Development of Autonomous Vehicle
Overview of Autonomous Driving Demonstration in ITS World Congress 2013

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Abstract: Recently, fully automated autonomous vehicles have been developed, and field examinations in public road have also been conducted, especially in United States. In this paper, preparation of our laboratory toward field examination of the autonomous vehicle is reported. Additionally, overview of demonstration in the ITS world Congress 2013 (ITSWC2013) is reported.

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1 INTRODUCTION

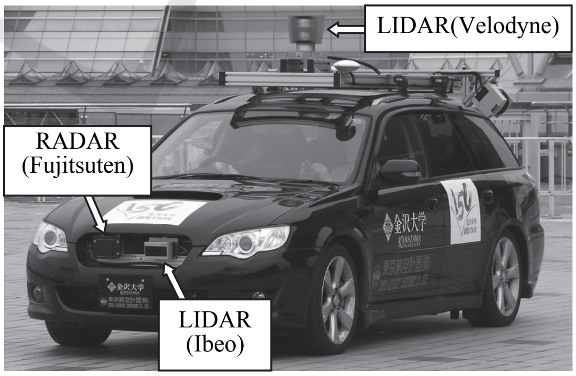
Recently, there are many researches related to autonomous vehicle in all over the world (Montemerlo, 2008), (Broggi, 2006). Especially, in the United State and EU, some tests on public road have been conducted and researches related to this area become very popular.

Unfortunately, in Japan, autonomous vehicle test in public road have not been permitted, however some vehicles are demonstrated in some events in recent years. For example, in Tokyo Motor show 2011, Toyota Motors exhibits autonomous vehicle named A.V.O.S. (Advanced Vehicle Operation System). Moreover, in last year, ITS World Congress, which is one of the biggest conferences in this field, is conducted at Tokyo Japan, and some autonomous vehicles were demonstrated.

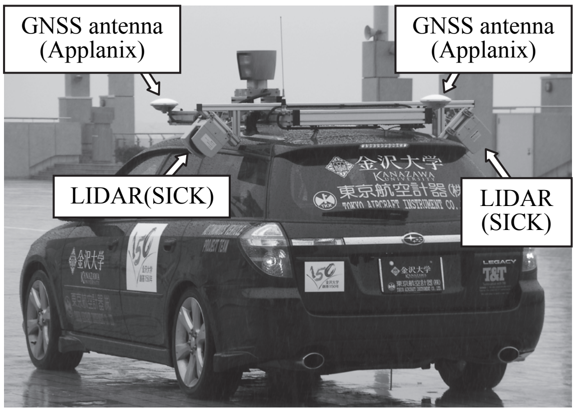
In this paper, system overview of autonomous vehicle developed by Kanazawa University is introduced, and overview of demonstration in the ITS World Congress 2013 is shown.

2 ONBOARD EQUIPMENT

Figure 1 shows our autonomous vehicle. In this vehicle, various sensors and actuators for autonomous navigation are equipped. Therefore, to drive such equipment, additional sub-battery is installed in trunk room, and the sub-battery has a mechanism to be charged by an alternator, which is exchanged to large power from original one, via isolator. Moreover, a 100V 1500W inverter system is also equipped.



(a) Sensors for obstacle detection



(b) Sensors for localization

Figure1: Onboard perception sensors.

