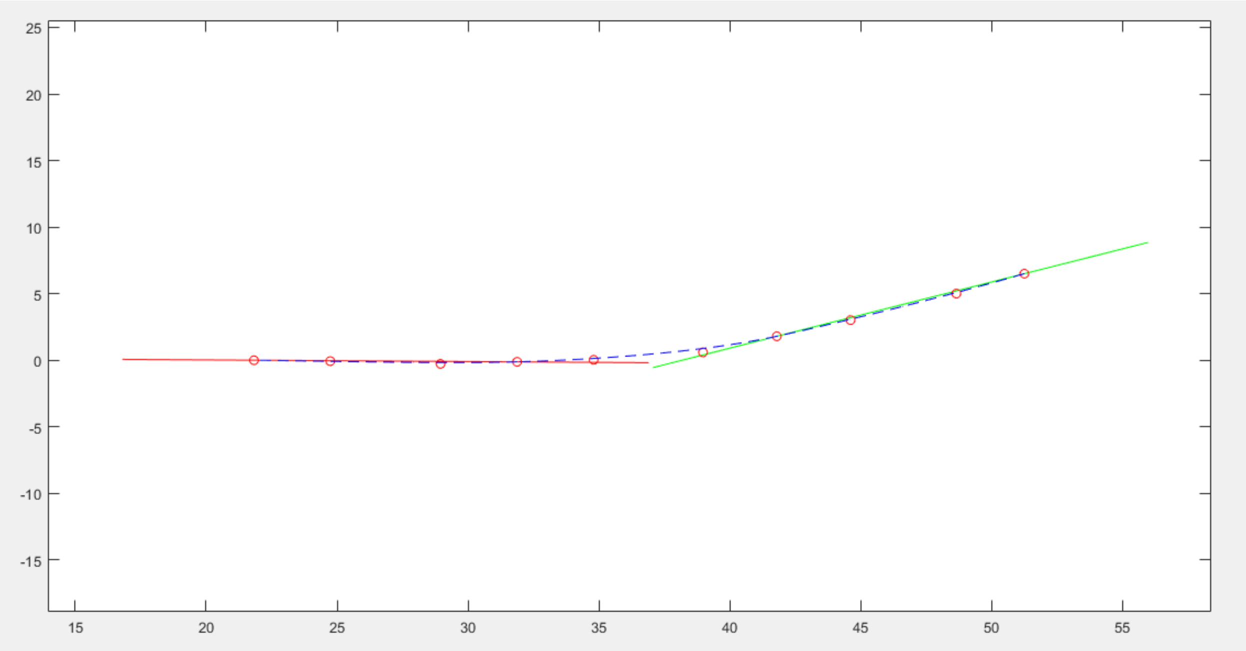

Fig. 3.3. Matlab model of trackless 2 section train trajectory

On Fig 3.3 shows a model of trackless train trajectory. Green and red straight lines are the base of car sections. Red points show axles and their rotation vectors. Bleu dotted line represent trajectory of movement.

3.3. Neural network for help steering.

It's possible to use a neural network to process data and make a decision.

Taking into consideration the fact that the artificial neural network was invented by analogy with human brain neurons, it is necessary to address the problem in terms of "if there was a human on the computer." It's necessary to conduct a small thinking experiment.

Thinking experiment. Let's assume that behind each axle sits its own driver, who controls the turn of his own steering wheel. The driver observes the behavior of the previous axle and accordingly decides how to rotate the steering wheel. The person does not think about the exact angle of rotation of the wheels, because the person is physically incapable to estimate precisely how many degrees the previous axis has been rotated and then recreate the same angle on its own axis. In addition to this, the angle of rotation of the axis is variable over time, and accordingly a person needs to evaluate and memorize many digital values, which with a certain delay need to be reproduced. A person is not able to memorize so much information and reproduce it in the required sequence. Additionally, it should be kept in mind that the speed of the vehicle is also variable over time, in the result of which the speed of change of the steering angle on each axle should be proportional to the speed of movement at the current moment and correspond to the same proportion of the previous axis.

Instead of everything mentioned above, people evaluate the situation more subjectively. The driver will evaluate the behavior of the previous axis and attempt to reproduce it on its own. Observing the trajectory, the person makes a decision in which direction to turn the steering wheel. Also, a person decides whether the steering wheel is rotated sufficiently or not, using more or less comparison approach, instead of determining the specific steering angle. Accordingly, it can be concluded that the artificial neural network must evaluate its own trajectory and its correspondence to a given trajectory.

A person evaluates the situation with his/her eyes, visually perceiving the information about the behavior of the vehicle. Unfortunately, there is no human eyes in the artificial neural network. As the eyes simulation the camera can be used connected to another artificial neural network designed for pattern recognition, but most likely redundancy. However, it is possible to evaluate the trajectory not only visually. Turning to the algorithmic execution of the task, it is possible to get a record of the trajectory of movement of the previous axis, which will consist of an array of coordinates. Taking into account the initialization algorithm, it is possible to obtain the current coordinates of the desired axis thanks to the information from the encoders.

It can be concluded that for the operation of the neural network, it is sufficient to input the current axis coordinates, the desired axis coordinates and the current wheel angle to the input. At the exit of the neural network there will be only three neurons, namely "turn left", "continue straight" and "turn right". There are 5 input layer neurons and 3 output layer neurons. The number of neurons in the hidden layer may be variable. Initial number is 4 neurons (see Fig. 3.4).

Network Training. In order to train the neural network, a training set with data obtained experimentally in a computer model is required. The model completely replicates the system, but under ideal conditions, resulting in the absolute accuracy of algorithmic method [29]. There is the same comparison of the real coordinate with the necessary with a simple logical comparison. The result of this comparison is written as the result that the neural network should output. The trajectory of motion will be spelled out on the randomly generated and stored arcs. The number of possible cases to begin with will be close to one hundred [31].

Coordinates from training sets will be fed to the input of the neural network. Output results will be compared to model results and adjustments will be made to the coefficients, weights of neurons and their relationships.

Similar to the initial set, a set of test coordinates will be generated. This set will check whether the network produces the correct results or further training is required. The number of hidden layer neurons will also change. After repeated training and validation, the results will be compared and the optimum number of neurons will be selected.

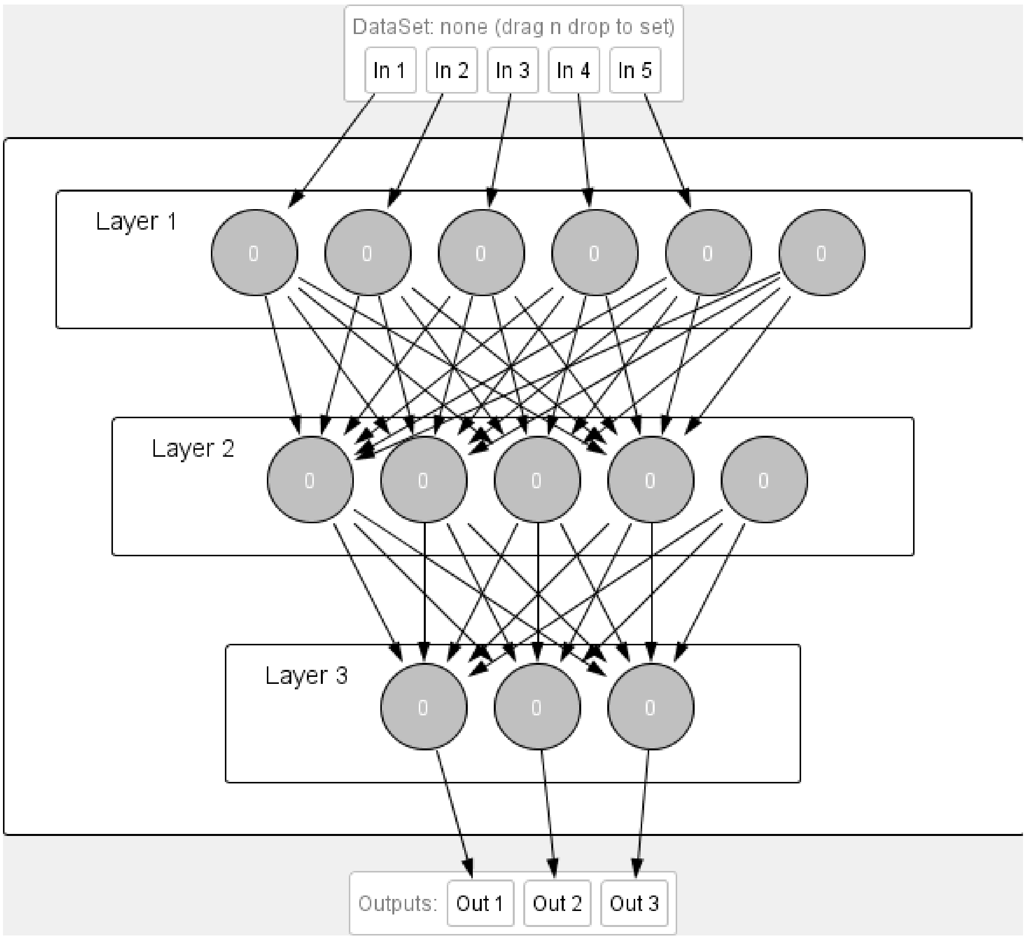

Fig. 3.4. three layers' neural network

3.3.1. Creating a training set for a neural network. Since the neural network has the current coordinates and the angle of rotation of the wheels, the desired coordinates at the input as well as the output such as "change the angle to the left", "leave as is", "change the angle to the right", it is necessary to model the behavior in ideal conditions and record results in the appropriate array [32].

