SYSTEMS IN THE CAR

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Who would have thought that when one obtains a driver's license and enters the drivers' club, has become a part of a huge system. If you belong to a system, you have to adopt the rules which are prevailing in this company:

- Periodically, even if you do not drive a car, you must go to a medical examination, where doctors decide whether you may stay in this club or you will be transferred to another system.
- You have to pay tax because in the car maintainers' system you have to do this.
- You need to ensure safety, therefore, a contract must be signed with one of the car and/or travel insurance companies.

Even if you did not sit in your car yet, you can see that you became a voluntary or involuntary member of many systems. But let us remember! The reason why you acquired the driver's license was not for becoming a part of these systems. The real system, you worked for is only a closed box of a few cubic meters that separates you from the rest of the world. In this system where if you did not forget to get gas, you may look at the world gliding beside you through a large glass surface, at a velocity you want.

I wonder what this system knows, what makes itself in everyday man's eye so alluring?

The car is a system. This entity is separated with a distinct edge from the rest of the world. However, if we want to describe a car as a system we would be in trouble. We do not really speak about a single system. A car is sum of different systems, as it contains mechanical, electrical, chemical, and other systems. And it contains chemical-electrical and electro-mechanical systems, too. Then, after all what are the parts representing the car you drive?

1. Systems in the car

We do not have to think too much. All these parts represent the car.
In the car, for example, there is

- a mechanical system driven by chemical components (motor) (Figure 1)
http://hu.wikipedia.org/wiki/Otto-motor

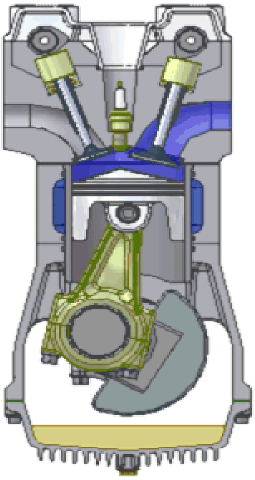
combustion of fuel out ←  ← gas in

Figure 1. Internal combustion engine producing rotary motion

- a system converting kinetic energy into electrical energy (generator-battery (Figure 2.) http://www.vezess.hu/hirek/szazeves_generator/44214/

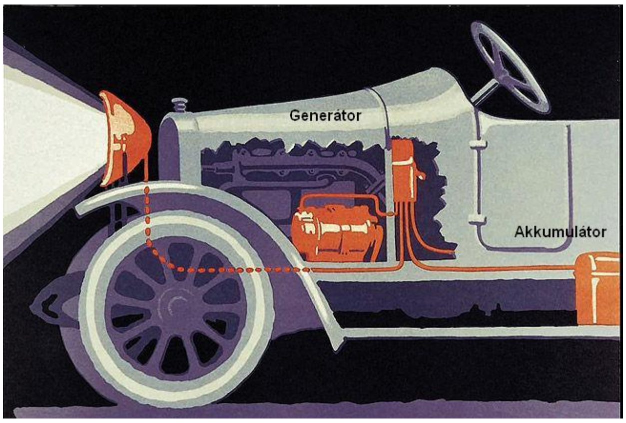


Figure 2. shows the vehicle's electrical energy production system

- a computer-controlled security system (ABS) http://hu.wikipedia.org/wiki/ABS (Figure 3)

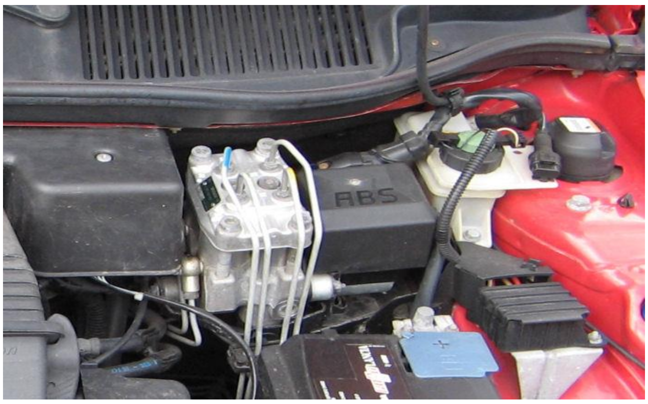


Figure 3. A 4-channel ABS system of a FIAT Punto

- a mechanical or semi-automatic control system (brake assist system) (Figure 4.)
  http://lezo.hu/szerkezettan/futomuvek/fek/tipusok/hidraulikus.html

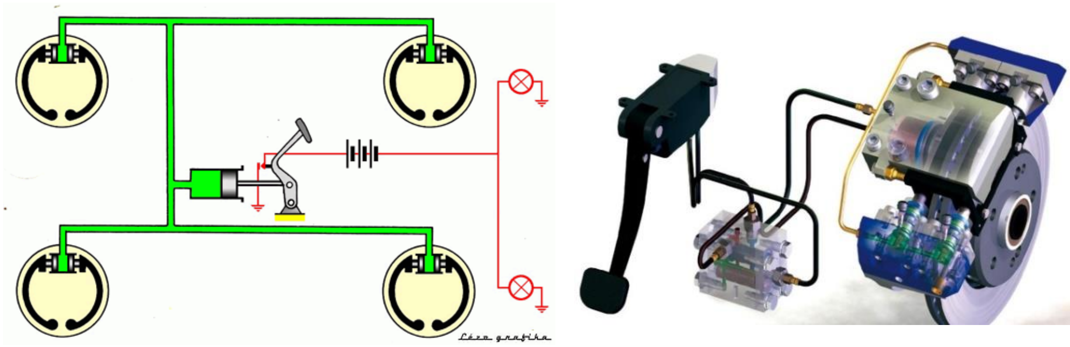


Figure 4. The vehicle brake booster system

In this chapter we deal with the following two sub-systems of the car: cooling of the engine and speed control.

2. Control in the car - temperature control of the engine

The system model of the engine is used to design the control system. It is clear to everyone that if the heat deducting from the working engine is less than the heat which comes out of the engine, the engine gets warmer.

Limitations:

In theory, this will continue until the engine has melted. This case describes an unstable system, because at the end of the process we are not able to restore the original system.

Goals:

Of course, not this is the goal which has a vision of our eye.
We want to specify an operating temperature for our motor and we do not want to have a higher temperature.

In the first example let's take a closer look into the engine's cooling system. The task of this system is to keep the temperature of the motor at its operating point. It is easy to solve this problem in case of simple vehicles, because if the wind produced by the motion is guided to the engine, we solved the cooling problem. For more complex engines this solution does not work because the engine heat production is much greater than what could be controlled by the produced wind. Therefore, a fan is placed to the front side of the motor, and the fan's speed is commensurate with the temperature of the engine. This process has often a similar encounter in the kitchen. We are not able to eat hot soup, so it must be cooled first. We begin to blow it. If the temperature has to be decreased just a little, or only a small amount of soup has to be cooled, e.g. just a spoonful amount, you just have to blow it a little. However, if you want to cool the whole plate quickly, then certainly you have to buckle down to blowing or another method has to be applied; e.g. pouring a little cold water into the hot soup.