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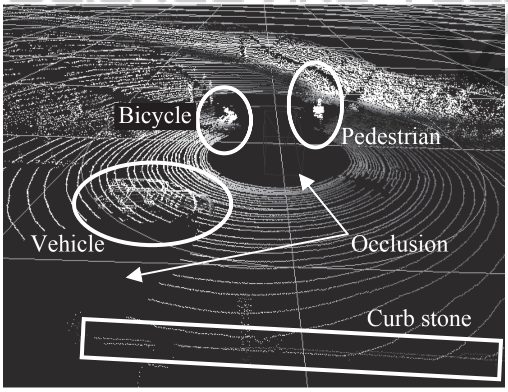
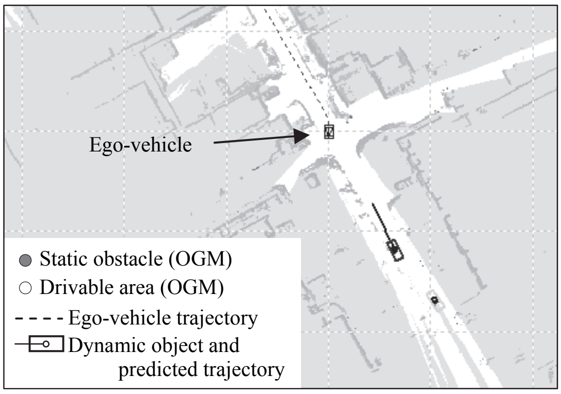
In this vehicle, in order to percept under complex environment like urban road, some sensors are equipped. In front of the vehicle, a multi-layered LIDAR (SICK LD-MRS) and millimeter-wavelength RADAR (Fujitsu-ten) are installed. These sensors are used to detect distant obstacles. Moreover, three LIDARs are equipped on roof of the vehicle. The one of three LIDAR is a high definition LIDAR (Velodyne HDL64E-S2), and this is used to detect middle range obstacles. In this LIDAR, 64 laser transmitters are embedded, by rotating 360 degrees around vertical axis, three-dimensional position of all direction can be given at 10 times per second. From the LIDAR, since dense three-dimensional information of 1.3 million point per second can be given, three-dimensional position of almost all vehicles, sidewalls, road surface, and so on can be given up to about 60 meters as shown in figure 2(a). The rest of two LIDARs(SICK LMS 291-S05) are used to detect the lane markers. They are positioned in each side of vehicle looking at the road near the vehicle.



(a) Raw laser point cloud



(b) Example of typical scene percepted by Environment Perceptor.

Figure 2: Overview of Environment Perceptor.

In addition, to obtain precise vehicle trajectory for always, GNSS/INS (Applanix POS LV220) is used. This system consists of Distance Measurement Unit (DMI), Inertial Measurement Unit (IMU), and two GNSS receivers, which includes a GPS/GLONASS azimuth heading measurement subsystem, and thereby it is possible to obtain vehicle position at 100Hz by Kalman filtering for tightly coupled GNSS/INS integration. Therefore, it is possible to measure vehicle position with accuracy of 3cm in position, 0.05 degree in attitude when GPS/GLONASSS signal can be observed, and RTK correction signal can be given. Additionally, this system has an accuracy of less than 0.7m after 1km or 1minute of travel without GPS/GLONASS signals.

In this vehicle, actuators are installed on steering, gas pedal, brake, shift and parking brake to realize autonomous driving. Moreover, to realize natural driving, horn switch, turn signal and hazard switch can also be controlled by computer. These actuators are controlled via motor controller EPOS2 manufactured by MAXSON motor, real-time control can be achieved via CAN-bus network.

3 SYSTEM OVERVIEW

Figure 3 shows a system overview of our autonomous vehicle. The software architecture used in our vehicle is designed as a data driven pipeline, which individual modules process information asynchronously. Each module communicates with other modules via an anonymous publish/subscribe message passing protocol.

As shown in figure 3, our autonomous vehicle system is roughly composed of three modules of Perception, Path planning and Controller modules. In perception modules, there are three modules of Lane marker detection, Map matching and Environment perception. The lane marker module extracts lane marker on both side of the vehicle by using side looking LIDARs. From these LIDARs, distance and reflectivity can be obtained, and lane marker positions, curvature of the lane marker are estimated from these measurement. The map matching module refine pose estimate given from the GNSS/INS system (Suganuma, 2011), since typically GNSS/INS system has significant drift error under urban environment. The rest of perception module is Environment Perception, which is main process of these modules and is used to generate important information to safety driving. The Environment Perception extracts static obstacles and estimate motion of dynamic object around the

