Editor: Alberto Broggi
University of Parma, Italy
broggi@ce.unipr.it

An Automated Gas Station Attendant

Shiu Kit Tso, Ka Lun Fan, Yongde Zhang, and Chun Man Chan, *City University of Hong Kong*

So far, this department has covered many different aspects of intelligent transportation systems: innovative vehicles and transportation methods, new ideas for infrastructures and public transport, human–machine interfaces, and new approaches to renting cars. However, regardless of the transportation method or type of fuel—electricity or gasoline—future vehicles will still regularly need refueling. Automated refueling is not tightly related to guidance, but it will become important when automatic vehicles travel on our roads.

In this installment, Shiu Kit Tso, Ka Lun Fan, Yongde Zhang, and Chun Man Chan describe the status of automatic refueling systems and propose a robotic solution. As they mention, although refueling requires attention only once in a while during the complete vehicle life, automatic refueling involves other important aspects, such as safety, security, or personnel reduction.

If you have any comment on this department, feel free to contact me. I also seek contributions on the current status of ITS projects worldwide as well as ideas on and trends in future transportation systems. Contact me at broggi@ce.unipr.it; www.ce.unipr.it/broggi.

—Alberto Broggi

Having to staff a gasoline station with human attendants at night or in remote rural areas poses several potential difficulties, including health hazards and security problems. To eliminate the need for attendants in such situations, we have designed and developed a laboratory prototype of an automatic petrol-refueling station (see Figure 1). Our APS incorporates a user terminal, refueling robot, sensing system, and motion control system. It aims to provide automatic, intelligent, fast, and convenient 24-hour automobile refueling.

The user terminal

The terminal provides a simple user interface consisting of a smart card system, keyboard, monitor, and printer. After inserting a smart card into the smart-card reader, the user keys in a password and selects the kind and amount of fuel. The user can check the smart card's records and updated status. During refueling, the monitor displays the procedure's progress. The printer outputs a receipt after the APS completes the refueling. In addition, the terminal features an emergency key so that the user can stop the robot immediately. The robot resets automatically after the user releases the key.

In a deployed system, the terminal would be designed for outdoor use, and the user would be able to access it while seated in the car. Both the smart-card reader and the computer would need to be protected from possible abuse.

The robot

An end effector connected to the robot's wrist holds the gas pump nozzle and moves it to the parked car's gas tank opening. After the APS determines the opening's inclination, the wrist adjusts the nozzle's pitch and yaw to prepare it for insertion. Figure 2 shows the end effector inserting the nozzle into the tank opening. (As a separate development to simplify refueling, we have built a combined gas tank lid and cap that lets the nozzle enter the tank opening without unscrewing the cap.)

A Cartesian frame with three independent axes carries the end effector. Each of the frame's three sliding, prismatic wrist joints can change its coordinates without affecting the other two axes' coordinates. The end effector is attached to the end of the z-axis, whose extensible length is 800 millimeters. Because the z-axis is arranged horizontally, this joint must bear the maximum bending moment when fully extended. The maximum loading at the z-axis joint's tip is 10 kilograms. This axis has three sections and is driven by a ball screw. If the axis were divided into more than three sections, the last section's diameter might be too small, thus decreasing the joint's strength. The Cartesian frame and wrist joints together provide five degrees of freedom, which are useful for adjusting the nozzle when inserting it into the tank.

Sensing

Our APS uses four types of sensing devices: infrared sensors, a flow sensor, a force/torque sensor, and a vision system. A microcontroller controls all the sensors (except for the vision system) and integrates all the sensor signals. It sends the data in an appropriate format through an RS-232 interface to the main computer. The microcontroller also controls the gasoline valve and the counter displays, which show the gas output and price.