A model of the system is used to design control. These processes can be easily modelled. We need to know the status of the signals determining the state of the process, in this case, the temperature of the engine or that of the soup. We have to determine how to control the system (intervention): we will blow. Information has to be obtained about the changes of the status of the system during the control process, that is, we need to know whether still it is needed to blow or not. This process is supervised by its state variables. In this case this is the temperature. However, we need to measure this state variable, for example: using a thermometer or our tongue.

However, the accuracy is also important. While measuring the operating temperature of the engine it is no problem if our measurement is wrong up to 10 degrees, we do not have to expect greater consequences usually. But 10 degrees may no longer be acceptable in case of the soup. When control is implemented, we need to know the measurement results, and we have to compare them to the desired temperature. From this we will know whether it should still be blown and how strongly. Then our only task is to ensure the cooling capacity which is proportional to the difference between the desired and the actual temperature, and direct it toward the process.

The temperature of the motor is influenced by three factors:
• heating capacity resulting from the operation of the engine
• cooling capacity of the environment
• cooling capacity blowing to the engine

The differential equation of the system shows what may cause a temperature change of the engine during a time unit. This may derive from changes of the heat coming out of the engine or from the cooling effect of the surrounding air or from the cooling effect of the amount of air blown to the engine. Equation 1. shows how the operating temperature of the engine changes when a fan is used.

$$\frac{dT}{dt} = \frac{Q_{motor}}{c_{motor} \cdot m_{motor}} - c_{envir}(T - T_{envir}) - c_{air}(T - T_{envir}) \qquad (1)$$

where the meaning of the notations is as follows:

T	temperature of the engine [K°]
t	time [s]
Q_{motor}	heating capacity delivered by the engine [Joule/sec]
c_{motor}	heat transfer coefficient of the engine [Joule/kg K°]
m_{motor}	mass of the engine [kg]
c_{envir}	heat transfer coefficient of the environment [1/sec]
c_{air}	heat transfer coefficient of the air [1/sec]
T_{envir}	temperature of the environment [K°]

Intervention options

Perhaps it is also clear to everyone that in the North Pole the fan needs less energy to achieve the same working temperature as if the same system is cooled at the equator. And we also need less cooling energy provided by the fan if our car is speeding on the roads. Everybody saw cars which had to push out of the line in the middle of a traffic jam because the cooling water has boiled.

Control of the process

If we know the value of the operating temperature from a user's manual, then the input signal of the control system, the reference signal is already available. The temperature measured outside of the engine block can be used as the output signal of the uncontrolled system. The only thing we have to do is to make a controller and to decide whether we want to regulate (open-loop control) or control (closed-loop control) our process. In case of a simpler vehicle the regulator is the convenient choice when the wind is simply fed to the engine, and as we can see in Figure 5., the cooling is solved. The figure also shows clearly that the actual cooling capacity of the surface can be increased by varying the surface of heatsink. Here the problem is that this cooling capacity can't be changed in the future.

Figure 5. Air-cooling in simple engines

In case of more complex engines it does not work because the engine heat production is much greater than what could be regulated by the driving wind. Therefore, a fan is set up on one side of the motor as shown in Figure 6, its speed is proportional to the engine temperature. In this case we also need the value of the output signal of the controlled process, i.e. a feedback loop has to be inserted to the system, because different speeds have to be set on the fan depending on the ambient temperature to achieve the given operating temperature.

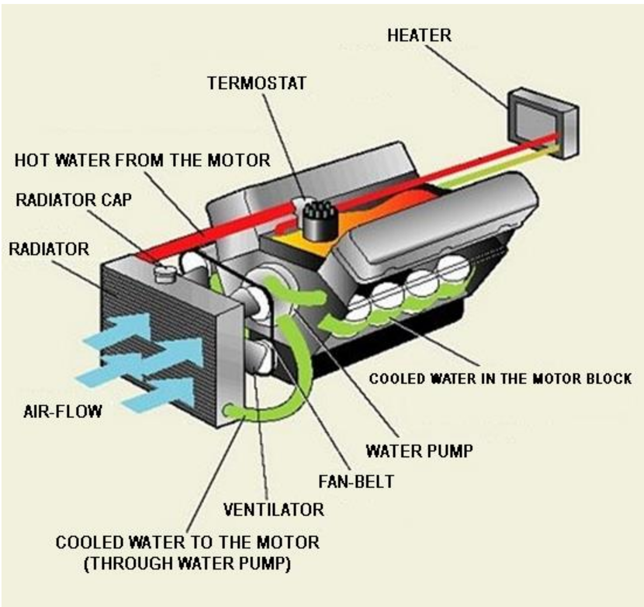


Figure 6. Water cooling system by fan in the engine block

Similar process often happens in the kitchen. We can't eat the hot soup (Figure 7.), so either we wait while it is cooling down or we start to cool it.

Figure 7. The hot soup is inedible

If we have time to wait and in the equation we substitute the temperature of the engine by the temperature of the soup, then we can see that the first part of the equation represents the internal heat source and the second part shows the cooling effect of the surrounding air.

$$\frac{dT}{dt} = \frac{Q_{soup}}{c_{soup} \cdot m_{soup}} - c_{envir}(T - T_{envir}) \qquad (2)$$

However, due to the stressful way of our life often we do not have time. So we start to blow the soup. If the soup is not so hot and we want to reduce its temperature a bit or we have only a small amount of soup, for example a spoonful amount, then we just have to blow it a bit as shown in Figure 8., meanwhile we can measure the temperature by our tongue. If our tongue remained in a good condition the soup can be gulped leisurely.

Figure 8. Air cooling method in case of small amount of soup

However, if we want to cool the whole plate quickly, then certainly we need great effort to blow or we have to interject another method. E.g.: We add materials with very high heat removal effort (a glass of cold water is poured into the hot soup). If we do not want to use an absolutely sure method, e.g. to put an ice rod into the soup, then we do not have to give up blowing, so both cooling methods can be used to achieve our goals, as shown in Figure 9.

Figure 9.: Combined cooling methods in case of larger amount of soup

The rate of cooling, that is the result, like in our former example, is proven by the law of tongue preservation.

To control the temperature of the engine

we have to know the signals determining the status of the process, in this case the temperature of the engine (or of the soup).

• We need to determine the form of the control: we will blow and we do not want to pour cold water on the engine.
• We need information how the status has changed under regulation, that is, we need to know whether we still have to blow or not.
• We need to determine the input and output signals of the control system:
Setpoint: The achievable working temperature
Output: current temperature of the engine, as well as in case of control we need to know the control signal(s) as well (speed of the fan).
• We need to know the temperature-reducing effect of speed, i.e. how the angular velocity depends on the temperature $\omega = \omega$ (T), to prepare a temperature/speed converter. We want to reduce the temperature by blowing high speed air mass to the engine which transfers the heat released from the engine, thereby the engine block is cooled.

After that, it is easy to establish a control system. The process to be controlled is driven by its state variables. In this case this is the temperature.

The setpoint of our system is the working temperature which is read from the users' manual, while the output signal, the current temperature is measured on the engine.

However, we note that the measured temperature of the engine depends on the combined effect of several factors, i.e. their combined impact will provide the current temperature. In short, this means that in many cases the temperature of the engine may be the same. E.g .: The temperature will be the same either if we rotate it at high speed and use high air cooler capacity, or if we rotate it at a lower speed and use a smaller air cooling capacity.

