Autonomous Moving Technology for Future Urban Transport

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OVERVIEW: In anticipation of the aging of society, autonomous moving technology is being developed with the idea of using autonomous vehicle sharing systems as a new form of urban transport. The first priority for autonomous moving systems designed for use among people is that they protect people's safety. Three core technologies required for making it a practical means of transport are external sensing, localization, and obstacle avoidance. Hitachi is building up its capabilities in these core technologies through the development of outdoor autonomous moving robots, logistic support robots, and similar. Public road testing of outdoor autonomous moving robots is undertaken at the Tsukuba Challenge (RWRC) and ongoing work on the development of logistic support robots is aiming to deliver efficient automation of logistics in factories, distribution centers, and elsewhere.

INTRODUCTION

AS the world's population have been increasing in the 21st century, more than half people on the earth now lives in urban areas. The construction of urban transport infrastructure that suits activities of people, environmental requirement, and financial restriction has become even more important. Developed economies in Europe and America as well as Japan are also experiencing problems such as aging populations and a hollowing-out of city centers. This is underpinning a notable trend toward right-sizing cities and reducing dependence on internal combustion automobiles. In the growing cities of East Asia and elsewhere, work continues on establishing public transport to alleviate problems with traffic congestion and the carbon emission.

New urban transport systems face the following challenges.

(1) Reduce environmental impact.

(2) Support travel by the elderly and other people with impaired mobility.

(3) Reduce operating costs.

Hitachi is planning to develop an autonomous vehicle sharing system as one approach to resolving these issues and is conducting research into autonomous moving technology.

Fig. 1 shows an overview of the concept.

This system assumes use of high-speed public transport such as trains for long-distance inter-city travel and uses autonomous vehicles for intra-city travel, e.g. from user's home to the nearest station and from the final station to their destination. To save on resources and reduce use of city space for car parking, the vehicles are shared. Because users can call the vehicles to their homes and then leave them on reaching their destination, the system makes it easy for even elderly people with physical infirmities to move around. The system also reduces operating costs by having the vehicles drive themselves to and from the pick-up and drop-off points.

The key to this approach is autonomous moving technology. The remaining technical challenges that need to be resolved if vehicles are to move through cities reliably and safely under their own control without special infrastructure such as guide paths include external sensing, localization, and obstacle avoidance.

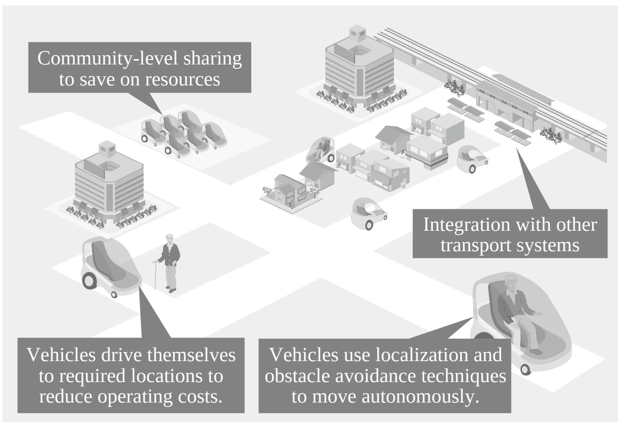


Fig. 1—New Form of Urban Transport Using Autonomous Moving Technology.
The figure shows an example (concept drawing) of public transport provided by single-person vehicles incorporating robotic functions for autonomous movement.

This article describes an outdoor autonomous moving robot and logistic support robot, two examples of work Hitachi is doing in response to the challenges of autonomous moving technology.

BASIC TECHNOLOGIES FOR AUTONOMOUS MOVING SYSTEMS

The following section describes the basic technologies used in autonomous moving systems and the associated development challenges. Fig. 2 shows the block diagram of an autonomous moving control system.

The main elements are: (1) external sensing which senses shape, position, and speed data from the surrounding environment and uses this to determine the information required for autonomous movement, (2) internal sensors that determine position, speed, and other information about the robot's current state from its past movement history, (3) a localization function that determines the robot's movement and position from the external sensing and internal sensor information, (4) an obstacle avoidance function that invokes action to avoid collisions with obstacles in the vicinity of the robot that are identified by the external sensing function, and (5) a path planning function that determines the robot's final and intermediate destinations, speed of movement, and other similar parameters. The robot generates its trajectory based on the instructions from path planning, the robot's current position as determined by the localization function, and the requirement to avoid obstacles, and uses the "moving servo control" function to operate the robot's drive mechanisms with the speed and direction required to follow this trajectory.