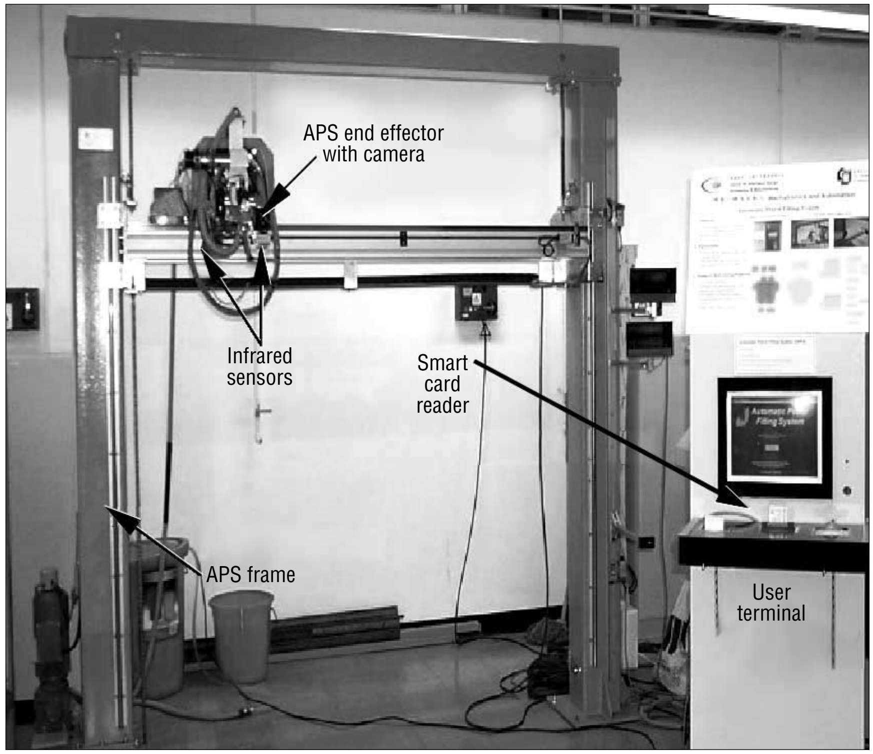

Figure 1. The laboratory setup of our APS (automatic petrol-refueling station) prototype.

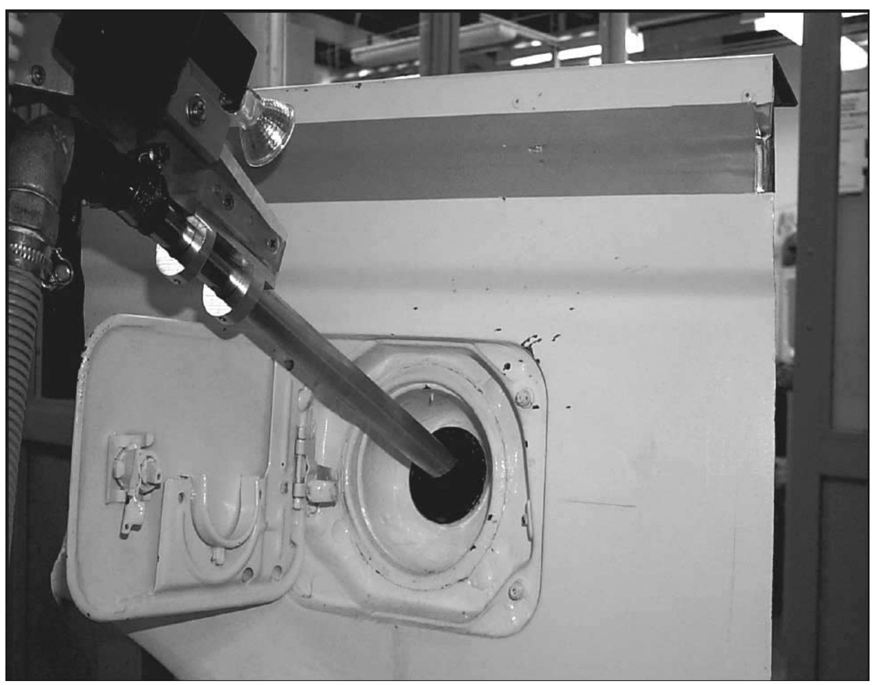

Figure 2. The end effector inserts the gas pump nozzle into the gas tank opening.