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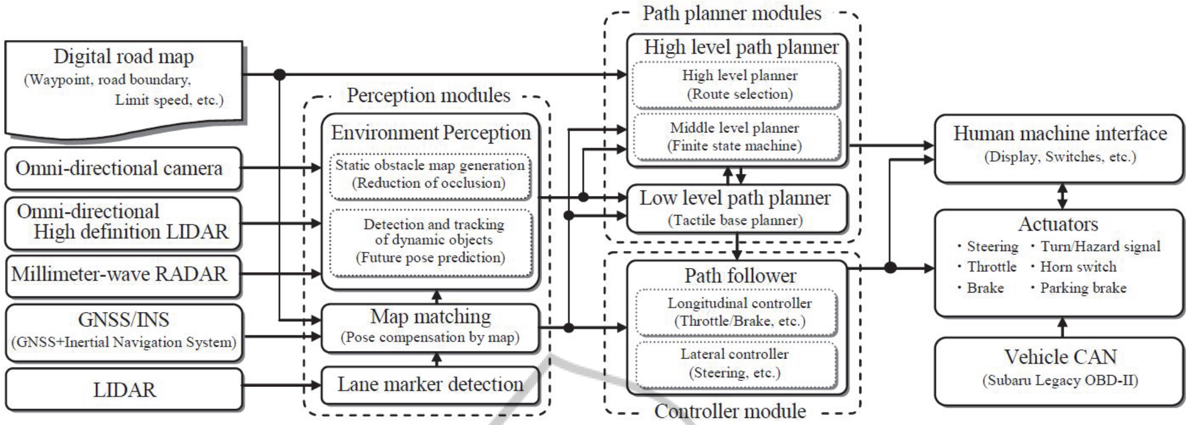
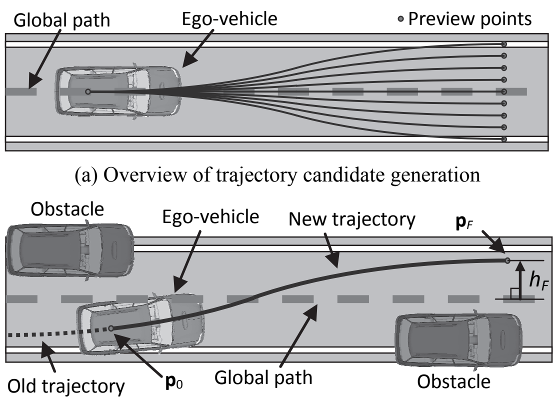


Figure 3: Overview of system architecture of the autonomous vehicle.

vehicle based on onboard sensors. The main sensor used in this module is a LIDAR mounted on roof of the vehicle. Figure 2(a) is an example of point cloud given from this LIDAR. As mentioned above, dense three-dimensional information of 1.3 million points per second can be given. However, even such dense point cloud can be given; there still exist occluded region as shown in figure 3(a). Therefore, in our system, Occupancy Grid Maps (OGM) (Elfes, 1989), which is a method to estimate posterior probability of existence of obstacle, is adopted. Since the OGM is a method to extract static obstacle, we can also extract measurement given from dynamic obstacle by extracting inconsistency of OGM. Then extracted measurement belongs to dynamic obstacle is clustered, and the clustered objects are tracked using Interacting Multiple Models (IMM) Filter to estimate its motion (Bar-Shalom). Figure 2(b) is an example of typical scene perceived by Environment Perception.



(a) Overview of trajectory candidate generation

(b) Connection between new and old trajectory

Figure 4: Overview of local path planning.

The Path planning modules generate feasible trajectory which the vehicle can be safely navigated based on information comes from Perception modules. In Path planning modules, there are two main modules. The High Level Path Planner module consists of High Level planer and Middle Level Planner. The High Level Planner selects optimal path from digital map like car navigation system. Middle Level Planner decides driving action like forward driving, lane change, stop, and so on depending on the situation based on Finite State Machine. The Low Level Path Planner module generates trajectory, which the autonomous vehicle finally follow. In our implementation, as shown in figure 4(a), multiple path candidates are generated simultaneously, the best trajectory is chosen based on multiple evaluation value such as safety, lateral offset from global path, and so on. Each trajectory of these candidates is generated to become minimum lateral jerk and to be smoothly connected to old trajectory as shown in figure 4(b).