The array will contain the corresponding coordinates, the current angle of rotation of the wheels and, accordingly, the answer that changes the angle of rotation. The answer will be calculated by subtracting the current angle of rotation from the angle between the trajectory and the wheel vector. Then, using simple logic operations, compare and write the corresponding numbers:

- Sufficient number - increase left angle;
- Zero - leave the angle unchanged;

- Negative - increase the right angle.

The training array will contain 8 columns: 5 input and 3 output. An example of a training array is shown in the Table 3.1.

Table 3.1

Sample of training data

Current x	Current y	Desired x	Desired y	Current angle	Turn left	Go ahead	Turn right
36.472	0.034	37.419	0.098	-3.313	0.99	0.01	0.01
46.149	1.289	47.123	1.434	-2.783	0.01	0.01	0.99
21.840	0.010	22.749	0.002	0.010	0.01	0.99	0.01

But for proper functioning of the neural network, it is necessary to scale the data within the activation function. The best is to keep the data out of bounds [-1; 1]. Test networks will have coordinates from -100 to 100, so it would be logical to divide all coordinates by 100. And since the angle of rotation will not exceed 90°, respectively, the angle will be divided by 90. The neural network has a bad impact number 0, so to avoid zero it is necessary to add or subtract one hundredth from a coordinate or angle. This will not cause changes but will allow the network to function properly [125, 127].

Then the prepared data should be uploaded as a training set to NeurophStudio and finally, launch of training starts. Part of the training set is shown in the Fig. 3.5 below.

Test Results ✕ NewNeuralNetwork1.nnet ✕ TrainingSet1 ✕

Input1	Input2	Input3	Input4	Input5	Output1	Output2	Output3
0.3	1.0E-4	0.30928	1.0E-4	1.0E-4	0.01	0.99	0.01
0.2	1.0E-4	0.20928	1.0E-4	1.0E-4	0.01	0.99	0.01
0.1	1.0E-4	0.10928	1.0E-4	1.0E-4	0.01	0.99	0.01
0.30928	1.0E-4	0.31848	2.7E-4	0.032	0.99	0.01	0.01
0.20928	1.0E-4	0.2184	1.0E-4	1.0E-4	0.01	0.99	0.01
0.10928	1.0E-4	0.1184	1.0E-4	1.0E-4	0.01	0.99	0.01
0.31848	2.7E-4	0.32775	8.6E-4	0.10798	0.99	0.01	0.01
0.2184	1.0E-4	0.22748	-5.0E-5	1.0E-4	0.01	0.99	0.01
0.1184	1.0E-4	0.1275	1.0E-4	1.0E-4	0.01	0.99	0.01
0.32775	8.6E-4	0.33702	0.00121	0.13607	0.01	0.01	0.99
0.22748	-5.0E-5	0.23653	-1.5E-4	-0.00731	0.01	0.01	0.99
0.1275	1.0E-4	0.13658	1.0E-5	2.9E-4	0.01	0.01	0.99
0.33702	0.00121	0.34624	0.00106	0.13972	0.01	0.01	0.99
0.23653	-1.5E-4	0.24559	-1.8E-4	-0.00495	0.99	0.01	0.01
0.13658	1.0E-5	0.14567	3.0E-5	0.00233	0.99	0.01	0.01
0.34624	0.00106	0.3554	3.3E-4	0.13104	0.01	0.01	0.99
0.24559	-1.8E-4	0.25467	-6.0E-5	0.00484	0.99	0.01	0.01
0.14567	3.0E-5	0.15475	3.0E-5	0.00232	0.01	0.01	0.99
0.3554	3.3E-4	0.36449	-9.7E-4	0.11693	0.01	0.01	0.99
0.25467	-6.0E-5	0.26379	2.1E-4	0.01573	0.99	0.01	0.01
0.15475	3.0E-5	0.16383	-1.0E-5	-7.6E-4	0.01	0.01	0.99

Fig. 3.5. Part of prepared training set

By entering a training set it could possible to train neural network. 500 to 3000 training iterations were selected. Accordingly, a graph of the errors of the neural network was displayed. The systematic reduction of the error indicates the success of the training. After one training cycle, a test was performed for the correctness of the neural network. The test kit confirmed that the network is learning in the right direction. The figure shows the neural network error curve during training. As it can be seen at the beginning of training, the value of the error was not so great (around a quarter) and immediately this value dropped to 0.215. The following can be observed as the cosine error decreases to 0.075.

Next, a few training sets with other types of turn paths were passed through the neural network for training.

After several such sets, the error increased to 0.2, which is quite big. But despite such an error, the system is almost wrong in returning the correct result. After a few more trainings of neural network error go down again (see Fig. 3.6, 3.7).

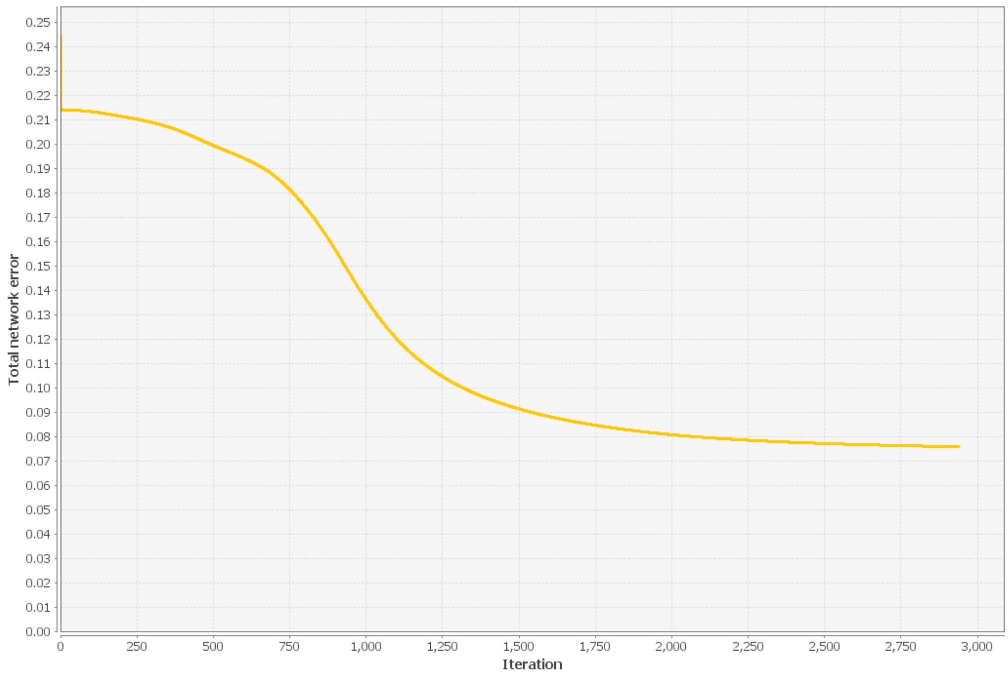

Fig. 3.6. Total network error graph

```
Input: 0.452; 0.0124; 0.4617; 0.0137; -0.0086;  Output: 1; 0; 0; Desired output: 0.99; 0.01; 0.01;  Error: 0.01; -0.01; -0.01;
Input: 0.6775; 0.049; 0.6873; 0.0507; -0.0001;  Output: 0.0861; 0; 0.9251; Desired output: 0.99; 0.01; 0.01;  Error: -0.9039; -0.01; 0.9151;
Input: 0.5692; 0.0302; 0.579; 0.0319; -0.0102;  Output: 1; 0; 0; Desired output: 0.01; 0.01; 0.99;  Error: 0.99; -0.01; -0.99;
Input: 0.4617; 0.0137; 0.4714; 0.0151; -0.0077;  Output: 1; 0; 0; Desired output: 0.99; 0.01; 0.01;  Error: 0.01; -0.01; -0.01;
Input: 0.6873; 0.0507; 0.6972; 0.0524; -0.0001;  Output: 0.035; 0; 0.9712; Desired output: 0.99; 0.01; 0.01;  Error: -0.955; -0.01; 0.9612;
Input: 0.579; 0.0319; 0.5888; 0.0336; -0.0091;  Output: 1; 0; 0; Desired output: 0.01; 0.01; 0.99;  Error: 0.99; -0.01; -0.99;
Input: 0.4714; 0.0151; 0.4812; 0.0165; -0.007;  Output: 1; 0; 0; Desired output: 0.99; 0.01; 0.01;  Error: 0.01; -0.01; -0.01;
Total Mean Square Error: 0.15528974410958082
```

Fig. 3.7. Neural network output

3.4. Conclusion to the chapter

This chapter explores and describes the algorithm for operating a vehicle control program. The logic and construction of the corresponding neural network were described. A training model for network training has been developed. Successful training and network performance was checked.