However, our chosen state variable has to be measured. For example, the temperature of the engine is measured by a thermometer (or the soup temperature by our tongue). The accuracy of the measurement is also important. When the working temperature of the engine is measured by a bias up to 10 degrees, this has no significant consequences in the operation. But in case of the soup this range may not be acceptable.

The block diagram of the closed loop control system is shown in Figure 10.

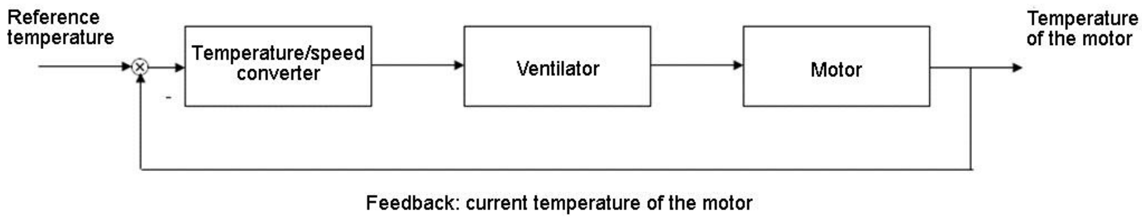


Figure 10. Control of working point temperature of the engine

The result of our measurement has to be compared with the desired temperature, because this shows whether we should still blow or even how strongly we have to blow. Then our only task is to create a cooling capacity which is proportional to the difference of the desired and the actual temperature to control the process. Let's examine the control process in more detail.

First consider the process to be controlled shown in Figure 11. In this case, the input signal is a cooling capacity which is proportional to the speed of the fan, while its output signal is the temperature. In the real world the process also has a second input signal, the injected fuel quantity. Now it is considered as a constant quantity, as well as the cooling derived from air condition. This latter can be done, because - according to the direction of travel – the fan which is located in front of the engine covers completely the engine block, so only the effect of the ambient temperature shows up directly.

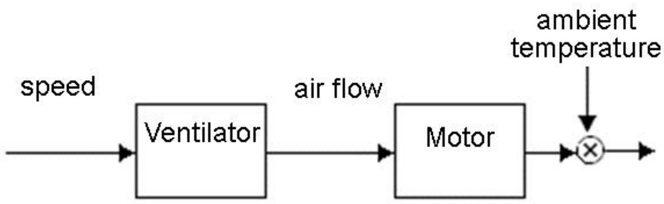


Figure 11. The process to be controlled and the controller

To describe our process a converter is needed which turns the angular velocity into cooling capacity and another one which transforms the cooling capacity into temperature of the motor. Another device – a differentiator – is also required, which can compare the desired and the actual temperature, because otherwise we can’t determine the speed which will provide a proportional cooling capacity to be directed to our process.

In this process the heat of the internal combustion engine warms the engine block slowly while it is externally cooled from outside with a fan, taking into account the ambient temperature. Since the outside surface is cooler than the inside of the engine, the heat flows from inside to the outside surface, but from the fan cool air also flows to this surface. The internal capacity heats the surface of the engine, while the outside air flow cools it. The stronger the cooling is, the greater the difference is between the engine and the ambient air temperature.

This heat transfer process is slow. To examine its behaviour an equivalent electrical circuit can be analysed, whose mathematical equations are analogue to those of the original process. Thus the behaviour of our system can be followed by a faster model. The equivalent electrical circuit shown in Figure 12 models the thermal process.

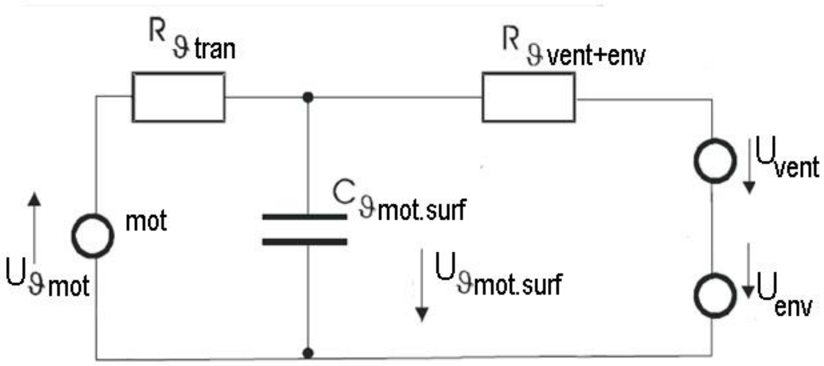


Figure 12. The working point temperature of the engine is controlled by a fan

Here ϑ_{mot} is the inner temperature of the motor, which is substituted in the circuit diagram by the corresponding $U_{\vartheta_{mot}}$. This voltage charges the $C_{\vartheta_{mot.surf}}$ capacitor through the $R_{\vartheta tran}$ resistance. That is, since the engine conducts heat well, approximately this temperature will appear on the surface of the engine. The temperature of the outer surface of the motor is characterized by voltage $U_{\vartheta_{mot.surf}}$, which appears at the capacitor $C_{\vartheta_{mot.surf}}$. In contrast, the air flow of the fan and the ambient temperature discharge the $C_{\vartheta_{mot.surf}}$ capacitor. The outer temperature and the ventilator cool the surface of the motor. $R_{\vartheta vent+env}$ gives the heat transfer from these two components.

The transfer function of the process is specified in (3) where the temperature (ϑ) is replaced by the voltage (U), and the $R_{\vartheta vent+env} / R_{\vartheta tran}$ = 0.026/48 rate expresses the ratio of the air and the steel heat transfer coefficients.

$$U_{mot.surf} = U_{\vartheta mot} \cdot \left(1 - \frac{R_{\vartheta vent+env}}{R_{\vartheta tran} + R_{\vartheta vent+env} + R_{\vartheta tran} \cdot R_{\vartheta vent+env} \cdot C_{\vartheta mot.surf} \cdot s}\right) - \qquad (3)$$

$$(U_{env} + U_{vent}) \cdot \frac{R_{\vartheta tran}}{R_{\vartheta tran} + R_{\vartheta vent+env} + R_{\vartheta tran} \cdot R_{\vartheta vent+env} \cdot C_{\vartheta mot.surf} \cdot s}$$

It can be seen that in case of constant ambient temperature and constant engine capacity the temperature of the engine depends only from air flow generated by the fan. In the following example consider changes of external temperature of the engine. Suppose that the outside temperature is 25 °C, which is now considered as unit airflow, and we will change the amount of air blown by the fan. If the internal temperature of the engine is 400 °C, the first member of the equation (3) shows that how much lower temperature can be measured on the outer surface of the engine block, because of the effect of the engine block itself. Calculation shows that the difference with these values is approx. 0.2 °C. This represents 0.05% error rate, which is probably negligible. If the mass of air blown to the engine block by the fan is 5 units, then the response function shown in Figure 13 will unfold before our eyes. The same process can be seen that in case of blowing tenfold amount of air, greater quantity of heat can be diverted from the engine, that is, the temperature of the engine block is reduced more.