Autonomous movement refers to a form of positioning control whereby the robot moves to a target destination specified by path planning using the robot's current position determined by the localization function as feedback, and is the function used to travel to the target destination by modifying its trajectory appropriately (or, if necessary, halting temporarily) if a collision with an obstacle in its path is predicted.

One of the challenges for the practical implementation of such systems is how to come up with external sensing methods that can accurately sense the environment through which the robot is moving. Sensing methods include techniques that work by energy projecting type, such as laser scanners, milliwave radar, and ultrasonic radar, and image processing techniques such as stereo vision. Similarly, satellite-based GPS (global positioning system) is a commonly used technique for determining absolute position. Localization is essential if the vehicle is to reach its target destination reliably and this requires a way of obtaining precise information about the vehicle's own position by effectively utilizing different forms of information that complement each other such as position data obtained using internal sensors and external sensing and absolute position data obtained directly using methods such as GPS. A reliable way of avoiding collisions with people and other obstacles is an important consideration if autonomous moving robots are to be used in environments that contain people. This requires external sensing methods that reliably identify obstacles in the robot's path and the development of highly robust collision avoidance algorithms that can either detour around a detected obstacle without loss of movement efficiency or, if necessary, come to a temporary halt.

OUTDOOR AUTONOMOUS MOVING ROBOT

Hitachi has participated in the Tsukuba Challenge [RWRC (Real World Robot Challenge)][1] which has been held in the city of Tsukuba in Ibaraki Prefecture since 2007 with the aim of developing core technologies for implementing new transport systems and has been demonstrating an outdoor autonomous moving robot which in a 2009 test successfully traveled on public roads for a distance of 1.1 km

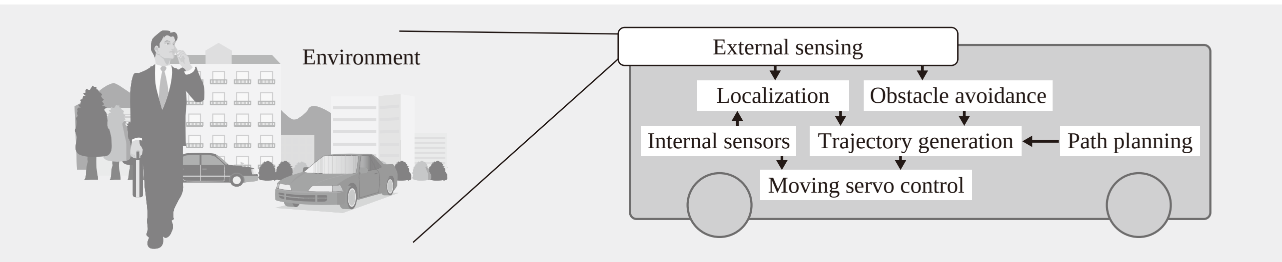


Fig. 2—Block Diagram of Autonomous Moving Control System.
The vehicle is equipped with internal sensors and external sensing that sense the surrounding environment together with functions that utilize this information for identifying the vehicle's location and avoiding obstacles.

under its own control. The practical implementation of outdoor autonomous moving technology is an area of considerable international activity, one particular example being the 2007 DARPA (Defense Advanced Research Projects Agency) Urban Challenge (part of the DARPA Grand Challenge)[(2)], a race for autonomous vehicles on urban streets run by DARPA in the USA. This was a pioneering test of the operation of a number of autonomous vehicles on urban streets without any people. In contrast, the initiative being described in this article involved travel on sidewalks, park footpaths, and other pathways with a mixture of circumstances and more complex topography than roads, and demonstrated autonomous movement in an environment shared with people and filled with a large but indeterminate number of pedestrians. The work can be thought of as another step toward the wider adoption of mobile robots in a future in which people and robots act in partnership.

Fig. 3 shows a photograph of the outdoor autonomous moving robot.

The robot uses a simple differential two-wheel type drive mechanism. The sensors used for external sensing consist of a large number of laser scanners which are able to measure shape data directly from the outdoor environment. By optimizing the roll and pitch orientation of the two laser scanners located at the top of the robot[(3)], the system can acquire three dimensional shape data with few gaps for the regions above and to the sides of the robot and also the path surface as the robot moves along. Another forward-facing and downward-tilting laser scanner is fitted in the robot's mid-section to obtain a reliable assessment of the path surface and two laser scanners oriented in the horizontal direction are attached at the front and rear of the robot's base to improve the performance of obstacle detection. Differential GPS is also used to obtain the robot's absolute position. Fig. 4 shows an example of the 3D (three-dimensional) data obtained by the laser scanners.