CHAPTER 4
RATIONALE OF ECONOMIC EFFICIENCY

4.1. Determination of the stages of the technological process and the total duration of the research

The essence of this section is the economic substantiation of the master's thesis, since it allows to establish the expediency of conducting research work and to substantiate economically the expediency of the use of certain means.

The aim of the master's thesis is to study the methods and means of implementing the steering system of the wheels of all axles of the vehicle.

It is well known that developing a reliable and efficient management system takes considerable time. It should be noted that the time consumption depends on the developer's skills and capabilities. The developer must have sufficient programming skills, be able to adequately apply the mathematical approach, be well aware of the object of study.

The development of this information system can be divided into the following stages:

- statement of the problem;
- gathering the necessary information and its subsequent processing;
- making decisions on the choice of the optimal way to solve the task;
- analysis of mathematical model of information system;
- development of the information system program algorithm;
- setting up the environment for the development and operation of a ready-made program;
- writing the program;
- writing and processing of documentation (electronic and paper).

Time or previous experience is used to estimate the duration of individual work. Such standards include the duration of writing operations (commands), which in some enterprises are: for one operation – 0.5-1.6 hours or 8 hours for five operations (duration of change).

In the absence thereof it's better to consult with the expert assessments to determine the duration of each stage:

with three estimates:

$$T_{вс} = (t_{min} + t_{тн.й} + t_{max})/6,$$

with two estimates:

$$T_{вс} = (3t_{min} + 2t_{max})/5,$$

where $T_{вс}$ is the expected (average) value of the duration of the stage; t_{min}, so-called, t_{max} – respectively the minimum, most probable and maximum estimates of the duration of the stage.

In order to determine the total duration of the R&D (in our case software development), it is recommended to summarize the data of the time consumption in performing the individual stages in Table 4.1.

It is advisable to take the time of the scientific supervisor to perform separate stages with insufficient information within 5% of the total time spent by engineers to perform these stages.

Table 4.1

Main stages and time of their implementation in the R&D

№	Stage	The average execution time of the stage, h	
		Engineer	Manager
1	Formulation of the problem	3	10
2	Information collection and analyses	10	5

Continuation of the table 4.1

№	Stage	The average execution time of the stage, h	
		Engineer	Manager
3	Making decisions on the choice of the optimal way to solve the task	5	4
4	Analysis of mathematical model of information system	15	10
5	Development of the algorithm of the control system program	15	5
6	Setting up the environment for the development and operation of a ready-made program	2	1
7	Writing a program	80	5
8	Writing and documentation (electronic and paper)	20	10
Total		150	50

4.2. Determining the costs of wages and social contributions

According to the Law of Ukraine "On remuneration", wages are "remuneration calculated, as a rule, in monetary terms, which the employer or his authorized body pays to an employee for the work he has done."

The amount of wages depends on the complexity and conditions of the work performed, professional and business qualities of the employee, the results of his work and economic activity of the enterprise. Wages consist of basic and additional wages.

The basic wage is accrued for the work performed at tariff rates, unit rates or salaries does not depend on the results of economic activity of the enterprise.

Extra pay is a component of employee pay, which includes wage costs that are not related to actual hours worked. Accrue additional wages depending on the achieved and planned indicators, conditions of production, qualification of performers. The source of additional pay is a material incentive fund, which is created at the expense of profit.

The main salary consists of a straight salary and a surcharge, which in the case of enlarged calculations is 25% - 35% of the straight salary. When calculating salary, the average number of working days per month should be taken - 25.4 days / month, which corresponds to 203.2 hours / month. The amount of monthly salaries of the manager and engineers should be taken in accordance with current standards. The basic salary is calculated by the formula:

$$З_{осн} = T_{c} \times K_{г}, \quad (4.1)$$

where T_c – is the tariff rate, UAH;

$K_{г}$ – is the number of worked hours.

Position salaries (tariff rates) by the digits of the Uniform tariff grid are determined by multiplying the salary (rate) of employee 1 of the tariff category by the corresponding tariff coefficient. When the salary (tariff rate) is determined in UAH with pennies, figures up to 0.5 are dropped, from 0.5 and above - are rounded to one hryvnia. In 2019, salaries (tariff rates) are calculated in accordance with the Law of Ukraine "On the State Budget of Ukraine for 2019".

The minimum wage in 2019 is equal to the subsistence minimum for able-bodied persons 4173 UAH, i.e. 25.13 UAH / hour, we will accept 100 UAH. for the engineer, for the head - 120 UAH.

Tariff rates: project manager - 180 UAH per hour, engineer - 100.0 UAH / hour.

The basic salary will be:

$$З_{осн} = Т_{осн} \cdot К_{год}$$

Manager:

$$З_{осн} = 180x50 = 9000\ UAH$$

Engineer:

$$З_{осн} = 100x150 = 15000\ UAH$$

The additional salary is 10-15% of the basic salary:

$$З_{дод} = З_{осн} \cdot К_{допл}\ , \quad (4.2)$$

where $К_{допл.}$ – the rate of additional payments to employees 0,1.

Hence the total cost of wages is determined by the formula, and are:

$$В_{оп} = З_{осн} + З_{дод}, \quad (4.3)$$

Manager:

$$В_{ОП} = 9000 + 2700 = 11700\ \text{UAH}$$

Engineer:

$$В_{ОП} = 15000 + 4500 = 19500\ \text{UAH}$$

Thus, the total amount is 31200 UAH. In addition, social contributions should be determined:

- unemployment insurance fund - 2.1%;
- pension fund - 32%;
- social insurance fund - 2.9%;
- social insurance against accidents and occupational diseases - 1%.

In sum, these deductions are 38%. Therefore, the amount of contributions to social events will be:

$$Вс.з. = ФОП \cdot 0{,}375,$$

$$Вс.з. = 31200 \cdot 0{,}38 = 11856 \text{ UAH},$$

where ФОП – payroll, UAH.

The calculations of labor costs are summarized in the following Table. 4.2.

Table 4.2

Consolidated cost estimates for wages and salaries

№	Employee category	Basic salary, UAH			Additional salary, UAH.	Payroll, UAH.	Total labor costs, UAH. 6=3+4+5
		Wage rate, UAH	Num. of worked hours, h.	The actual salary accrued, UAH.			
1	2	3	4	5	6	7	8
А	Б	1	2	3	4	5	6
1.	Manager	180	50	9000	2700	4446	16146
2.	Engineer	100	150	15000	4500	7410	26910
Total				24000	7200	11856	43056

4.3 Calculation of electricity costs

Electricity costs of 1 equipment are determined by the formula:

$$З_в = W \cdot T \cdot S \,, \qquad (4.4)$$

where W – required power, kW;

T – number of hours of equipment operation;

S – cost per kilowatt-hour of electricity.

According to the NERC of Ukraine Resolution No. 538 from April 24, 2017, the cost of electricity is 2,24473 UAH/ kW.

Computer power is 500 Watt with a router connected, the number of operating hours of the equipment according to Table 4.1 is 200 hours.

$$З_в = 0{,}5x200x2{,}24473 = 224{,}473\ UAH.$$

4.4. Calculation of material cost

The results of the calculation of material costs are summarized in Table 4.3.

Table 4.3

Determination of the cost of materials

Material	Unit	Cost rate	Price, UAH	Cost, UAH	Transport and procurem ent cost	Total material cost, грн
Paper A4	pack	2	100	200	-	200
Paper A1	thing	8	20	160	-	160
Refilling the cartridge to the printer	thing	1	100	100	-	100
Internet cost	thing	1	200	200	-	200
Total						660

4.5. Calculation of depreciation

A characteristic feature of the use of fixed assets in the production process is their restoration. In order to restore labor in kind, it is necessary to reimburse them in the cost form, which is carried out by depreciation.