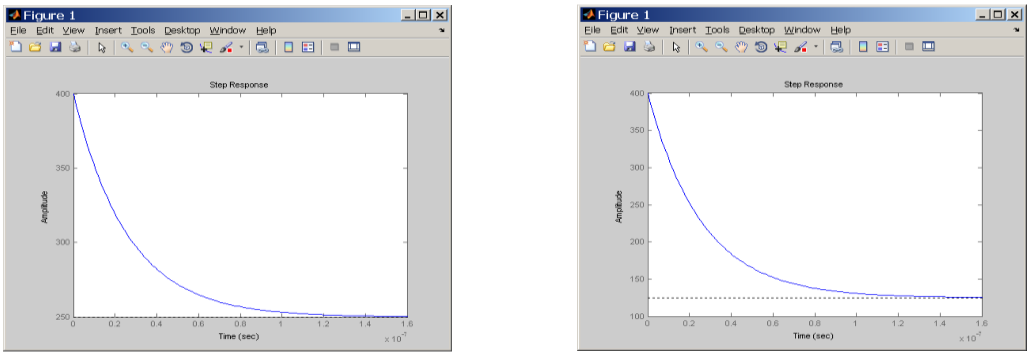


Figure 13. Changes of the external temperature of the engine in case of blowing 5x and 10x more amount of air

But why do we choose an electronic model, when we want to model the thermal process? Many explanations do exist. First, their equations describing the processes are similar. We know, that neither the voltage of a capacitor can change by leaps nor does the temperature of an engine. On the other hand, the electrical processes are performed much more quickly than the thermal ones, that is, if an exact correspondence can be found between equations of the two systems, the slowly thermal process can be simulated by a faster process, so we get results in characteristics of the changes of our process faster, as it is also shown in time axis of Figure 13. Here the process is completed in microseconds, but in reality these processes take several minutes. Think about that, in wintertime after starting the engine how much time do we have to wait to get warm in the car?

3. Speed control

The process

The injected amount of fuel (m = ρ · V) is commensurate with the speed reached. Though the rate of proportionality is not known, but the car's speed can be calculated (4) as an arithmetical product of the wheels radius (r), the speed (ω) and a multiplicative factor of gearbox (v = c · r · ω).

$$\frac{\rho V}{t} = k(\omega - \omega_0) \quad \text{and} \quad v_{car} = c \cdot r \cdot \omega \qquad (4)$$

(4) shows that the change in the engine speed, taking into consideration a proportional factor k, is only determined by the injected amount of fuel, that is, in theory, the more fuel is supplied to the engine, the greater the speed will be. With more fuel – taking into consideration the limiting factors – the speed can be increased, of course not infinitely.

Limitations:

• Lower limit: a minimal amount of fuel is required for engine operation (idling), otherwise the engine shuts down.

• High Limit: The maximum quantity is given, because we can't inject more fuel into the engine than the volume of the cylinders are.

Goals:

• To achieve the required speed of our car.

During the everyday activities, almost every action performed by a driver starts series of control events. Perhaps the most obvious of these events are the acceleration or deceleration. In this case, our goal is to operate our car at another speed. That is we want to reduce or increase the working speed of the vehicle as it is shown in Figure 14.

Figure 14. Speed change

In this case the control model of the system can also be plotted (Figure 15.), where the **internal state of the system**, the current speed of the vehicle is denoted by (v_{act}) and the **input signal** is the new speed (v_{in}) which can be set by pressing the accelerator or the brake. Do not forget, that this becomes zero if we are to stop. Negative rates, however, are very difficult to produce because it has to be done by serious interventions. This would mean that not only the magnitude, the absolute value, but also the direction of the speed have to be changed, as the speed is a vector quantity. Do not try to produce negative speed suddenly. Let it be always a result of a process that is realised either making a 180-degree turn at constant speed or first reduce the absolute value of the speed to zero to stop and then switch into reverse and start back. Contrary to popular belief and action movies if you switch into reverse immediately you have got some problem. With this gesture you don't achieve the desired effect, however, the car repair costs can escape through the roof because the replacement of the gears is quite expensive. First the kinetic energy of the moving ahead vehicle grinds the gears because they moved in the opposite direction. True, that we achieved to stop our car quickly enough, but after the arrest there will not be longer viable gears by which we could start to reverse.

The **output signal** of our system (using vector values) can be given as the actual speed of the vehicle (v_{act}).

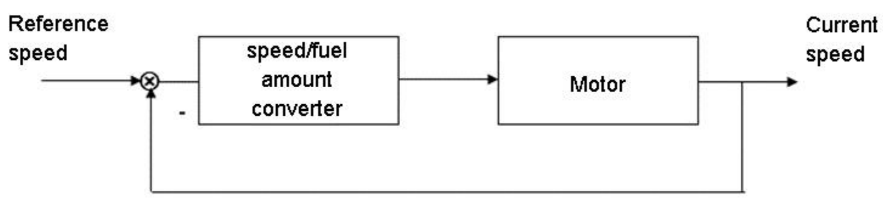


Figure 15. Changing the speed of the car

Perhaps you feel that there are no interfering signals in this system, because if you press the gas pedal, the vehicle accelerates, or if you press the brake, then it will slow down. We probably would not be so confident in our previous statement, when we change an Audi into a Trabant. In this case we don't guess the cabin sounds or smells as interfering signals. Suppose that we want to overtake with these two vehicles a third one travelling at speed of 80 km/h. In case of Audi the actual speed of our vehicle changes from 80 km/h to 100 km/h immediately when we step on the accelerator and the overtaking is just another moment. In case of a Trabant the situation is absolutely different, because the previous results can be achieved just as shown in Figure 16. This is explained by the fact that 80 km/h speed is close to the Trabant's maximum speed. That is sure, in normal case you would increase its speed up to 100 km/h only if the whole family is not in the car or at least you must leave your child's school bag at home. That is, in our case, the response time and/or efficiency of the engine can be interpreted as interference signal response that may inhibit or help us to achieve the requested speed.

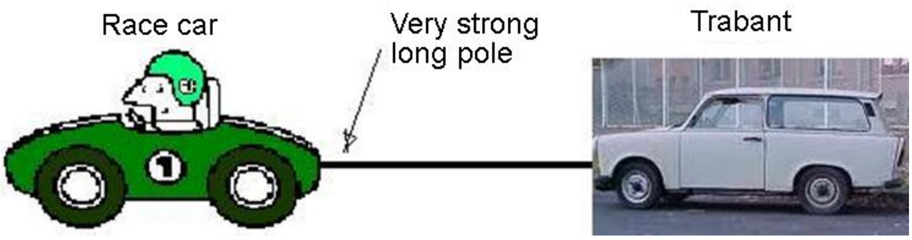


Figure 16. Speed of a Trabant - over a certain speed - can be increased by a long pole and a race car

If we want to carry out a change, we need time. The previous example shows, that this is certainly strongly dependent on the type of car. We could say that every time we can get closer only with a small step to achieve the desired goal, but we never can say that these changes happen immediately. Maybe these changes happen very quickly for the human senses, but never immediately. This will be particularly conspicuous, if we suddenly want to force our car to achieve a higher speed. If we suddenly press till the floor the accelerator pedal, we can feel that our car does not react immediately, but it needs to take a "short" time to realize that the accelerator pedal has been pressed.

