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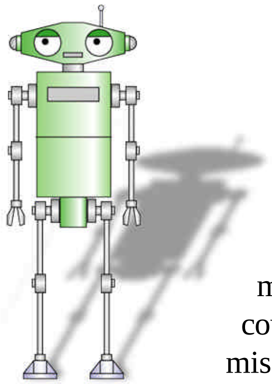
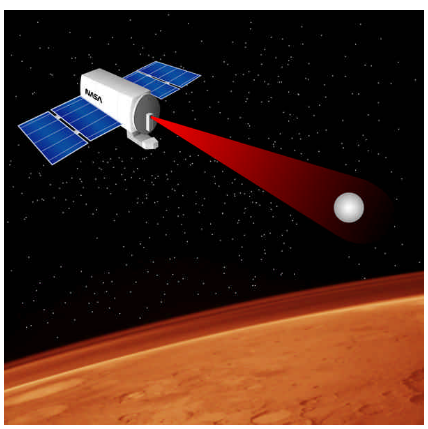


System Engineering a Robot

During the next decade, NASA may join with space agencies in other countries to do a very difficult Mars mission. No, we won't be ready to send people there yet. That's still quite a ways off. But we may be ready to collect Mars soil and rock samples and return them to Earth. Although no definite mission design has been selected, the mission may involve a two-part lander (since one part has to blast off from the surface carrying the samples), a rover to collect the samples on the surface, and an orbiter that can retrieve the sample canister that has been put into orbit around Mars and bring the samples back to Earth.

For many reasons, returning Mars samples to Earth is still a very hard problem. Just consider for a moment the problem of the Earth-bound spacecraft in orbit around Mars. It has to find and catch the sample canister after it has blasted off the surface into Mars orbit. Mission controllers back on Earth will certainly be of no help. Mars will be so far away that a command signal would take several minutes to travel from Earth to the spacecraft. No, the sample return spacecraft will be on its own.

What is needed is an *autonomous rendezvous* technology. This technology would enable the spacecraft to size up the situation, decide what to do, and carry out its task with no help or communication with humans. NASA's New Millennium Program identifies new technologies that will be needed for future NASA missions and then tests them in space to make sure they will work. The New Millennium's Space Technology 6 mission hopes to test an Autonomous Rendezvous system in Earth orbit. The rendezvous system would fly in 2004 as part of the payload onboard an Air Force satellite.



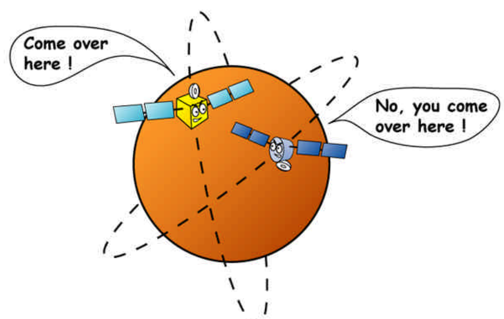
NASA's New Millennium Program Space Technology 6 mission will test advanced autonomous rendezvous technology.

The rendezvous system would include a laser radar sensor (called *LIDAR*) that would act as the eyes to find and detect the distance to a target spacecraft (which would be one that is no longer operating). Using the information from the LIDAR, the software would then calculate the steps necessary to reach the target and give instructions to the thrusters on the spacecraft to change its attitude (orientation in space) and velocity so that the spacecraft would move toward the target. The LIDAR would continue to give feedback to the computer and the software would continuously check and update its calculations and instructions to the spacecraft to close in on the target.

It Starts with Careful Thinking

Engineers who design spacecraft systems think carefully about the problem they are trying to solve, what capabilities the system must have, and how they can use all the new technologies, tools, techniques, and tricks they can think of to come up with the simplest, most effective, and fool-proof design possible.

The autonomous rendezvous problem is particularly difficult because there are two objects, both moving in three dimensions and oriented in different directions in space, possibly not only orbiting at different altitudes, but also in different orbital planes.



No-hands Parking

Let's try thinking about a much simpler problem. Let's suppose we want to design a "Autonomous Parallel Parking System" to help drivers park their cars in tight spaces between other cars along the street. This system would be an option (although probably not a cheap one!) that a car buyer could purchase with a new car.

First, if you haven't taken driving lessons yet, see the illustrations in the next column for a short lesson on how to parallel park.