Depreciation is the process of transferring the value of fixed assets to the value of newly created products for the purpose of their complete restoration.

Computers and office equipment belong to the fourth group of fixed assets. For this group, the annual depreciation rate is 60% (quarterly - 15%).

To determine depreciation, we use the formula:

$$A = \frac{Б_В \cdot Н_А}{100}, \qquad (4.5)$$

where A – depreciation for the reporting period, UAH.

$Б_В$ – the carrying amount of the computer at the beginning of the reporting period, UAH.

$Н_А$ – depreciation rate, %.

$$A = \frac{30000 \times 15}{100} = 4500 \text{ UAH}$$

4.6. Calculation of overhead costs

Overhead costs are associated with the maintenance of production, maintenance of the management apparatus of the enterprise (firm) and the creation of necessary working conditions.

Overhead costs can amount up to 20% of the basic and additional wages of employees:

$$Н_В = В_{О.П} \text{x. } 0.2 \,, \qquad (4.6)$$

$$Н_в = 31200 \text{x} 0{,}2 = 6240 \text{ UAH.}$$

4.7. Drawing up cost estimates and determining the cost of R&D

The results of the above calculations are summarized in Table. 4.3. The cost ($C_в$) of GDR is calculated by the formula:

$$С_в=В_{о.п.}+В_{с.з.}+З_{м.в.}+З_е+Т_в+А+Н_в\,, \qquad (4.7)$$

$С_в$=31200+11856+225+660+4500+6240=54681 UAH

Table 4.4

Cost of R&D

Cost	Sum, грн.	% of total
1	2	3
Wages and salaries (basic and additional wages)	31200	57,06
Deductions for social events	11856	21,68
Material cost	660	1,21
Electricity cost	225	0,41
Depreciation	4500	8,23
Overhead	6240	11,41
Total cost	54681	100

4.8. Calculation of the price of R&D

The price of R&D can be determined by the formula:

$$Ц = \frac{С_В \cdot (1 + Р_{рен}) + К \cdot В_{н.і.}}{К} \qquad (4.8)$$

$Р_{рен.}$ – profitability rate, 30 %;

$К$ – number of orders;

$В_{і.н.}$ – the cost of information driver, грн.

Thus the price is 71100 UAH.

Determine the amount of profit:

$$П = Ц - С_в , \quad (4.9)$$

According to this formula we get 16419 UAH.

4.9. Determination of economic efficiency and payback period of capital investments

Production efficiency is a generalized and complete reflection of the end results of the use of labor, means and objects of work in the enterprise for a certain period of time.

Cost-effectiveness (ER) is the ratio of production output to resources consumed:

$$E_P = П / С_в , \quad (4.10)$$

where $П$ – profit;

C_B – cost.

$$E_P = 16419/54681 = 0{,}3.$$

Along with economic efficiency, the payback period of capital investments is calculated (T_p):

$$T_P = \frac{1}{E_P}, \quad (4.11)$$

$$T_P = 1 / 0{,}3 = 3{,}33 \; year.$$

The feasibility of developing a program can be said taking into account the following criteria shown in Table 4.5.

Table 4.5

Technical and economic indicators of R&D

№	Indicator	Value
1	Cost, UAH	54681
2	Planed profit, UAH	16419
3	Price, UAH	71100
4	Economic efficiency	0.3
5	Payback period, year	3.33

As a result of the calculations, we can conclude that on each invested hryvna the project earns 0,3 hryvna and therefore payback period will be around three years and 4 months. It should be noted that these calculations are nominal in nature and their main purpose is to estimate the approximate cost of researching and creating this product. The nominal nature of the calculations is due to the fact that this software product is for research purposes.

CHAPTER 5
OCCUPATIONAL SAFETY AND HEALTH IN EMERGENCY SITUATIONS

5.1. Occupational health

The research deals with the mathematical and software of computerized vehicle control systems. Research is required to work with computers of various types, so when working with this technique, it is necessary to observe the rules of occupational safety, fire safety and fire safety.

According to the law of Ukraine [34], normative-legal acts on labor protection are obligatory for performance in production workshops, laboratories, workshops, on the sites and in other places of labor and vocational training, arranged in any educational establishments.

All devices in computer systems require power from the mains, with electromagnetic fields generated by these devices particularly affecting the human body directly working with the radiation source. Under the influence of radiation on humans, acute and chronic forms of impaired physiological functions of the body are possible. Such disorders occur as a result of the action of the electrical component of radiation on the nervous system, as well as on the structure of the cerebral and spinal cord, cardiovascular system.

The premises where the installation and further work with the computerized devices used for the survey are to be carried out must comply with the design documentation of the home, agreed with the competent government authorities. In addition, sanitary lighting standards, requirements for microclimate parameters (temperature, relative humidity), the degree and strength of vibration, sound noise and fire resistance of the room must be taken into account. Specific indicators of these sanitary norms are in the State sanitary rules and norms of work with the visual display terminals of computers [35].

Adequate premises must be provided with central or individual heating, air-conditioning or ventilation systems. When installing these systems, it must be ensured that the heating batteries, water pipes, ventilation cables, etc., are securely hidden under protective shields that will prevent the potential worker from getting energized.

During the study, it is necessary to observe the proper mode of work and rest. Otherwise, the workforce significantly increases the strain of the visual apparatus, there are complaints of dissatisfaction with work, headaches, irritability, sleep disorders, fatigue and pain in the eyes, waist, neck and arms.

Workplaces should be positioned in such a way as to avoid direct light. It is advisable to position the light sources on both sides of the screen parallel to the direction of view. To avoid light reflections of the screen, the keyboard in the direction of the eyes of the user, from the lamps of general lighting or sunlight, it is necessary to use anti-slip mesh, special filters for screens, protective visors, on the windows - blinds.

The display screen should be perpendicular to the view direction. If it is angled, it causes hubris. The distance from the display to the eyes should slightly exceed the usual distance between the book and the eyes. There must be a special protective screen in front of the monitor screen, especially the older types. In his absence, you should sit at arm's length from the monitor.

Filters made of metal or nylon mesh are not recommended because the mesh distorts the image due to light interference. Glass polarization filters provide the best image quality. They eliminate virtually all glare, make images crisp and contrasting.

When dealing with textual information (in data entry and editing mode, reading from the current system status screen, programming logic, and directly writing code with further customization and testing), the most physiologically correct image is black characters on a light (white) background.

The monitor should be positioned in the workplace so that the screen surface is centered at a distance of 400-700 mm from the user's eyes.

Depending on the light source, production lighting may be: natural, generated by direct sunlight and scattered sky; artificial light sources and combined, in which natural light is insufficiently supplemented by artificial light. Natural lighting is divided into: lateral (one - or two-sided), which is carried out through light openings (windows) in the outer walls; upper - through lights and openings in roofs and ceilings; combined - combination of upper and side lighting. Artificial lighting can be common and combined.

In addition to the above, an important component of occupational safety is the fire safety of the premises. The main directions of fire safety are elimination of conditions of fire occurrence and minimization of its consequences. Facilities must have fire safety systems in place to prevent fire, human effects, and the material values of hazardous fire factors, including their secondary effects. Such factors, according to [36], include:

- flames and sparks;
- high ambient temperature;
- toxic products of combustion and thermal decomposition of materials and substances of smoke;
- reduced oxygen concentration;

According to [36], the fire safety of the facility must be ensured by a fire prevention system, a fire protection system and a system of organizational and technical measures.

The main baseline data in the development of a set of technical and organizational solutions to ensure the required level of fire safety in each case is the current legislative and regulatory framework on fire safety, properties of materials and substances used in the production cycle, materials, substances and features of production.

According to the Regulations on the procedure for development, approval, revision, cancellation and registration of fire safety regulations, the State Register of Fire Safety Regulations (NAAP) was created, which includes about 360 titles of documents, which are divided into 8 groups of different levels and types: national, inter-sectoral, sectoral normative acts, normative acts of ministries, other central executive bodies, interstate standards on fire safety, state standards of Ukraine (DSTU) on fire security industry standards for fire safety regulations in the construction industry for fire safety.

In addition to the documents listed in the aforementioned register, there are a number of special-purpose regulations, separate sections of which regulate fire safety requirements, such as [37], which defines the requirements for electrical equipment. Based on these data, the criteria for the hazard of the object, the category of premises and buildings by explosive and fire hazard, as well as the classes of explosive and fire-hazardous zones are determined.

During the work, an analysis of the existing legislative acts and norms on the arrangement of work premises was carried out. A description of the parameters, features of the placement of light sources and fire safety measures in the premises, where the research and development of a computer system for controlling the behavior of the vehicle is carried out.