These processes are modelled in two ways. Depending on what is important for us, we can say that the process is modelled by a multitude of small changes, which describe (or draw) the entire process as a result. But the process can be considered also in another way. At the beginning of the process, as long as the changes are small or nothing happens, we will not take into account any changes. We start to follow the changes only when their range is observable for us, what we can already see or what we are able to measure with our existing instruments. This is the overlooked time which is called dead time, because during this time we do not expect any essential reaction from the system, although we know that a new process has been started.

After having pressed the accelerator pedal we are only interested in the result, so we can say that within an eyelash or 1 second after that the accelerator pedal has been pressed the car has reached the desired speed, or at least we get some signs that the acceleration has been started. This result could be seen if we could do 1-2 camera images in every second about the process. However, the picture about the process would be different if we could do 1,000 images per second in the process. In this case, we would see that the first 10-100 images show nothing. Just if we looked at the process further, then we would see that the car's speed really begins to change. How does this happen? What does that little bit extra fuel volume make in the engine, which is added to the originally injected fuel and is also ingested to the engine's combustion chamber - because the gas pedal is pressed higher? Figure 17 shows what happens in the engine. It is not difficult to imagine that the explosion of this given amount of fuel moves back the easily movable plunger because the pressure which has been increased suddenly exerts great effort on the surface of the cylinder head.

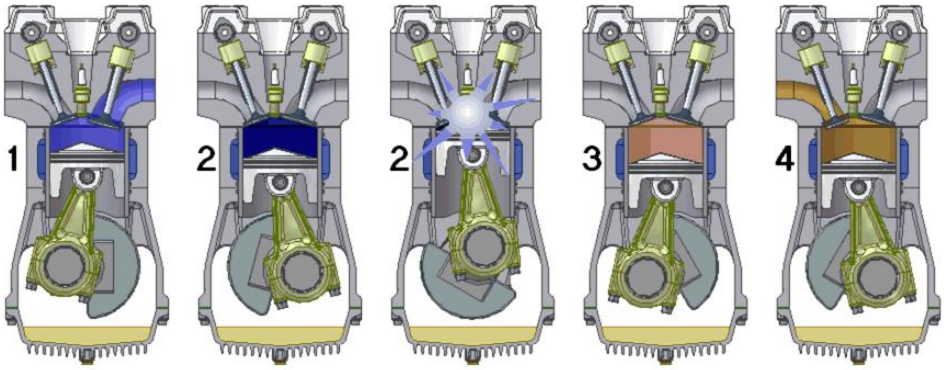


Figure 17. Operating phases of a four-stroke engine

http://hu.wikipedia.org/wiki/Otto-motor

If more fuel is injected, the explosion will be larger, which means greater force to the cylinder surface. If the cylinder head would be only in a tube, we should see that the cylinder head flies out of the tube and falls down somewhere on the ground. The place where it falls down depends on the force which is applied to the cylinder. If the force is higher, the cylinder flies farther. Now, however, the cylinder is unable to fly because the shaft of the engine forces it to a circular orbit. Our previous idea is going to change now: the cylinder will do that certain circular orbits more quickly because of the larger force. The effect of the additionally injected extra fuel is that the shaft of the engine rotates faster. Use (1) to describe this mathematical process! Let M [kg] denote the amount of the fuel, V [m3] is the volume of the fuel, which additionally is added to the initially injected fuel quantity M [kg]. We know that our car moves with speed v_{car} using the injected fuel M. Relationship (5) is derived from (4), the new speed of our car can be calculated, which is derived from the effect of the additionally injected fuel quantity m [kg] during t[s] time and it is shown that the angular velocity has been increased.

$$\frac{(M+m)-M}{t} = \frac{\rho \cdot V}{t} = k\omega_1 \quad \text{and} \quad v_{car\_new} = c \cdot r \cdot (\omega + \omega_1) \qquad (5)$$

4. Intelligent systems in the car

Nowadays, several systems can be built into the car that technically support the drivers (power steering, ABS, parking assist system, etc.) and ensure the proper handling of emergencies. Sensors that monitor weather conditions (light, rain, humidity) help drivers in decision-making. Satellite communication supports navigation and orientation (GPS). Besides the technical aspects to increase security, improve passenger comfort, use fuel more efficiently, reduce pollutant gas emissions to the environment are also important factors. Car tracking and accident-free driving are helped by driver's condition monitoring systems. Traffic monitoring and communication with the other drivers to implement cooperative driving systems help to safer driving. These new systems, ease of driving use sophisticated sensors and integrated computer technology built in the car.

The computer science and the mechanical (artificial) intelligence presses forward in structural units of the car and in driving.

In February 2011, news came to light that the IBM supercomputer named Watson won using its artificial intelligence against two really educated humans in the most popular quiz of the United States. The computer used maximum 2208 processors at the same time. Its superiority cleared mainly in lexical knowledge, although sometimes it could not cope with the secondary meaning of the words. And its humor was equal to zero. The experts, however, considered a real breakthrough performed by the machine: since it was able to understand people's conversation, so the most likely answers were given to the questions. It used the knowledge accumulated within the scientific progress of artificial intelligence only in the last two decades to its amazing performance.

German researchers work on a system that allows drivers to control their various electronic devices found in the car with minimal effort. The solution is that the drivers can control their devices (audio and air-conditioning equipment, digital car radio, electric windows etc.) not even lifting their hands from the wheel, and in most cases it is sufficient to move their right index finger to manage these systems. The system named Geremin is based on cameras. It needs far less computing capacity compared to a traditional system and it can work reliably even under difficult conditions (i.e. changing visual conditions). The operating principle is based on an instrument named teremin. This instrument was developed by Lev Sergeyevich Tyermen Russian physicist in 1919 and this instrument was the first one that could work just through gestures, without the musicians had touched the instrument itself. In this technology named Geremin the effects of human finger movements influence the alternating electrical fields. One antenna is enough to recognize interactions between the human hand and the electrical field. The antenna is mounted on the car’s dashboard. The signals of the antenna are read by a computer and the signals are sorted by a special algorithm to find the different gestures. The system was tested by six volunteers. The researchers asked the volunteers to perform ten, so-called microgestures with their index fingers, e.g. form a circle in the air with his finger while their hands still remain on the steering wheel. Best result of the detections was 86 percent, while the worst one was only 28 percent. The reason of relative lack of precision is that this technology currently uses only one antenna. However, researchers want to use two antennas in the subsequent tests, and in addition - like their American colleagues – they want to combine gesture control with voice control.

But what is really artificial intelligence? Probably Wikipedia gives the most succinct definition to this question. "While the artificial intelligence is a product of science fiction, currently it represents a major branch of computer science that deals with intelligent behavior, learning and machinery adaptation. For example it deals with the ability to respond inquiries of diagnosis or consumers in different problems like process control, planning and scheduling as well as handwriting, voice and face recognition. It became a discipline that tries to give answers to real-life problems. "

Using problem of a parking assist system, below an example of "machine intelligence" is discussed to performed technology of machine recognition, learning, assessment, intervention.