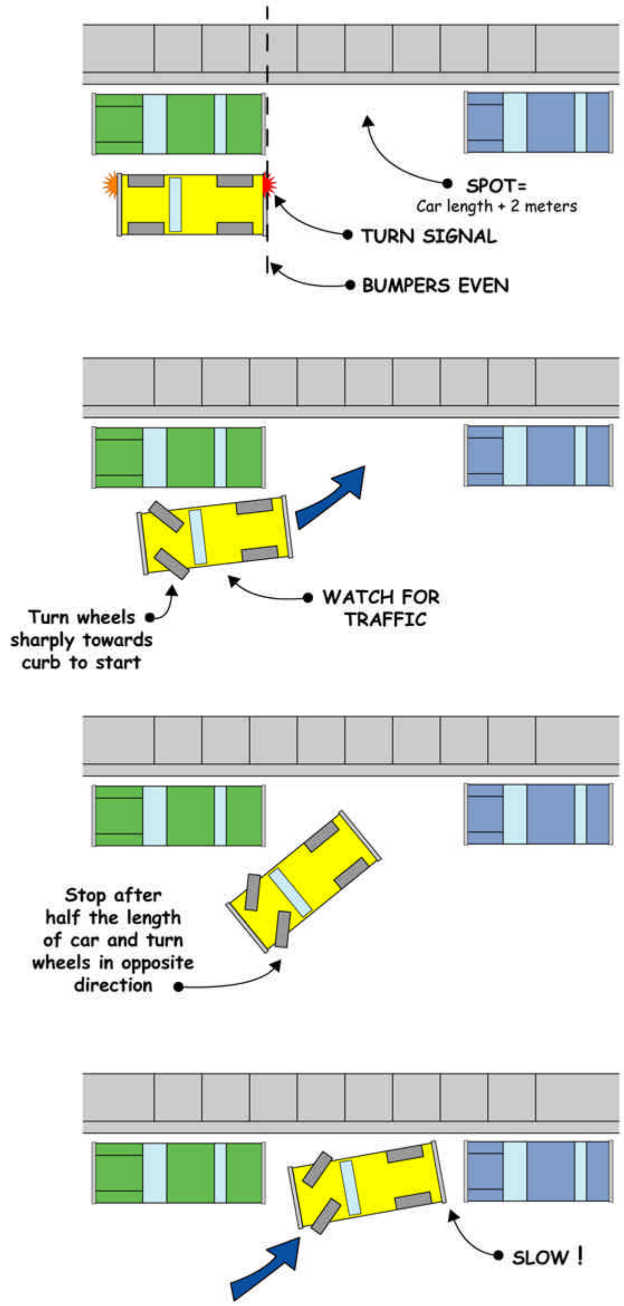
Now, on the next page is an example proposal for an "Autonomous Parallel Parking System." You may find, as we did, that the longer you think about a problem such as this, the more complex it becomes. You can keep adding "what ifs" and ways to deal with them. What if a car suddenly comes speeding up from behind just as the car starts backing up? What if a pedestrian steps off the curb behind the car? What if a sensor on the car detects a bird flying by and the computer "thinks" the car is about to hit something? A really well-designed autonomous system will include pre-planned strategies for handling just about everything that could possibly go wrong.

Pick a Problem

Note to teacher: This activity may require three class periods: (1) introduce the ideas, discuss the example, divide into groups and pick and problem; (2) work on the design, begin the report and drawings (which can be completed as homework); (3) share designs with the rest of the class.

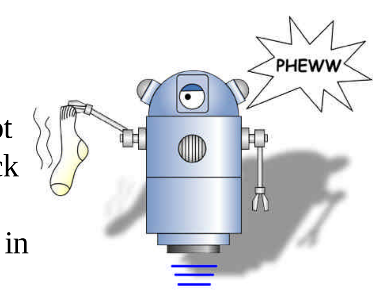
Divide the class into groups of three or four. Each group picks one person to be the recorder. This person will make notes on the ideas and decisions of the group.

Now, each group thinks of a task that could be done by a robot or other machine, or a program running on an ordinary computer. Think it through the way we have for the "Autonomous Parallel Parking System." Use your imagination! Don't worry about whether the technology you need (like "LIDAR") has been invented yet, as long as you describe what the technology does.



Here are some other suggested problems to analyze:

- Design a "cruise control" program that will drive a car at maximum speed (within the speed limit) while maintaining adequate stopping distance behind the vehicle ahead.
- Design a program that will park a car in a garage.
- Design a program for a robot to enable it to locate and pick up dirty socks lying on your bedroom floor and put them in a hamper.



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Example (Imaginary invention only!)
Autonomous Parallel Parking

Description:

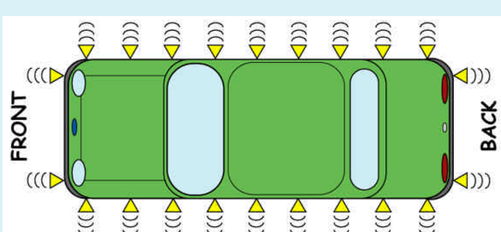
An autonomous system that will parallel park a car between two other cars without driver intervention.