The left side of the figure (a) shows 3D shape data generated from the robot movement test site shown on the right (b). The development tested the idea of using the shapes of structures located above the height of a person as positioning landmarks that would not be influenced by people, vehicles, or other objects moving at ground level. The figure shows an example of how the dots representing the stand of trees at an elevation of 2.5 to 3 m provide good landmarks. The path surface has also been detected without any gaps and the shapes representing the feet of the people standing around the robot have also been successfully acquired.

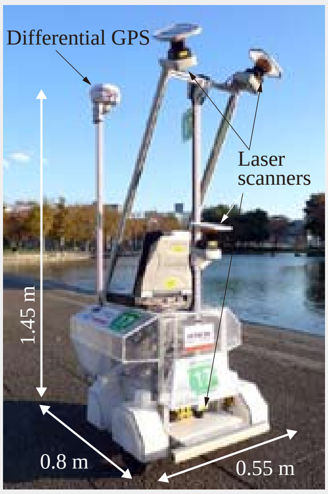
The localization function achieves its robust position estimation by basing it on the following three pieces of self-position measurement data.

(1) Odometry measurement

Self-position estimation using a dead reckoning calculation based on sensor data from encoders that measure the number of wheel rotations and a rate gyroscope that measures orientation

(2) Scan matching positioning

This estimates the robot's current position by comparing the 3D dot cluster for the surrounding environment obtained by the laser scanners with a map generated from stored dot cluster data.



GPS: global positioning system

Fig. 3—Outdoor Autonomous Moving Robot.
This outdoor autonomous moving robot was entered by Hitachi in the 2009 Tsukuba Challenge [RWRC (Real World Robot Challenge)] held in November 2009.

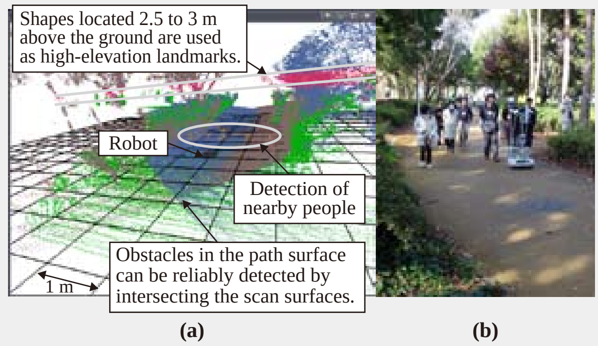


Fig. 4—Example Measurement of Moving Environment Using Laser Scanner.
The figure shows example 3D (three-dimensional) data obtained by three forward-directed laser scanners on the outdoor autonomous moving robot.

(3) GPS positioning

This estimates the robot's absolute position using a base station as the origin.

Although odometry measurement can perform localization reliably and continuously, the cumulative error associated with movement progressively increases. In contrast, scan matching and GPS, although only intermittently effective, can provide absolute position data. Also, because the scan matching technique selected for this development uses high structures such as buildings or stands of trees as its landmarks, its localization performance in crowded locations is very good. GPS, on the other hand, performs well in places where the robot is under an open sky free of anything that might interfere with the radio signals from the GPS satellites. The error characteristics of these methods are complementary and their respective position estimates can be combined stochastically using an extended Kalman filter and outliers eliminated using the chi-square test to achieve accurate and reliable localization.

Fig. 5 shows an example of localization performance. The example involves a trajectory that passes near buildings and the localization results are in good agreement with the actual trajectory thanks to the success of the chi-square test in eliminating the effect of outlier errors in the GPS position (multi-path error caused by signal reflection off the building walls).

As shown in Fig. 6, obstacle avoidance works by setting up a potential field defining the obstacle risk level which it treats as a repulsive force in the vicinity of the robot along with waypoints along the target trajectory which it treats as an attractive force. The robot avoids proximity to obstacles as it moves along its target trajectory by assigning the sum of these forces to control points set in the robot's direction of movement. Collision safety is improved by limiting the robot's velocity based on the size of the repulsive force exerted by obstacles.