Parking assistance systems (Practical application of artificial intelligence)

Everyone has heard about cars, which are advertised as “the car is capable to park without the help of human hands”. It is simple to implement the parking process, since the car is lead in reverse, in "S" track to achieve the desired result, and our car is immediately found between two other cars. But did you already try this? In Figure 18, it does not seem to matter when you start the "S" curve compared to our first car, otherwise we can break the rear of the car standing in front of us. It does not matter how far we reverse in this path, because it can impinge on the curb. If the first two hurdles are already beyond us, in the third phase the car must be stopped carefully without bumping the second car at the end of the "S" curve.

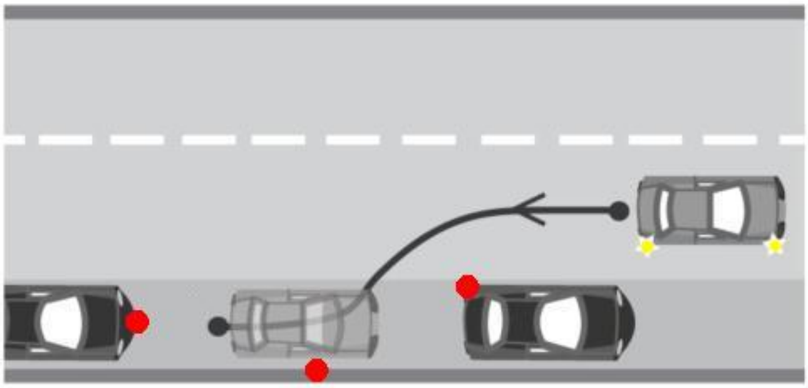


Figure 18. *Tracks and threat of reverse parking*

To adapt automatically the track shown above, follow flowchart in Figure 20. The soul of a parking assistance system is the controller, which controls and monitors the steering wheel structure of our vehicle, while it measures the real parking orbit data of our car and compares them to the planned track as well as corrects them if necessary. The procedure itself sounds simple, but the implementation is very difficult.

Objectives and constraints in parking

The control process:
Using image recognition systems the car parking maneuvers can be executed automatically by artificial intelligence.
Limitations:
• the operation of parking is carried out when reversing
• in case of human intervention the process must stop immediately

Goals: To implement automatic parking maneuver without personal and material damage.

Let us analyze this process control in more details

What does a good parking assist system need to know? Pay attention to the well-precise appellation. This name does not say that our system parks our car without any problems in every case, but if all goes well, it will be able to finish the parking which was started successfully. What kind of disturbing circumstances may occur during parking?

Identification

The parking assistance system has to recognize that free area where our car can be parked safely. That is, it has to find the area shown in Figure 19. Just think what problems may occur for a video camera system. First, it has to recognize two vehicles then it has to determine the distance between the two vehicles. Of course, we have to assume that the system is definitely familiar to its own parameters.

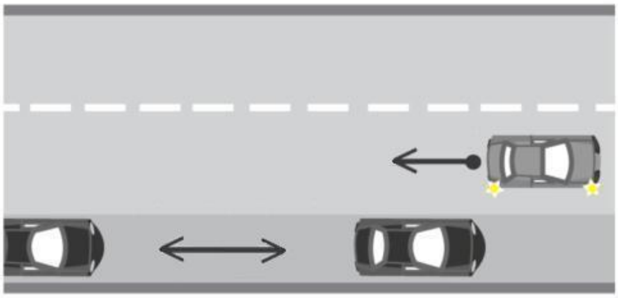


Figure 19. Recognizing a correct parking place

The process itself can be imagined as follows: the moving vehicle looks for license plates along a track. A license plate is usually located in a well-defined position in space, 1.5-2.5 meters away and at a height of 0.5-1 meters from the scanning vehicle. For the sake of our model forget now that foreign registration numbers are also available.

Planning

If a suitable area has been found for us, and we have checked that the area does not have "parking prohibited" feature (e.g. a parking prohibited sign), we can start planning the parking path of the car. At the end of the process, as it is shown in Figure 18, a reference path will be obtained. This will be the path where the center of our car, or some other privileged point must pass through.

However, for planning we need data, besides the car's parameters (length, width, wheelbase, width axles, wheel height, ...) the state variables and inputs of the system are required as well.

The block diagram of the overall process is shown in Figure 20. From among the processes indicated on the Figure, path planning and tracking of the path and control of these processes are dealt with.

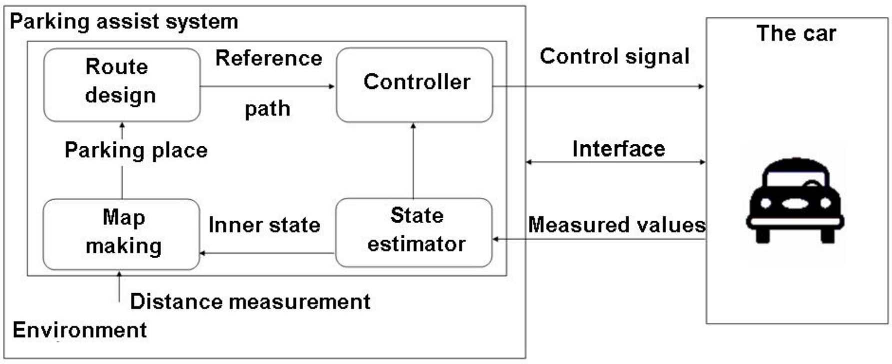


Figure 20. Block diagram of the system

State variables

In case of position control of motor vehicles simple state variables are used. We specify coordinates and orientation of a selected point of the car related to a reference coordinate system, as shown in Figure 21.

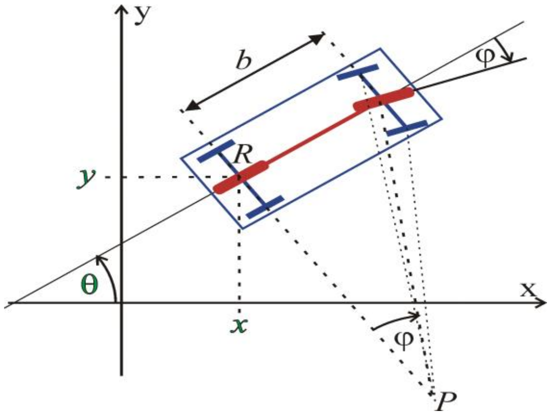


Figure 21. Interpretation of state variables and inputs of the system

In addition, we need inputs of the system, too. By the aid of two input signals the position of the car in the next time point can be determined, these are the angle of rotation related to the current orientation, as well as the current speed of the car are known.

State variable
Position of the car point R: x, y
Orientation of the car relative to the reference coordinate system: Θ

Input
The current rotation angle relative to the orientation of the car: ϕ
The current speed of the vehicle: v

The state equations can be written as follows:

$$\dot{x} = v \cdot \cos \Theta$$

$$\dot{y} = v \cdot \sin \Theta$$

$$\dot{\Theta} = \frac{v}{b} \cdot \tan \varphi$$

The state equations and input signals of the system are now available. The next step is to determine the output. In this case it is a bit difficult to determine the output because in opposite to the previously described systems, the output is not yet available.

The first part of the task is the theoretical design of the output, i.e. the design of the parking path of the car. We can say that we have a precise system output to drive through the vehicle on this theoretical path, only if the car parking path has been designed previously. In our previous tasks, the output has set our system to an already existing new state. Now a new component is added to the system shown in Figure 22 - first you need to plan your path!