5.2. The use of civil defense units in the aftermath of earthquakes

Today's conditions are characterized by a significant increase in the likelihood of major industrial accidents, disasters and natural disasters. Earthquakes, hurricanes and accidents at radiation and chemically hazardous objects are especially dangerous. Therefore, according to the Law "On Civil Defense of Ukraine" [38], such facilities form specialized units of civil defense.

In order to eliminate the consequences caused by major accidents, catastrophes and natural disasters, the head of civil protection of the region (city, district) has the right to involve all civil protection units, regardless of departmental affiliation. First of all, specialized civil defense units are involved and, if necessary, non-military civil defense units, civilian defense forces and the Armed Forces deployed in these areas are used.

According to the Resolution of the Government of Ukraine, the involvement of civil protection workers, employees, collective farmers enlisted in the NF is allowed for up to one month to combat emergencies.

NF personnel civilian protection for the period of involvement to deal with natural disasters, major accidents and catastrophes are provided with free food, shelters, clothing and transportation.

Costs related to work, food, housing, as well as other types of logistical support required to perform RINR in the lesion are offset by the financial and material resources of the state, ministries, enterprises, institutions where the accident or accident occurred.

Technique, transport, devices, means of protection and other property of formation are provided through the objects of national economy on the basis of which they are formed.

In order to prepare the HQs in advance, jointly with the formation commanders, they develop plans to bring them in readiness for R&D.

The points of collecting and bringing the units to readiness are arranged at their sites.

For the RINR, 2-3 echelons of civil defense forces are formed. The first echelon involves the formation of distressed objects, the second (third) involves the formation of adjacent objects (areas) [38].

Deploying forces to the cell of damage is carried out at the highest possible speeds of vehicles with strict observance of rules and safety measures.

The main task of the formations in the elimination of the consequences of natural disasters, major accidents and catastrophes is the rescue of people and material values. Unfortunately, the analysis of the elimination of the consequences of natural disasters, major accidents and catastrophes, which took place in recent years in Ukraine, revealed a large number of shortcomings in the actions of formations in extreme situations. The main disadvantages are:

- organizational misunderstandings;
- insufficient technical support of the formations;
- inability of individual specialists to effectively use modern mechanisms;
- weak initiative of the management of the formation;
- inability of the management of the formations to organize a clear interaction both inside the formation and outside with the neighbors;
- low efficiency of management and others [38].

There was a need to review some legislation in the field of disaster management, catastrophes, major accidents. To this end, Permanent Emergency Commissions (SCCs) have been set up in the state (oblasts, districts). The State Commission on Emergency Situations should coordinate and control the work of regional, city, rayon authorities on prevention, prevention and elimination of consequences of natural disasters, catastrophes, major accidents. Regional (district) PKNS have great rights and specific tasks for the prevention, prevention and elimination of consequences of emergencies.

It should be kept in mind that the process of improving the structure of civil protection continues. For example, last year a Ministry was formed, and in some areas - the Emergency Management.

In addition, in most chemically and radiation-hazardous facilities it is considered appropriate to introduce appropriate adjustments to the structure and preparation of civil defense units.

The nature and order of action of formations when performing tasks in extreme conditions depends on a natural disaster, accident or catastrophe, the situation, the number and preparedness of the forces involved civil protection, the time of year and day, weather conditions and other factors.

All formations of civil defense, military units must be constantly maintained at the required level of readiness for action in various extreme conditions. Notification of personnel of formations, their completeness, formation of grouping of forces should be carried out in short terms.

Willingness and success in performing tasks above where organization, discipline, order is better. Of particular importance and importance in the execution of RINR in the lesion focus are: consciousness of the personnel, moral and psychological stability, strong physical hardening.

The success of the actions of the formation of civil protection in extreme conditions is greatly influenced by timely organization and active conduct of reconnaissance of the work site and the nomination route. Intelligence tasks are usually set by the head of civil protection of the object (district, city). It specifies the purpose of the intelligence, what information and by what time to obtain, where and on what tasks to focus the main effort, which to use forces and means. If there are SDORs in the area of the next actions, then specialists in chemistry and physicians are necessarily involved in the exploration units.

Intelligence is transferred to civil defense headquarters, where they are summarized and analyzed to take effective measures to combat natural disasters or eliminate the effects of an accident or disaster.

In areas of natural disaster, intelligence determines: the boundaries of the disaster cell and the direction of its dissemination, objects and settlements that are at risk, places of concentration of people, ways of approaching equipment to work places, the condition of damaged buildings and structures, the presence of the affected people; locations of accidents at the Kem; RINR volume, possibility of carrying out work without PPE and others.

In areas of natural disaster and at sites of industrial accidents or catastrophes, measures are first and foremost aimed at saving people, preventing catastrophic consequences of disasters (accidents), preventing the occurrence of possible secondary factors that can cause death of people and destruction of property.

In the lesion focus is organized and maintained continuous interaction between the formations. The works are carried out continuously until complete completion. If necessary, the decision of the chiefs of civil defense is organized change and rest of the personnel of the formations.

5.3. The concept of optimal permissible, harmful and dangerous working conditions.

Working conditions at production are differentiated depending on the actually determined levels of factors of the production environment in comparison with the sanitary norms, rules, hygienic standards, and also taking into account the possible harmful effect on their health of workers.

By order of the Cabinet of Ministers of Ukraine No. 450-r of September 26, 2001 “On New Hygienic Classification of Labor and Indicators for Benefits and Compensation to Employees Employed in Work with Harmful and Difficult Working Conditions” a new hygienic classification of labor was introduced [39].

According to the hygienic classification of labor conditions are divided into four classes:

First class - optimal conditions - are conditions in which not only the health of employees is maintained, but also the preconditions are created to maintain a high level of efficiency. Optimal standards for production factors are set for the microclimate and factors of the work process. For other factors, optimal working conditions are those in which adverse environmental factors do not exceed levels considered safe for the general public.

Second class - acceptable conditions - are characterized by such levels of factors of production and labor process that do not exceed the established hygiene standards, and possible changes in the functional state of the organism are restored during a regulated rest or before the next change and do not adversely affect the health of workers and workers. their offspring in the near and distant periods.

Third class - harmful conditions - are characterized by levels of harmful production factors that exceed the hygiene standards and are capable of adversely affecting the working organism and (or) its offspring. Harmful conditions on the indicators of excess of hygienic standards and the severity of possible changes in the body of workers are divided into four degrees:

1st degree - working conditions are characterized by levels of harmful factors in the production environment and work process, which usually cause functional changes that go beyond the limits of physiological fluctuations (the latter are restored at a longer than the beginning of the next change in contact with the harmful factors) and increase the risk of poor health;

2nd degree - working conditions are characterized by such levels of harmful factors of the production environment and the work process that can cause persistent functional disorders, leading mainly to an increase in production-related morbidity, the emergence of individual signs or mild forms of pathology (usually without loss of professional);

3rd degree - working conditions are characterized by such levels of harmful factors of the production environment and the work process, which lead, in addition to the increase in production-related morbidity, to the development of occupational diseases, as a rule, of mild and moderate severity (with disability during work);

4th degree - working conditions are characterized by such levels of harmful factors of the production environment and work process that can lead to a significant increase in chronic pathology and morbidity levels with temporary disability, as well as to the development of severe forms of occupational diseases with a loss of general ability to work.

Fourth class - dangerous (extreme) conditions - characterized by such levels of harmful factors of the production environment and the work process, the impact of which during a work shift (or parts of it) creates a threat to life, a high risk of severe forms of acute occupational injuries.

Hygienic classification of labor is used for:

- employers of all organizational and legal forms of ownership;
- employees in order to obtain complete information on working conditions at their workplaces;
- institutions that monitor the observance of sanitary rules and regulations, hygiene standards in the workplace, and also conduct an assessment of working conditions in the certification of workplaces;
- institutions providing medical care for employees;
- social and health insurance bodies.

CHAPTER 6
ECOLOGY

6.1. Methodological bases for processing computer-based environmental information

"Environmental information (environmental information) is any information in writing, audiovisual, electronic or other material about:

- the state of the environment or its objects - land, waters, subsoil, atmospheric air, flora and fauna and their levels of pollution;

- biodiversity and its components, including genetically modified organisms and their interaction with environmental objects;

- sources, factors, materials, substances, products, energy, physical factors (noise, vibration, electromagnetic radiation, radiation) that affect or may affect the environment and human health;

- threat of occurrence and causes of environmental emergencies, results of elimination of these phenomena, recommendations on measures aimed at reducing their negative impact on natural objects and human health;

- environmental forecasts, plans and programs, measures, including administrative, state environmental policy, environmental legislation;

- costs associated with the implementation of environmental measures at the expense of environmental funds, other sources of financing, economic analysis carried out in the decision-making process on environmental issues.