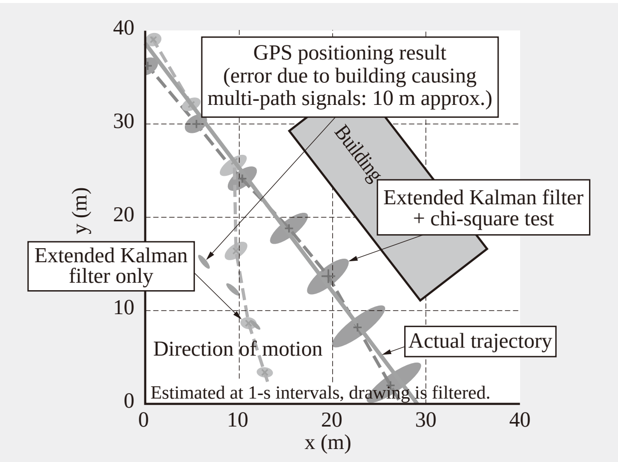


Fig. 5—Localization Accuracy Using Extended Kalman Filter and Chi-square Test.
Despite an error suddenly appearing in the GPS position data, reliable positions that followed the actual trajectory were produced using the localization results of the laser scanners and other methods.

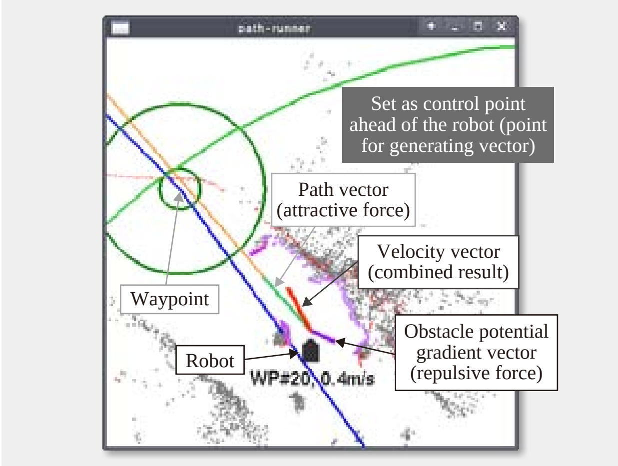


Fig. 6—Obstacle Avoidance Control.
The robot is able to avoid obstacles as it moves by treating obstacles as a repulsive force and waypoints as an attractive force and moving in the direction determined by the sum of these forces.

LOGISTIC SUPPORT ROBOT

An effective approach to logistics automation used in factories, distribution centers, and similar sites in the past has been to operate AGVs (automated guided vehicles) that travel along guidelines formed from magnetic tape or other markers embedded in the floor. However, as recent times have seen increasing use of cell production systems and other layout-free configurations in factories, Hitachi, Ltd. is working with Hitachi Industrial Equipment Systems Co., Ltd. on the joint development of logistic support robots to provide a flexible means of transport that does not require guidelines or other fixed infrastructure. The initial aim is to commercialize the next generation of logistics robots and, for the longer term, the development is working towards using this framework as a basis for supplying autonomous moving robot platforms that are capable of both indoor and outdoor operation.

Fig. 7 shows a photograph of the robot.

The robot's undercarriage uses a four-wheel steering mechanism with a small turning circle including the ability to perform spin turns and move

Fig. 7—Logistic Support Robot.
A feature of the logistic support robot is that it does not require guidelines and other fixed infrastructure. Deployment is planned at sites such as production lines and distribution centers.

sideways. The robot's sensors include a laser scanner that detects the shape of obstacles and other details of what is in front of the robot and an omni proximity sensor that can detect nearby obstacles around the robot in any direction. Bumper sensors are also fitted around the full circumference of the robot's undercarriage to detect any contact with obstacles and trigger an emergency stop. Designed to carry small items, the robot has a comparatively compact design with volume of 60 cm^3 and a payload of 20 kg. Its maximum speed is 1 m/s (3.6 km/h) which is equivalent to walking pace.

The localization function measures the shape of the surrounding environment with the laser scanner and uses the information obtained to determine the robot's position. Fig. 8 shows how localization is performed. The robot identifies its position by overlaying the horizontal cross section of its surroundings obtained by the laser scanner on previously acquired shape map data for its movement range and searching for a match. As shown in Fig. 9, the map data is generated by acquiring shape data as the robot is moved around its range and then progressively determining its position by overlaying the shape data for each increment of movement. Accordingly, when used in factories that use cell production or similar systems that involve frequent changes in layout, the task of reconfiguring its movement paths does not take long because the map data can be obtained quickly and easily simply by driving the robot around its range.