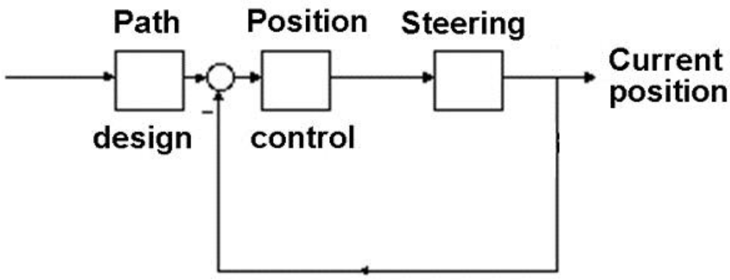


Figure 22. A simplified block diagram of the parking process

In the previous chapters we could see that the same task can be formulated in various ways. This is illustrated in Figure 23. The difference between Figure 22 and 23 is that while Figure 22 shows a serial process, where path design is followed by position control, then Figure 23 shows that the whole path design does not have to precede the design of the full parking process. It is sufficient to determine the final position or to plan a rough path and adjust our plan during control of the process to achieve the accurate goal. In this method the model of the process can help us a lot.

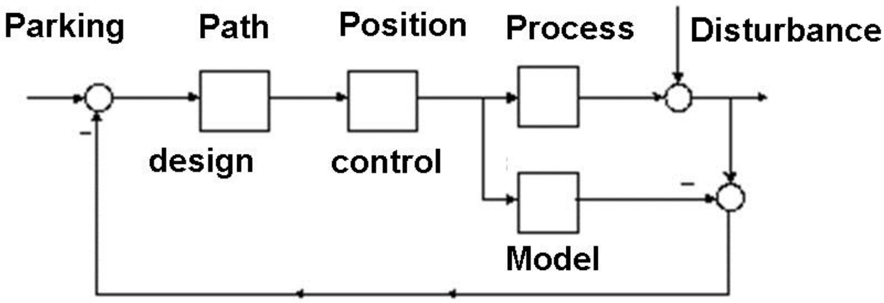


Figure 23. Block diagram of the model based control system

Another new feature compared to the previous ones is, that the goal of the control is not to reach a given output value, but in a finite time period, after having reached a position newer and newer output values enter replacing the previous ones.

Advantage of the system shown in Figure 23 lies in the fact, that we can try to control our process without any intervention to the real process. Note that two independent process controls do appear, and both processes, the real one and the model can be controlled. Since we have advance knowledge about parking, based on this knowledge we can develop a model. The model can be refined. If we can make a model which is accurate enough, with small error, the subtraction on the right side of Figure 23 results in almost zero signal, i.e. the output of the model provides exactly the same output as the real output of the process. So if our model - in addition to the actual parameters (speed, distance, orientation, ...) - was able to carry out parking without error, then the real system also will be able to do it.

Process tracking

let us follow the operation of the system shown in Figure 23. Let us suppose that we are very tired when finally we decide to stop for a coffee. The abundance of the vehicle parking in front of the cafe is perceived as a disturbing factor, but the image of the effect of caffeine in our mind forces us prompt to look for a place to park on the roadside. If this task can be managed by our car, then we just press the button “park”. Our car glides through along the cars which had been parked already and tries to find a hole among them which is big enough to park as it is shown in Figure 19. In case of former parking assistance system this free parking area was looked for by the driver. In the even older system all other diagrams were also replaced by human eye, hand and leg. Figure 24 shows that today this problem can be solved by a front and a back camera. These cameras help not only in finding parking places, but also, for example in the case of manual parking they help us to see hardly visible areas in front of and behind the car.

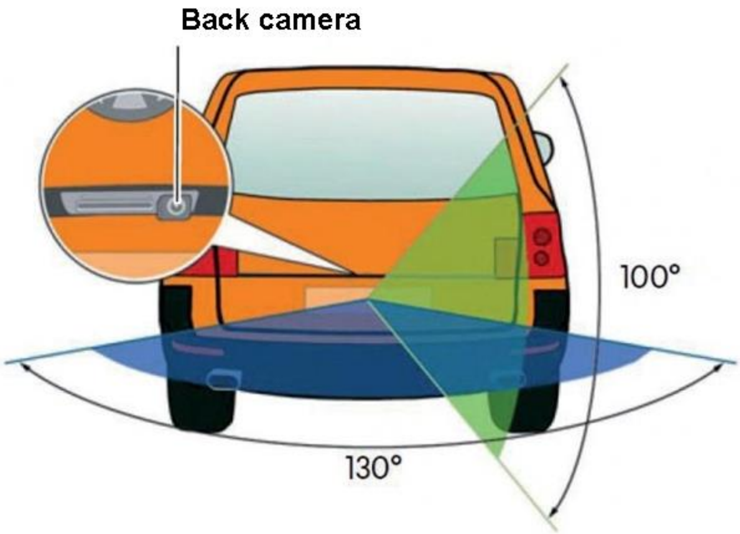


Figure 24. Location and angles of back front cameras

If we have the proper space, it is time to design the path. The car plans the parking process. When we try out our car parking assistance system the first time, we hope that the designers of this system did not forget to take into account the dimensions of our vehicle. During the second attempt we will have already experience about this. The price of our coffee can be significantly increased if we have to pay also the repair costs of the two cars shown in Figure 25.

Figure 25. Typically bad result of design process

What will be the output of the design? A track, which is for example shown by Figure 19. Having

designed our car parking trajectories, at the same time a model has been also created which shows that under certain (fairly small) speed, for each moment, in which position our car should be located on the track. Of course, these systems are designed so that when you touch the steering wheel, the system immediately returns the control to the driver, which is quite important in certain emergency circumstances.
As we start the process of parking, the first position to be achieved appears in the system's memory. To achieve this position the steering wheel and the power of the engine have to be controlled, that is to set to the correct value. This task can be carried out now by the system. Note that if the parking trajectories are adjusted according to the time constant of the mechanical movements (steering and engine power modifications), that is we have enough time to rotate the steering wheel and have time to step on the accelerator pedal or to brake, then we can move our car between two consecutive track points. If it can be done between any two consecutive points, finally we park on the selected parking place.

Theoretically it sounds beautiful. In reality, the situation is different. There is always a stray pedestrian, an object left on the street (see Figure 26), who or what may ruin our nice theories.

Figure 26. The back cameras help to detect obstacles too difficult to see

What to do if there is a discrepancy between the model and the measured position data? The response can be seen on Figure 27. We must change our position between two points until the output signal of the model and the real process output signal does not match. Obviously this solution contains a significant risk. If we can't move from one point to the other point by continuous movement, for example the difference between the estimated and actual position is too big, then if we stick to our original scheme, our vehicle would move back and forth. In this case, two solutions can be considered: either to plan a new route, or ignore some positions to be achieved from our plan and look for that position which is still could be reached.

What a board computer has to know to perform this process? If you re-think the parking process, we will find some corner points in the process.

First the appropriate size of a parking place has to be found. Then the start position should be set to complete the process. This will be followed by a coordinated effort of the steering wheel and the speed. At the end of the process the control of the car is given back to the driver. The phases of the maneuvers in which the car passes are divided into three significant parts as it is shown by Figure 27.