The Controller modules play an important role to follow trajectory generated by Path Planning modules. In these modules, steering, gas pedal, brake commands are computed. Additionally, horn, turn signal, hazard, parking brake and gear shifting command are also generated. Then these commands are directly sent to the actuator via CAN.

4 DEMONSTRATION IN THE ITS WORLD CONGRESS 2013

4.1 Implemented Functions

For the realization of intelligent autonomous driving, it is necessary to implement many functions to path planner modules. Following are basic functions implemented before ITS World Congress 2013.

- Automatic Route Selection

A function to select optimal route like car navigation system was implemented in High Level Path Planner module. The main difference from car navigation systems is to consider multiple lanes, and optimal lane is selected in case of multiple lane roads.

- Velocity Keeping

In case of no preceding vehicle conditions, a function to keep pre-set velocity was implemented in Low Level Path Planner Module. However, user pre-set velocity is overwritten in case of some situations, and more slow velocity is adopted to keep safety. First situation to overwrite the pre-set velocity is a case where user pre-set velocity is larger than limit speed described in digital map. It is clear that we must to keep limit speed by law. The second situation is the case where curvature or curvature rate of the course is significantly large. If the vehicle was drove at high speed, large lateral acceleration will be occurred to passenger in case of large curvature road, and steering wheel will be rotated at high speed in case of large curvature rate road. To avoid such dangerous situations, pre-set velocity is changed to smaller one in such situations. By these considerations, slowdown before curve is achieved.

- Distance Keeping

In case where a preceding vehicle exists, a function to keep its inter-vehicle distance was implemented in Low Level Path Planner module. In case where preceding vehicle exist on far position, autonomous vehicle is decelerated, and diminish its inter-vehicle distance until the distance reaches optimal value.

- Stop at Designated Position

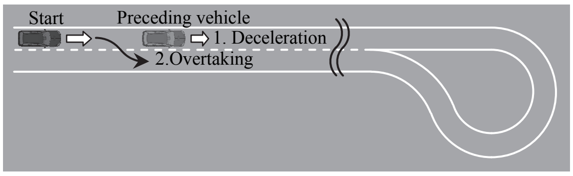
In case when the autonomous vehicle reaches destination, stop line and so on, a function to stop at designated position was implemented in Low Level Path Planner module.

- Obstacle Avoidance

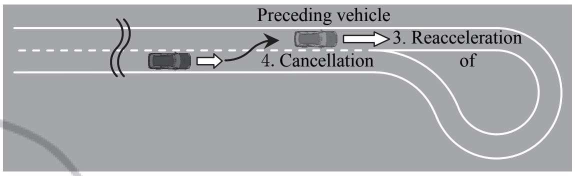
In case where obstacles exist within own lane, a function to avoid the obstacles is implemented in Low Level Path Planner module. However, there are many situations on obstacle avoidance. Therefore minimum jerk trajectory is selected within drivable trajectory depending on its situation to become comfortable driving.

- Overtaking

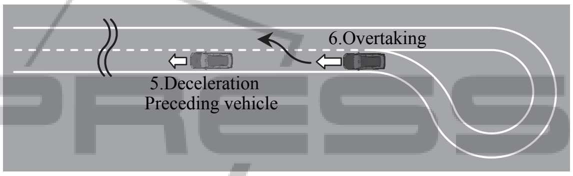
In case where obviously slow preceding vehicle exists and there is a passing lane, a function to overtake slow preceding vehicle was implemented. This overtaking action is implemented on a Finite State Machine on Middle Level Path Planner, achieved by changing optimal lane, suggested by high level path planner, to passing lane.



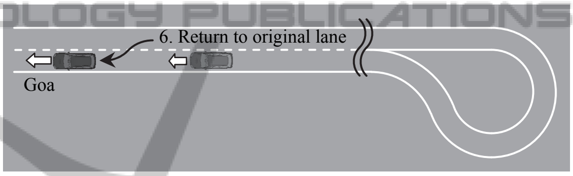
(a) Step 1 and 2



(b) Step 3 and 4



(c) Step 5 and 6



(d) Step 6 and 7

Figure 5: Overview of demonstration in the ITS World Congress 2013 (ITSWC2013).