- The main sources of such information are environmental monitoring data, inventories of natural resources, registers, automated databases, archives, as well as certificates issued by authorized state bodies, local self-government bodies, public organizations, individuals."

- Article 25 as amended by the Law of Ukraine on Natural Protection of the Environment No. 254-IV of 28.11.2002 [40]

All environmental information is raw data that must be processed to obtain the relevant environmental picture in relevant studies. To this end, certain methods and formulas have been developed and continue to be developed. Computer technologies are used to speed up information processing, as well as to increase the accuracy and sampling of data, reduce errors and the number of errors. Namely, they are writing computer programs that already incorporate methods and formulas for processing information.

Each program includes three main stages of information processing, namely:

- entering information into the program;
- direct information processing;
- output of the received processed information.

It’s possible to enter information mechanically by computer operator, automatically as well as mixed input. Mechanical data entry provides a graphical user interface with data entry fields. Automatic data entry involves connecting a database where metrics are stored. Data comes from electronic digital or analog sensors, other programs, simulations, or random number generators or prescribed algorithms, as well as other statistics that have already been pre-loaded into the database.

Maximum efficiency is achieved with the combined data input method. When the program is setting up, the database is changed with the information changed, and the coefficients and constants are entered manually for the corresponding study.

Direct information processing involves the logic behind which a computer program should handle data. It can be both a simple formula into which the corresponding data is substituted into the corresponding variables, and a complicated algorithm. This algorithm may include recognizing the various cases for which the appropriate method is to be used, not only the calculation of indicators, but also the prediction and prediction of certain events and cases.

The algorithms and logic of the program can be prescribed by the programmer according to methodological and statistical data, and can also be written program based on machine learning, which will recognize, classify and process data and based on them to make certain conclusions and forecasts that were not specified by the operator on before.

Often a computer program provides recursion or feedback to check the accuracy of calculations, filter errors and correct coefficients.

Information is output to the same database or graphical user interface. According to the stated task, the output can be both the numbers of environmental indicators that will be further processed and the immediate conclusions or forecasts.

Appropriate programs can be written in Microsoft Office Excel with or without macros, and can be written as a specific program specification in the form of software for a personal computer, a website, or specialized computer systems.

6.2. Reduced energy consumption and energy savings

Resource and energy conservation are one of the tasks of this scientific work. The idea is to increase passenger traffic while using fewer vehicle units and no need to build special infrastructure.

To calculate energy consumption, it is appropriate to compare the average new bus and the new tram. A situation is taken when the city needs to upgrade and improve its transport model and technical base of public transport. The question of whether to set up tram tracks, or to buy new buses. This is where an alternative should appear in the form of a vehicle that has a passenger capacity as a tram and is capable of using bus infrastructure, that is, ordinary urban roads and public transport stops.

For comparison, the popular MAN Lion`s City 18 city bus and Siemens ULF-B tram are selected [41, 42].

Table 1

MAN Lion`s City and Siemens ULF-B comparison

Parameter	MAN Lion`s City 18 [41]	Siemens ULF-B [42]
Length, m	18	35,5
Number of seats	49	66
Total capacity	152	207
Power, kW	265	8x52

In this case, energy consumption is the loss of capacity to carry one passenger:

$$E = \frac{P}{n}, \quad (6.1)$$

Where E is power consumption, P is power and n is number of passengers.

$$E_a = \frac{265}{152} = 1{,}74,$$
$$E_t = \frac{8 \cdot 52}{207} = 2.$$

The energy consumption was calculated for the case when both the bus and the tram boarded the maximum number of passengers and the vehicle used the maximum capacity. Under real conditions, maximum fill is not desirable, and transport uses only some of the capacity. It is also necessary to consider that there is a passenger flow. And in each city at different times it is different. For a more real value of energy, it is necessary to calculate energy intensity for rush hour, for a particular city. For each city it is necessary to count it separately, but for example it is enough to simulate an approximate city. Suppose 200,000 people live in city A, routes are routed so that at an average of 1,000 people per hour, one route is used.

It is also worth considering that the bus consumes the most energy during acceleration and within the city it often happens, because of the large number of traffic lights, intersections, stops and traffic flow that does not allow to move at a steady speed. Therefore, the power factor of 0.7 should be considered. The tram also uses the most power during acceleration, but because there are several traction motors and they are located along the entire tram, the acceleration costs are reduced. For a tram, the power factor will be 0.55. Usually no one wants to go in crowded traffic, so at peak times the load factor should be 0.9.

The energy intensity formula will look like:

$$E = \frac{K}{N \cdot k_n} \cdot P \cdot k_p \tag{6.2}$$

For a bus, the capacity of transporting 1000 passengers will be:

$$E_a = \frac{1000}{152 \cdot 0{,}9} \cdot 265 \cdot 0{,}7 \approx 1355$$

For a tram:

$$E_t = \frac{1000}{207 \times 0{,}9} \times (8 \times 52) \times 0{,}55 \approx 1228$$

For this simulation, the tram energy consumption will be slightly better than that of the bus.

From what we can conclude that the tram is considered an environmentally friendly transport not from the point of energy intensity and not energy conservation.

In this scientific work, a system is developed that will make the bus as long as a tram, which will accommodate a larger number of passengers, but will not require the construction of infrastructure, namely tracks, contact wires, additional light, etc. Reducing energy consumption can be achieved by using more efficient engines and better interior layout.

CONCLUSIONS

In this thesis was research the mathematics and software of vehicle computer control system:

1. Modern computer systems involved in vehicle control have been analyzed. Various driver assistance systems have been considered to improve safety and facilitate the routine process. Automation and levels of automation of driving from zero to full were considered. Autonomous vehicle is found to be the car with the highest level of driving automation. Various computerized vehicle steering systems have also been analyzed. An example of the implementation of multi-unit system, with automatic control of the rotation angle of the wheels of all vehicle axles in the form of a trackless tram was presented.
2. This thesis discusses how to obtain location information and how to process it. Neural networks, perceptron and their application in the task were also considered. The behavior of the vehicle under different rotary axle configurations was investigated.
3. Natural language processing hardware using neural networks has been analyzed. Efficiency of use of tensor processors in comparison with traditional server CPUs and GPU was investigated. Also, the structure of the tensor processor which is intended for the training tasks of neural networks, was considered.
4. In this thesis explores and describes the algorithm for operating a vehicle control program. The logic and construction of the corresponding neural network were described. A training model for network training has been developed. Successful training and network performance was checked.
5. The costs of the study were also estimated and justified. The normative acts for the working month are considered. And the environmental aspects of the work were analyzed.
6. Further development of the project will be the implementation of a layout managed by Raspberry Pi. Neural network training based on real data, with changes to the training algorithm. Ideally seeking investors and implementing a full-scale model.

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Supplement A

International Conference Abstracts on “Information Models, Systems and Technologies”

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
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МАТЕМАТИЧНЕ ТА ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ КОМП'ЮТЕРНИХ СИСТЕМ КЕРУВАННЯ ТРАНСПОРТНИМ ЗАСОБОМ

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MATHEMATICS AND SOFTWARE OF VEHICLE STEERING COMPUTER SYSTEM

Громадський транспорт є одним із найкращих шляхів зменшення трафіку на вулицях міста і, відповідно, зменшення шуму, шкідливих викидів в атмосферу та аварійності на дорогах. Основна проблема громадського транспорту полягає у забезпеченні його достатньої пасажиро місткості, частоти курсування і пунктуальності. Одним із найефективніших видів громадського транспорту є трамвай, але і він не позбавлений недоліків, найбільшим з яких є необхідність прокладання рельсів та їх подальше обслуговування.

У якості способу вирішення цієї проблеми може бути запропонована система, що дозволяє керувати поворотом усіх коліс транспортного засобу, і в результаті змусити довгий, багатосекційний автобус поводитися як трамвай на звичайному твердому покритті, такому як асфальт. Метою цієї дипломної роботи є опис необхідного математичного забезпечення цієї системи та розробка програмного забезпечення її керування.

Існуючі варіанти систем керування транспортним засобом передбачають рух по нарисованій на поверхні руху направляючій лінії. [1] Ціллю дослідження є спроба реалізувати рух транспортного засобу по віртуальній лінії, яку рисує водій кермуючи першою віссю.