Infrared

The APS employs two IR displacement sensors—one (IR-1) in the end effector and the other (IR-2) fixed on one side of the frame (see Figure 3). These sensors roughly but quickly estimate the gas tank opening's location.

Imagine that a driver has parked a car in front of the robot. First, IR-2 checks the clearance between the car and the robot, then reports whether the car is in the acceptable area. (If the car is not properly parked, the computer will issue a warning statement at the terminal to the driver. The robot will not perform any action until the car is properly parked.)

To shorten the time searching for the opening, the APS then moves the end effector (with IR-1) toward the rear of the car. (In Hong Kong, gas stations normally operate with single-file traffic flow—that is, in one way, out the other. So, the system does not need to determine which end is the car's front and which is the rear.) Starting from one end of the robot, the end effector moves horizontally at approximately one meter above ground to search for the car body. The search range is up to 1,000 mm wide and 800 mm long. The APS can use IR-1's and IR-2's range readings to calculate the car's parking angle (see Figure 4). This gives the yaw angle for the z-axis wrist. If the yaw angle is within the acceptable range, the end effector will move to the opening's rough location.

Vision

The vision system precisely locates the gas tank opening. The APS uses a vision system because it is the most flexible choice for this purpose.

First, a 2/3-inch CCD (charge-coupled device) camera captures an image of the tank's opening. With this camera, the APS can obtain a precise measurement from an image with over 400,000 pixels. However, the environment's brightness level can affect image quality. A relatively dark envi-

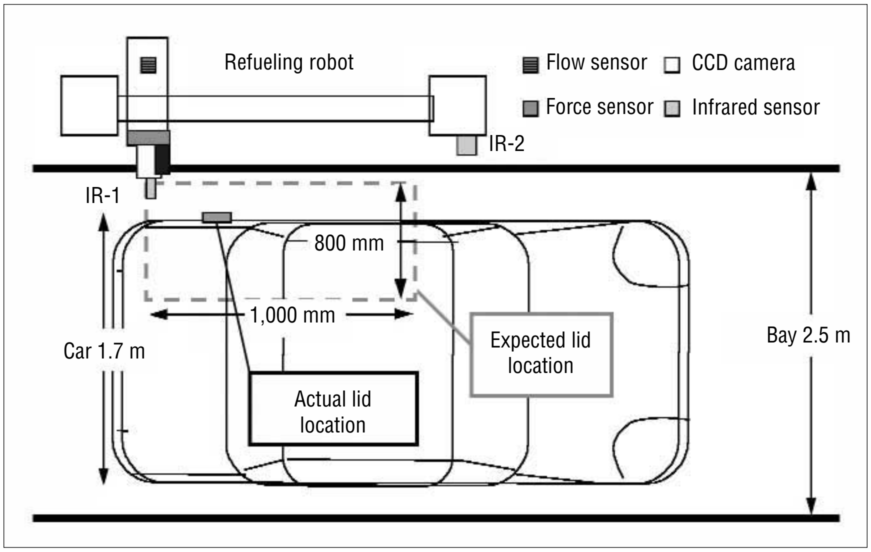

Figure 3. The range for searching for the gas tank opening.