The position of the car must go through.

A - initial position B - sloping C – clarification

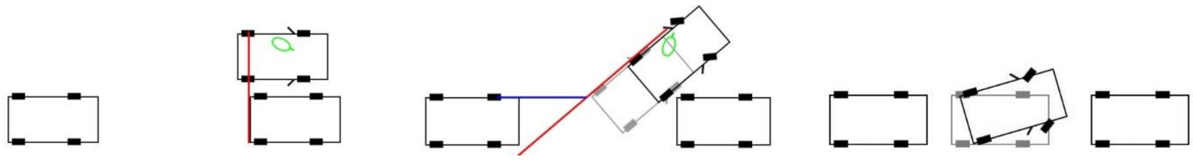


Figure 27. Significant phases of the parking process

Cameras are needed to realize the first task. The cameras should be able to interpret the images. The human eye can decide in seconds from Figure 28. whether the area is suitable for parking or not.

Figure 28. Search for suitable parking place

Our system executes the same function by measuring the height of the surface points on the spot. The markers on the picture show the required, safe-sized parameters of the parking place. After having found the parking place the starting position of the maneuver has to be set up. Two initial positions are shown in Figure 29, and the point indicates the end position of the process.

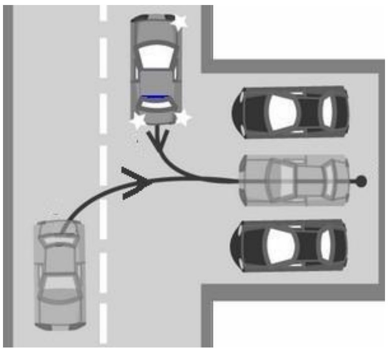


Figure 29. The start and end position of parking

The task of the on-board computer is not finished, when a parking place is found, even more difficult part of the process will begin. The time required to find the parking space is not limited, but in the parking process, our reaction time, in the combined play of the speed and the steering movements - in order to avoid accidents and vandalism – is significantly limited. From viewing point of the computer this means that information created from images of the cameras can be completed within the reaction time. From the computer this requires immediate - real time – responses and interventions. In case of a normal camera which can create 20-25 environmental images this means only 40-50 hundredths of a second reaction time. Of course, this time can be increased when only every second or third image is tested, but do not forget that the vehicle at speed of 10 km / h moves 11 cm during 0,04 sec. As it is shown in Figure 28, a bad maneuver with 20-30 cm errors can be fatal in a tight parking place.

In order to imagine our task, let's look what a picture evaluation means! Evaluation of the picture can executed in itself, or it can be compared to another image as well. While the search for parking places rather means the evaluation of one picture, the parking process is more related to a compared evaluation. If the first picture has been already completed, we have to wait for the next one. This image has to be transmitted to the computer's memory so that they can be compared. A normal size image contains 1280x960 pixels. In case of color image pixels, the size of this image is 1280x960x3 bytes which occupies 3.6 MB memory in the computer. If we want to transmit the pictures to the computer's memory within the reaction time, a very fast (737.28 Mbit/sec) network is needed, because 1280x960x3x8 bits / 0,04 sec takes 737.28 Mbit / sec. Today 100 Mbit / sec networks are used, so this is too fast data transfer. To avoid this often compressed data are transmitted. Image compression and unpacking, however, both on the transmitter and the receiver side take milliseconds. After transmission of the images they have to be compared pixel by pixel, and the differences have to be determined. This task has to be carried out on the extracted, original sized images, which means the comparison of millions of pixels. These differences provide the core values of the position changes, which determine the actual movement. The operation of comparison using today's multi-GHz processors, is not an insolvable task today. The updated position results usually mean two numbers, an x and a y coordinate. Then it is easy to perform the task. Unfortunately, moving the steering wheel, or changing the speed can be carried out even slower, than the image processing, therefore the calculations should be carried out with substantial safety reserves.

Optimal solutions
Optimal control systems can also be designed according to some criteria.

These criteria can be
- the shortest time,
- the shortest route,
- using the least amount of energy and
- parking should be carried out with the simplest movements.

Select one of the above, for example the shortest path. We know that in a flat surface, between two points the shortest way is a line. Unfortunately, we can’t move the car on the shortest straight line from the start point to the end point, because our car is not a point but it is a body with sizes. On the one hand, if we do not think so, then price of each parking process should include the repair cost of the car standing in front of us, because it is almost sure that we bump it during the maneuver. On the other hand, in this case one of the two cars standing parallel and side by side has to be moved by an inclined angle. Unfortunately, today our cars can’t move diagonally. This means that our car while making nearly two straight lines, as shown in Figure 30, has to move along a circular arc.

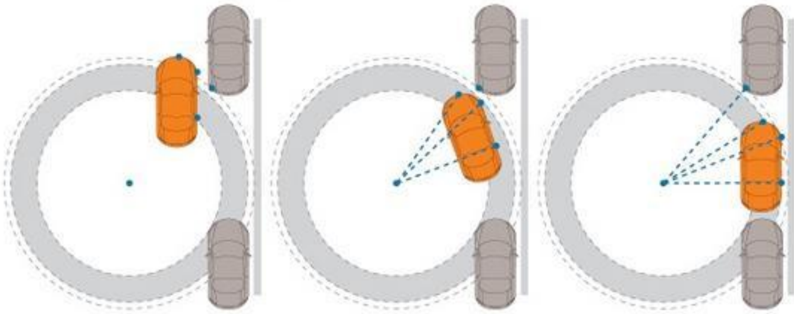


Figure 30. Optimisation of a parking event with extensive body

The shortest path specified in Figure 30. can be constructed from very simple approximations using 3 straight lines as it is shown in Figure 31.

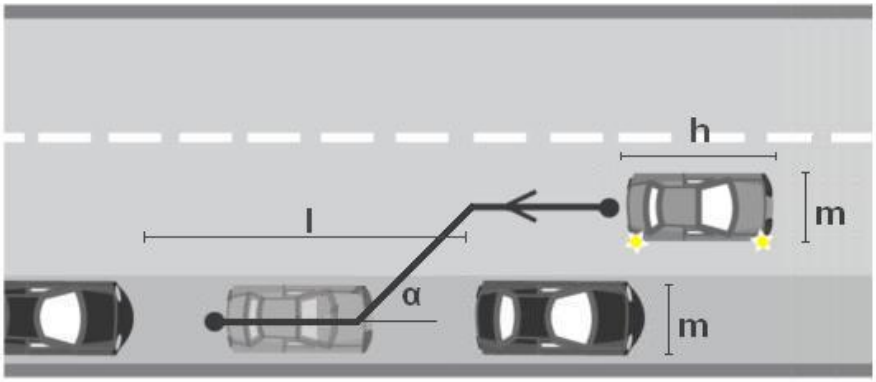


Figure 31. Parking parameters

If we assume that the parking vehicles are nearly of the same width, the parking should be carried out so that when before the final position of the parking the fulcrum of the car has reached m/2 height, then it has to be at least h units away from the left hand side car, and m/2 units away from the right car. This simple approximation shows that in the oblique section: sin α = m / 2 / h, and l > = h + m*ctg α. While the shortest distance can be calculated as h + m / sin α = h + m / m / 2 / h = 3h