Для реалізації поставленого завдання необхідно отримувати і обробляти дані спрямовані на визначення поточного місцезнаходження кожної секції відносно від інших секцій транспортного засобу. Маючі дані про геометричні параметри кожної секції та кути, під якими кожна секція знаходиться відносно сусідніх, можна вирахувати відносні координати кожної осі. Коли транспортний засіб розпочинає рух, тоді, враховуючи швидкість і напрям руху, буде вираховуватися нова координата першої осі. Завдання кожної наступної осі потрапити в координату попередньої осі. Враховуючи, що рух відбувається із змінною швидкістю варто виміряти нові координати через сталі відрізки часу. Швидкість руху транспорту в межах міста не перевищує 50 км/год, що відповідає приблизно 14 м/с. [2] Для більш-менш точної траєкторії потрібно, щоб відстань між координатами була не більшою, аніж пів метра, що приблизно відповідатиме радіусу колеса. Для такої точності необхідно робити 28 замірів в секунду. Для комфортної роботи варто обрати частоту оновлення 50 Герц.

Ключовою задачею, яку необхідно розв'язати є вибір та обґрунтування математичного забезпечення, яке описує кут повороту коліс й визначає кут зміни руху відносно поточного вектору руху секції. Одним із засобів, який може бути використаний для розв'язання цієї задачі є штучна нейронна мережа, яка буде мати на вході данні із датчиків повороту на кожній осі секції та такого ж датчику в місцях з'єднання секцій, а також дані про швидкість руху транспорту. На виході буде інформація про необхідний кут повороту коліс на кожній осі. При цьому кількість вхідних і вихідних нейронів має бути масштабована відносно кількості осей транспортного засобу.

Навчання штучної нейронної мережі буде проводитися на основі даних, отриманих транспортним засобом, що спроектований для руху по лінії.

Література

[1] A. Thompson, «China Built a Self-Driving... Something,» Popular Machanic, 2017.

[2] *Закон України про Правила Дорожнього Руху,* Київ, 2019.

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МАТЕМАТИЧНЕ ТА ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ КОМП'ЮТЕРНИХ СИСТЕМ КЕРУВАННЯ ТРАНСПОРТНИМ ЗАСОБОМ

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MATHEMATICS AND SOFTWARE OF VEHICLE STEERING COMPUTER SYSTEM

Public transportation is one of the best ways to reduce traffic on the city streets and therefore noise, harmful emissions and car accidents. The problem with public transport is to ensure that the passenger capacity, regularity and punctuality of public transport are adequate. One of the most efficient kind of public transportation is a tram, but it also has disadvantages, the biggest of which is the need for laying rails and their further maintenance.

As a solution to this problem, a system can be suggested to control the rotation of all wheels of the vehicle and, as a result, make the long, multi-section bus behave like a tram on a conventional hard surface such as asphalt. The purpose of this thesis is to describe the necessary mathematical software, and to develop software to manage such a system.

Existing options of vehicle control systems include motion along a guide line drawn on the surface of the movement line. [1] The purpose of the study is to try to realize the movement of the vehicle along the virtual line drawn by the driver steering the first axle.

In order to accomplish this task, it is necessary to obtain and process data aimed to determine the current relative location of each section from other sections of the vehicle. Knowing the geometric parameters of each section, and the angles at which each section is relative to adjacent, it is possible to calculate the relative coordinates of each axis. When the vehicle starts to move, then taking into the consideration the speed and direction of movement the new first axis coordinate will be calculated. The task of each subsequent axis is to get in the coordinate of the previous axis. Considering that the movement occurs at a variable speed, it is necessary to measure the new coordinates after constant intervals of time. The speed of traffic within the city does not exceed 50 km/h, which is approximately equal to 14 m/s. [2] For a more or less accurate trajectory, it is necessary to have a distance no more than half a meter between the coordinates, which approximately corresponds to the radius of the wheel. For this accuracy, it is necessary to make 28 measurements per second. For comfortable operation, select the refresh rate of 50 Hz.

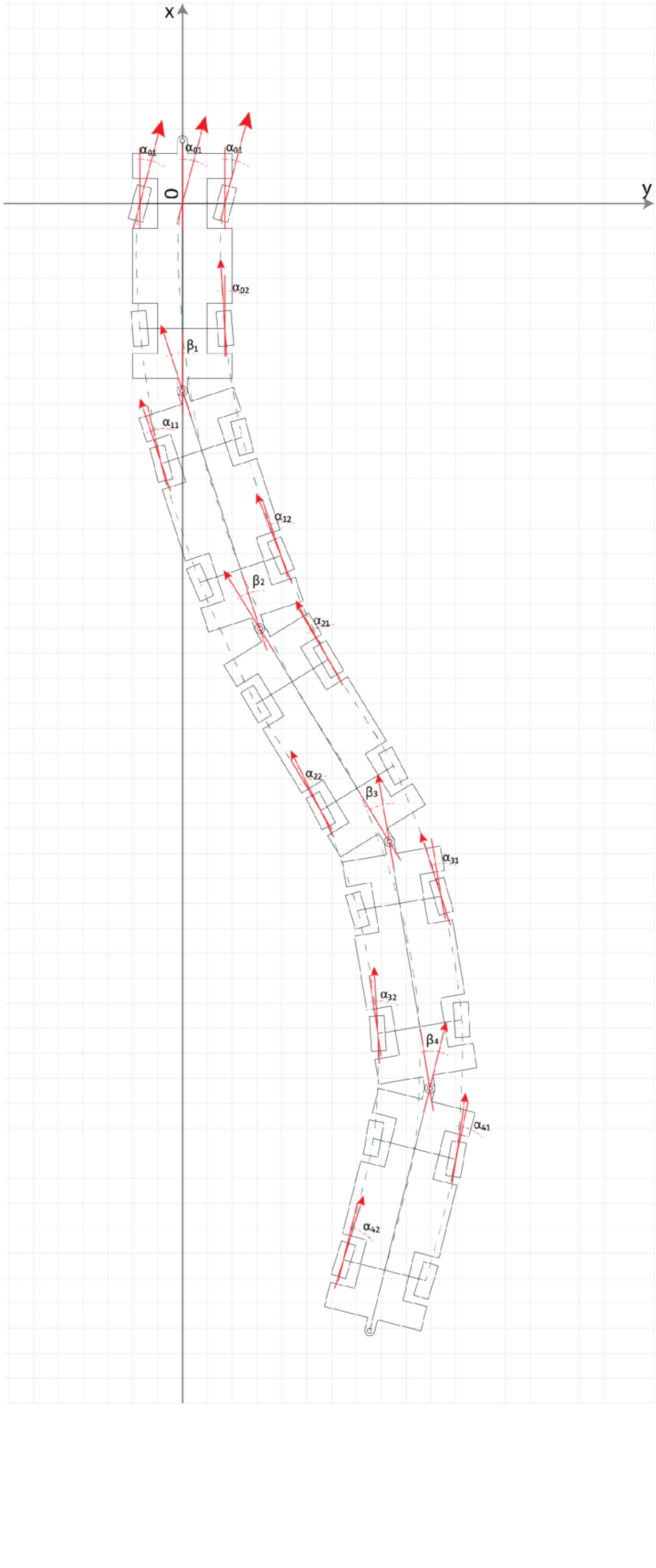
To calculate the angle of rotation of the wheels, a formula can be created that would determine the angle of change of motion relative to the current motion vector of the section. This task can also be delegated to machine learning, which in the future will be better able to respond to random events, as well as possible errors and quickly process and solve them. The artificial neural network will have input from the sensors of rotation on each axis of the section, from the same sensor at the points of connection of sections, as well as data about the speed of traffic. The output will include information about the required angle of rotation of the wheels on each axle. The number of input and output neurons must be scaled relatively to the number of vehicle axes.

Література

1. A. Thompson, «China Built a Self-Driving... Something,» Popular Machanic, 2017.
2. Закон України про Правила Дорожнього Руху, Київ, 2019.