These basic functions were adequately tested on a test course, and it was confirmed that it works reliably up to about 40km/h.

4.2 Demonstration in the ITS World Congress 2014

The autonomous driving demonstration in ITS World Congress 2013 was held in Tokyo. As shown in Figure 5, the demonstration site is a double lane course, and round trip autonomous driving was conducted in the course.

The scenario of the demonstration was as follows:

- Step 1. At first, preceding vehicle was driven at about 20km/h manually and decelerated to about 10km/h.
- Step 2. The autonomous vehicle keeps inter-vehicle distance while preceding vehicle was constant velocity of 20km/h. After detection of preceding vehicle deceleration, the autonomous vehicle automatically changes its lane and

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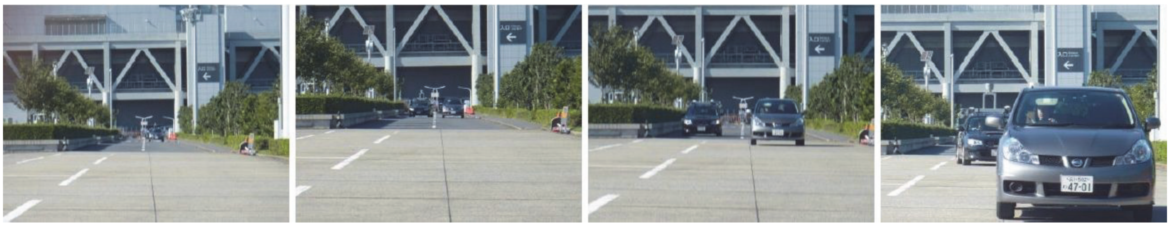
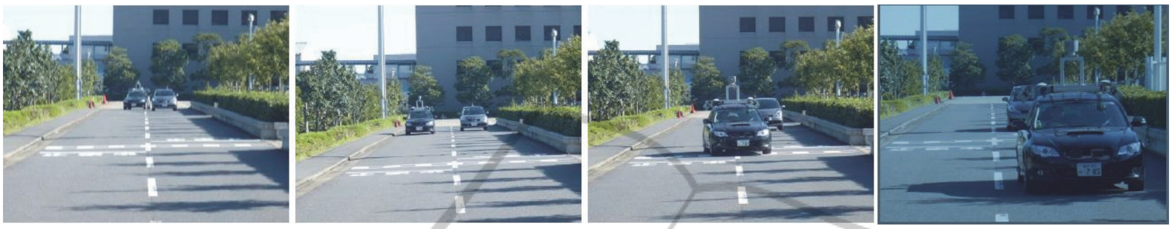


(a) Re-acceleration of preceding vehicle while overtaking



(b) Overtaking

Figure 6: Results of demonstration in the ITS world congress 2013.

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conducts an overtaking action.

- Step 3. Preceding vehicle was re-accelerated up to about 40km/h manually and overtaking action of autonomous vehicle was blocked.
- Step 4. After reacceleration of preceding vehicle, autonomous vehicle cancel overtaking action and return to original lane.
- Step 5. After U-turn of the farthest position of demonstration course, preceding vehicle was decelerated to about 10km/h manually.
- Step 6. The autonomous overtake preceding vehicle and drive in front of the manually decelerated vehicle.
- Step 7. The autonomous vehicle stops automatically at manually set destination.

Figure 6 shows some portions of above demonstration scenario. Through the demonstration, about 250 passengers including not only specialists from universities, companies and government, but also some medias and journalists experienced our autonomous demonstration. Some comments were received from participants but there were no negative opinions, and there were almost good impressions.

5 CONCLUSIONS

In this paper, system overview of autonomous vehicle developed by Kanazawa University is introduced, and overview of demonstration in the ITS World Congress 2013 is shown. In the future, we will extend our path planner modules to be able to use in more complicated situations, and improve robustness to be able to use in bad weather conditions for the realization of public road test in Japan.

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