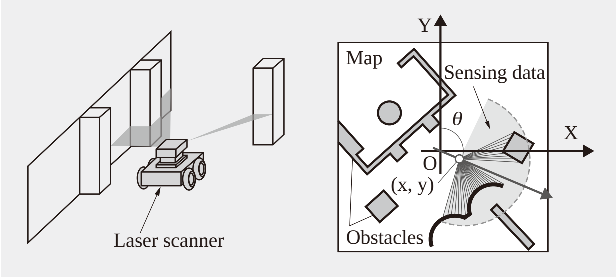


Fig. 8—Localization Method.
The localization function compares the shape of the surroundings acquired by the laser scanner with stored map data to determine the robot's current position and orientation.

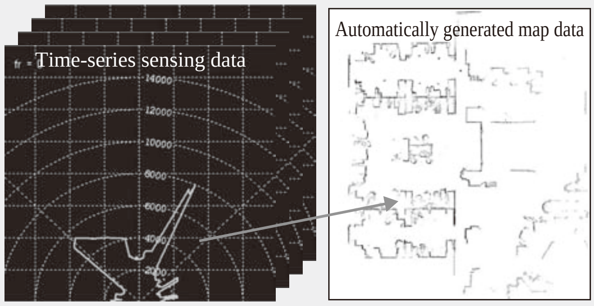


Fig. 9—Map Generation Process.
The map data shown on the right is built up by offsetting successively acquired instances of chart data based on position data acquired at the same time and storing the results as a map.

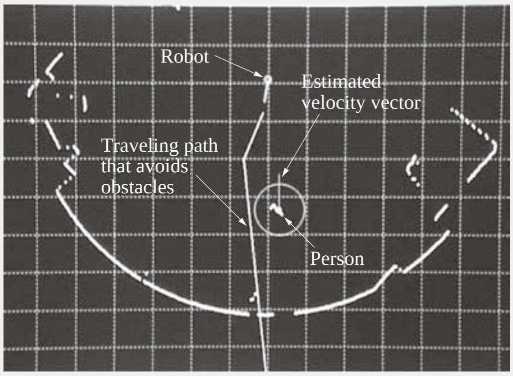


Fig. 10—Dynamic Generation of Traveling Path that Avoids Obstacles.
The robot progressively generates a safe collision-free path by estimating the likelihood of future collisions based on the velocity vector of people and other obstacles.

To provide safe operation when used in environments that contain people, this development adopted dynamic obstacle avoidance technology(4) from a previous development of a robot designed to coexist with people(5). The robot estimates the relative velocity vector of moving objects such as pedestrians from the movement history of obstacle position data acquired by the forward-facing laser scanner and determines whether a collision will occur if it continues to move along its planned traveling path. If a collision is predicted, the robot generates a new traveling path with a safety margin. The robot repeats this processing continuously to avoid the multiple moving objects that may appear as it moves to its destination (see Fig. 10).

CONCLUSIONS

This article has described an outdoor autonomous moving robot and logistic support robot, two examples of work Hitachi is doing in response to the challenges of autonomous moving technology.

The future use of autonomous vehicle systems that can act as a means of transport in urban environments is seen as a promising solution to the looming problem of an aging society. The outdoor autonomous moving robot described in this article demonstrated at the Tsukuba Challenge (RWRC) that it is capable of moving autonomously through environments containing people with sufficient accuracy that it does not deviate from footpaths. Hitachi plans to accelerate practical development through demonstrations at the Tsukuba City Robot Zone. Based on the know-how built up through technical demonstrations like this, Hitachi aims to implement autonomous transport systems with low operating costs designed to allow use by the elderly including sharable vehicles able to operate autonomously.

In the field of logistic support robots, in addition to its objective of commercializing an indoor autonomous moving system, Hitachi is also looking to develop this technology further to provide systems able to move and operate autonomously in outdoor environments. The aim is to provide services that offer considerate support to the lifestyles of the elderly by using this system to provide automated delivery to every home to help with things like routine shopping and assisting the elderly with carrying when they venture outside their homes. Together with the existing movement toward encouraging the adoption of electrically operated vehicles, it is also anticipated that making widespread use of electrically powered robot systems as a foundation for social systems for the elderly will make a major contribution to reducing the burden on the environment.

The obstacle avoidance function described in this article was developed as part of a joint venture between the University of Tsukuba and Hitachi and utilizes the results of research undertaken jointly with Professors Takashi Tsubouchi and Shin'ichi Yuta at the University of Tsukuba Intelligent Robot Laboratory.

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