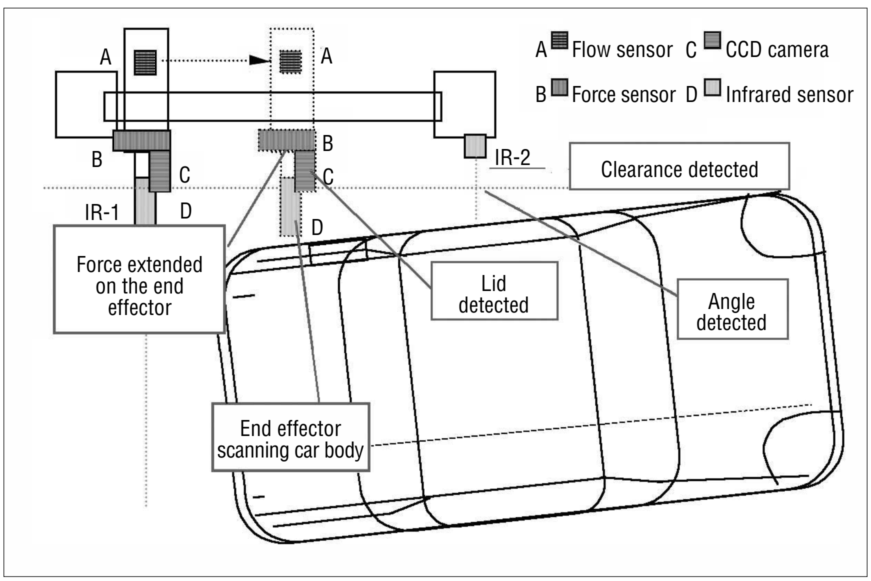

Figure 4. Yaw angle detection.

ronment will increase image noise; a light source originating from the side of the opening will generate a large shadow. To solve such problems, the end effector carries an artificial light source. When the camera takes the image, the light turns on to eliminate shadows and improve image contrast.

On the basis of the image, the APS determines the opening's position and orientation. It converts this data to the robot frame's global coordinates, which the microcontroller uses to drive the joints to the required positions.

Force/torque

During the entire refueling process, a force/torque sensor at the *z*-axis wrist gives feedback signals to aid motion control and to avoid damaging the car.

Flow

The flow sensor measures the quantity of gasoline delivered.

Shiu Kit Tso is the director of the Centre for Intelligent Design, Automation, and Manufacturing, City University of Hong Kong. His major interests are intelligent machine systems and service robotics. He has industrial experience in industrial electronics and automation. He obtained his BSc (Eng.) from the University of Hong Kong and his MSc and PhD from the University of Birmingham, UK, all in electrical and electronic engineering. He is a fellow of the Institution of Electrical Engineers and of the Hong Kong Institution of Engineers. He is a chartered engineer and a senior member of the IEEE. Contact him at the Centre for Intelligent Design, Automation, and Manufacturing (CIDAM), City Univ. of Hong Kong, Kowloon Tong, Hong Kong; mesktso@cityu.edu.hk.

Ka Lun Fan is an assistant engineer at the Centre for Intelligent Design, Automation, and Manufacturing, City University of Hong Kong. His major interests are service automation in medicine and in nondestructive testing (NDT). He has research and industrial experience in engineering design, biosignal processing, and NDT sensing. He received his PhD from Imperial College, UK. Contact him at the Centre for Intelligent Design, Automation, and Manufacturing (CIDAM), City Univ. of Hong Kong, Kowloon Tong, Hong Kong.

Yongde Zhang is a research associate at the Centre for Intelligent Design, Automation, and Manufacturing, City University of Hong Kong. His major interests are engineering design for automatic systems and climbing robots. He has research experience in mechatronics and robotics. He received his PhD from the Harbin Institute of Technology. Contact him at the Centre for Intelligent Design, Automation, and Manufacturing (CIDAM), City Univ. of Hong Kong, Kowloon Tong, Hong Kong.

Chun Man Chan is a research assistant at the Centre for Intelligent Design, Automation, and Manufacturing, City University of Hong Kong. His major interests are system integration for automatic mechanisms and climbing robots. He received his BEng (with first-class honors) in mechatronic engineering at the City University of Hong Kong. Contact him at the Centre for Intelligent Design, Automation, and Manufacturing (CIDAM), City Univ. of Hong Kong, Kowloon Tong, Hong Kong.

Other Robotic Refueling Systems

European engineers have been working on refueling robots since the late ’80s. In France, Robosoft (www.robosoft.fr) has developed Oscar, a robotic refueling system for buses. Using several sensors and a transponder mounted to a floor panel, Oscar automatically positions itself close to the gasoline tank cap.