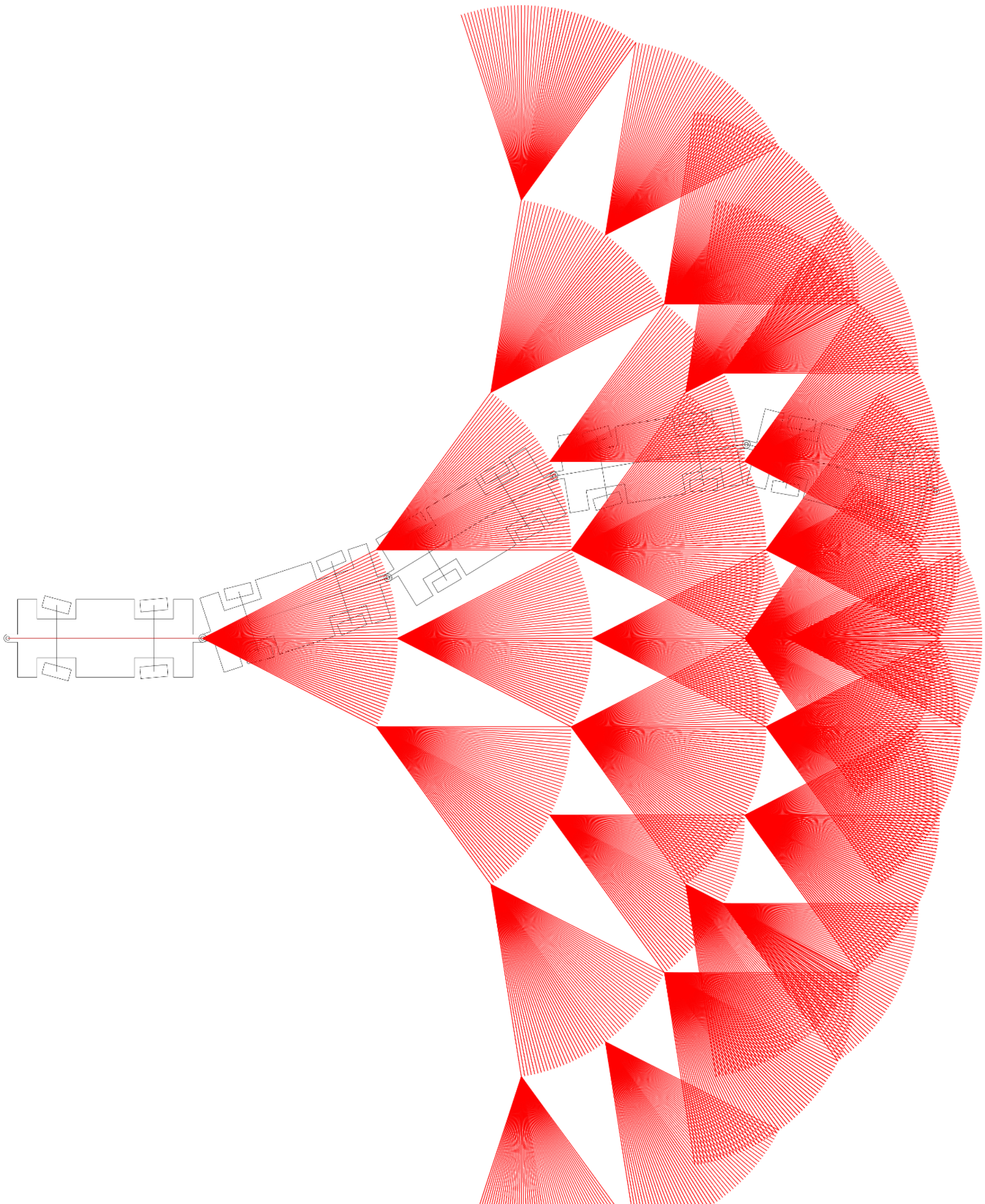
Supplement B

Motion vectors of sections and wheels



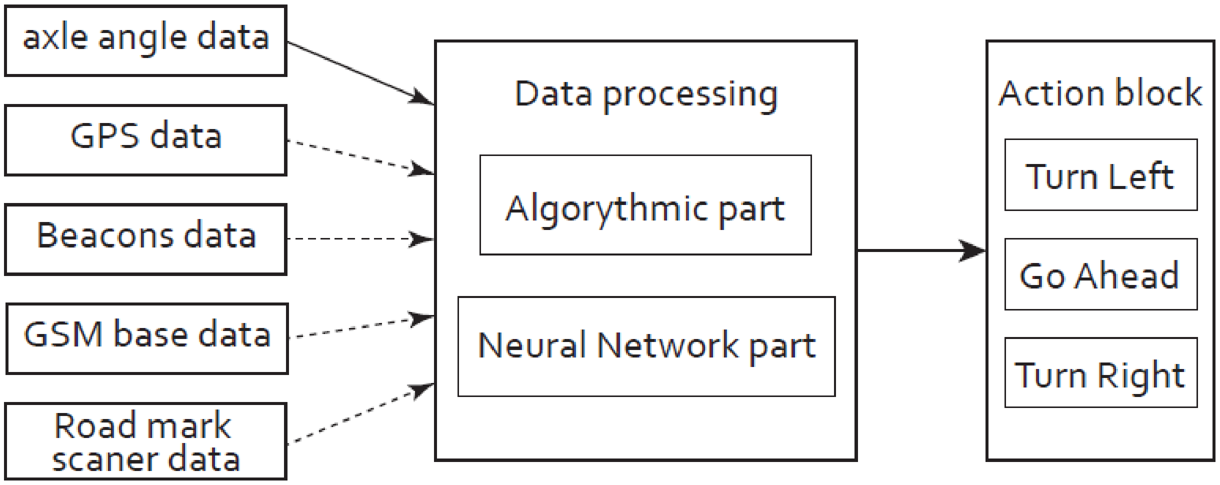
Supplement C

Conditional image of possible trajectories



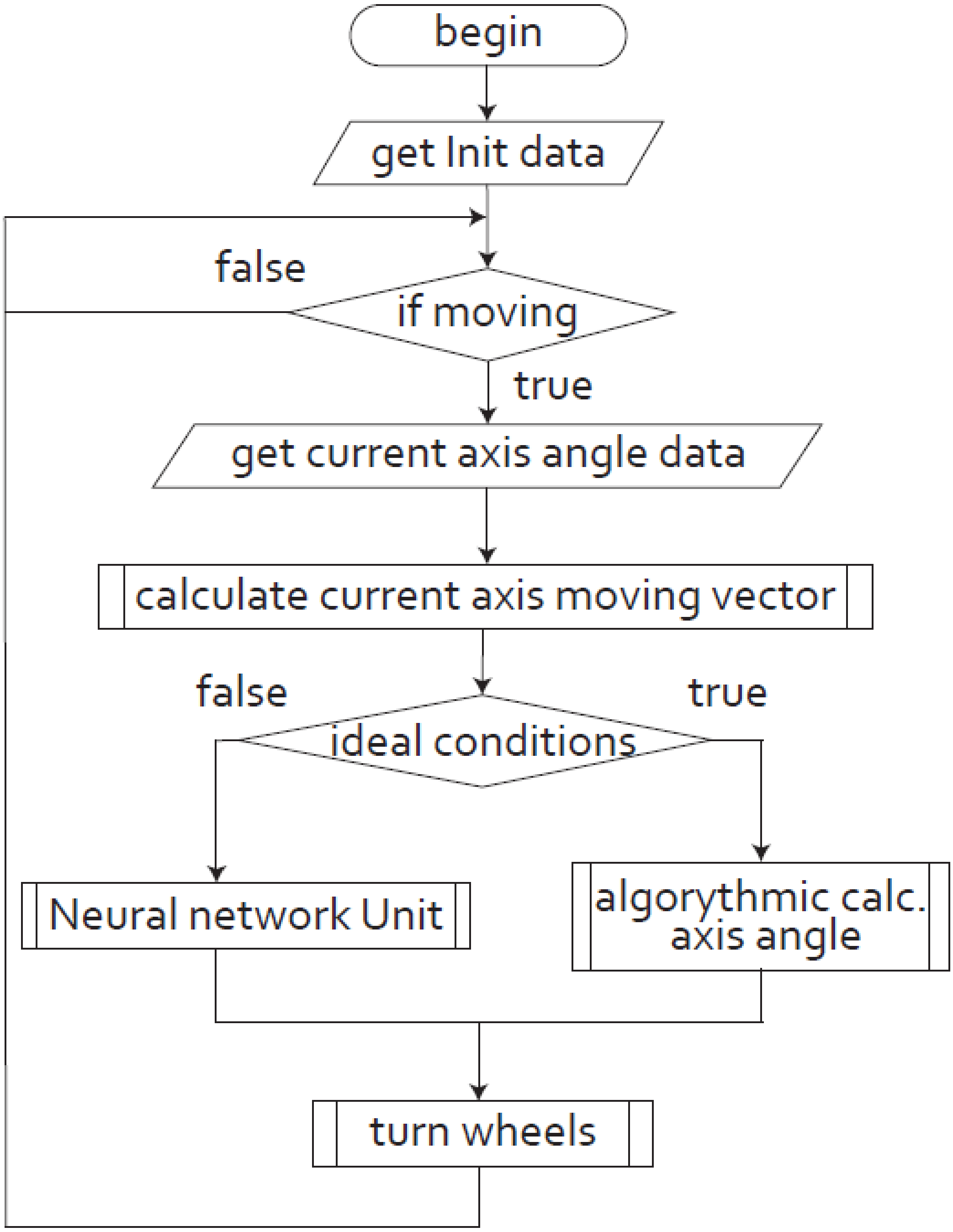
Supplement D

Data Lifecycle



Supplement E

Main Algorithm



Supplement F

Initialization algorithm