Requirements:

1. Upon stopping beside the car just ahead of a large enough parking space, driver shall be able to switch on autonomous parallel parking system.
2. Using computer-controlled steering, braking, and automatic transmission mechanisms on the car, the system shall be able to maneuver the car into a space equal to the length of the car plus 2 meters (about 6 feet), leaving 7 to 30 centimeters (3 to12 inches) between the tires and the curb.
3. System shall be able to sense the distance to obstacles ahead, behind and on both sides of car up to 10 meters (about 33 feet) away.
4. During parking maneuvers, no part of car shall be closer than 7 centimeters (3 inches) to any part of another car.
5. The car shall be parked with no more than one reverse maneuver and one forward maneuver.
6. If the car is on a hill, system shall turn front wheels against curb to prevent car from rolling downhill.
7. Once activated, autonomous parallel parking process shall take no more than 30 seconds.
8. System shall be able to detect unforeseen conditions or system failures, shut down, and signal for driver intervention.
9. System shall allow immediate driver intervention at any time.
10. System shall signal when car is in final parked position and return control of car to driver.

Design (partial):

- System will include laser radar sensors (LIDAR) on both sides of front and rear bumpers and at least every 50 centimeters (20 inches) along the sides of the car, including the extreme front and rear . Sensors will be able to detect distance to objects up to 10 meters (about 33 feet) away, to an accuracy of 1 cm (about .5 inch). Sensors will be able to measure speed and acceleration relative to nearby objects.
- Data from sensors will be sent to onboard computer, which will calculate instructions for forward or reverse gears, acceleration, deceleration (including braking), and turning.



- These instructions will be passed to electronic controllers for the vehicle's transmission, accelerator, steering system, and brakes.
- New data will be collected from sensors and passed to computer for recalculation of all output instructions 10 times per second, thus forming a continuous feedback loop that will immediately correct tiny errors and assure accurate placement of vehicle.
- Vehicle will include a driver panic button on the steering wheel, which will abort the process instantly and release all controls to driver.

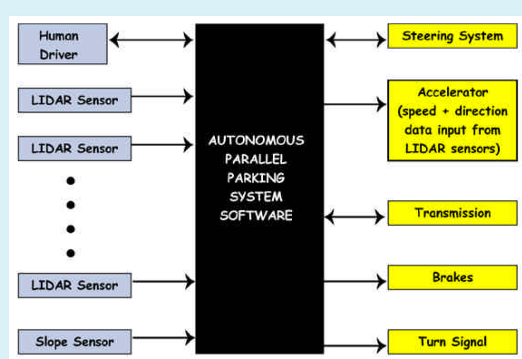
Software Inputs:

- Indication of which side of street (left or right) to park on—switch set by driver.
- Operational mode (on or off)—switch set by driver.
- Distance from obstacles—data from LIDAR sensors.
- Speed (including direction)—data from LIDAR sensors.
- Acceleration—data from LIDAR sensors.
- Front wheel angle—data from sensor in steering system.
- Slope of road—data from slope sensor.

Software Outputs:

- Go/no go signal to rest of system (based on distance inputs from sensors).
- Instructions to turn indicators.
- Instructions to transmission.
- Instructions to accelerator.
- Instructions to steering system.
- Instructions to braking system.
- Failure warning to human user.

Interfaces:



- Design software to control a lawnmower so it will autonomously mow a rectangular lawn of certain dimensions.
- Design a robot that will do some small task on an assembly line for making cars or some other product.
- Design a program to control a device to autonomously clean the bottom and walls of a swimming pool.

QUESTIONS TO ASK YOURSELVES:

Write down the group's responses to these questions. Then prepare a report to share with the class, including these responses, plus the drawings.

1. What is the overall problem to be solved?
2. Now, imagine a machine (sort of like a robot) that includes a computer and software that will solve the problem. This machine, with its computer hardware and software, we will call the "system." What are the specific requirements of this system? Include measurable performance characteristics, if possible. Use the words "shall" or "must" to describe what the system needs to be able to do.
3. What will be the overall design of this system? How will you organize the requirements so that you group similar ones together so they can be met by the fewest separate parts of a system? Are there requirements that will be just too hard to meet and maybe could be sacrificed? For example, would it be enough if your autonomous parallel parking system could detect obstacles up to only 15 meters away, rather than 20 meters? Include drawings, if they will help show your design thinking.
4. In thinking about how the software will be designed, what kinds of information will be coming into the program from the outside (called inputs)? What kinds of data or instructions will the program be providing (called outputs) after it has processed the inputs?
5. Draw a picture of how the different parts of the system will communicate with each other (called interfaces). Don't forget the human! You might act out the rules or steps the robot will follow in doing the task and make this part of the presentation to the rest of the class.

Learn more about ST6 at nmp.jpl.nasa.gov/st6 . For another fun activity and more about another new Space Technology 6 technology, see The Space Place web site at spaceplace.nasa.gov/st6starfinder/st6starfinder.htm. Also, go to spaceplace.nasa.gov/phonedrmarc/jun2002.html to read Dr. Marc's answer to "Is there life on Mars?".

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