German researchers have also developed several robotic refueling systems. In 1993, Anton Bauer GmbH designed and constructed Robin (www.ipa.fhg.de/srdatabase/robin.html), like Oscar, to refuel buses. Also like Oscar, Robin uses a transponder to obtain a bus’s geometrical data as it enters the lane for refueling. To scan the position of the bus’s gasoline tank cap, the transponder, its associated sensors, and the manipulator move on rails parallel to the bus’s longitudinal axis. Five inductive distance sensors help Robin precisely adjust the gas pump nozzle.

The Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer IPA), in conjunction with BMW and Mercedes-Benz, has designed a robotic refueling device for automobiles (www.ipa.fhg.de/information/Daten&Ereignisse/euro_inno.php3 [in German]). Unlike other systems, this one can establish a solid connection between the nozzle and the gas tank opening. A set of cameras detects the car’s exact position (especially the gas tank cap), and laser scanners monitor the robot’s workspace. The IPA claims that this system can remove 95 percent of the toxic vapor and can refill a car with liquid hydrogen.[1]

In Northern Europe, Sweden is one of the pioneering countries to install robotic refueling systems at stations throughout the countryside. In 1991, Autofill Europe (www.autofill.se [in Swedish]) developed the Autofill system. Autofill consists of a pump, a robotic manipulator with three prismatic joints, and a user terminal connected to the station’s main computer. A transponder, fitted with various types of sensing modules, transmits vehicle data (for example, dimensions) to Autofill. Guided by a camera and other sensors, the manipulator positions the nozzle in front of the lid. A vacuum gripper opens the lid. Distance sensors help Autofill accurately reposition the nozzle before guiding it into the gas tank opening.

Reference

1. “Fraunhofer IPA Tankroboter,” *IEEE and Fraunhofer IPA Database on Service Robots*; Fraunhofer Institut für Produktionstechnik und Automatisierung, Stuttgart, Germany, 1998, www.ipa.fhg.de/srdatabase/ipatankrobot.html.

Motion control

The robot’s five degrees of freedom comprise the three linear motions (x, y, and z) for the frame and two rotational motions (pitch and yaw) for the end effector. The APS subdivides motion control into frame control and end effector control. If the car parks in the expected space, the gas tank opening’s position and orientation will lie within a reasonable range. We can also limit the range of the five DOFs to suitable values. For the prototype, X is 1,200 mm, Y is 800 mm, Z is 1,900 mm, pitch is 200°, and yaw is 150°.

A programmable logic controller executes the x-, y-, and z-axis control. The APS sends the computed coordinates and speed to the PLC, which then controls the frame’s three AC motors via three inverters. An encoder on each motor monitors the motor’s position, which it sends back to the PLC.

Two DC servomotors drive the end effector. A controller card controls them, and a current amplifier supplies their power. The controller card contains a PD (proportional-derivative) controller for each motor.

Moreover, the controller card uses the signals from the force/torque sensor to apply both force control to the x, y, and z motions and stiffness control (with suitable force control gains) to the pitch and yaw motions.

We developed our APS to be a more or less immediate solution that provides the essential functions and assumes minimum alteration to current cars. Its basic concept is similar to other systems (see the sidebar). However, unlike the others, it does not use transponders, and it exploits force sensing. The APS’s simple but robust mechanical-system design lends itself to outdoor use with minimum maintenance requirements. We plan to make our system safer by replacing the DC motors at the wrist with pneumatic motors.

Besides eliminating the problems associated with human gas station attendants, automatic refueling systems can assist drivers who are unable or unwilling to handle gas pump nozzles. Such features augur these systems’ eventual popularity. However, for this prediction to come true, researchers must develop highly reliable, safe, and secure systems.

Acknowledgments

We are grateful to the Research Grants Council, Hong Kong SAR, for providing a Central Allocation grant supporting several service robot projects.