

DEVELOPMENT OF A TEST-BED FOR OUTDOOR AGV RESEARCH

by Teoh Eam Khwang, Wijerupage Sardha Wijesoma, Wang Dan Wei, Arjuna Prabhath Balasuriya, Kodagoda Ranadheera Sarath Kodagoda, Lu Zhongkang, Ye Cang and Tan Chai Soon

ABSTRACT

The development of techniques for autonomous navigation and control of vehicles has become an important and active research topic in the face of emerging markets for advanced Autonomous Guided Vehicles (AGVs) and mobile robots. In this paper, we describe the on-going development of a test-bed for outdoor AGV research. There are four major aspects to the development of this system. They are the sensor module, vehicle and controller module, navigation module and system integration module. In this paper, the work completed, results obtained and the plan for the next phase of this research project will be presented.

INTRODUCTION

AGVs have found many applications in manufacturing, military and health, to name a few areas. However, the AGVs' depth and breadth of penetration into the markets have been severely hampered due to their present degree of navigational autonomy in real-world environments. In the face of the above and the emerging markets for advanced AGVs, the development of techniques for autonomous navigation and control of vehicles has become an important and active research topic. By autonomous navigation, we mean the vehicle's capability of purposefully moving without any human intervention.

In our approach, we designed a vehicle (see Figure 1) and plan to construct it out of a golf car. In our next phase of work, sensors such as the camera for the vision system; differential global positioning system (DGPS), accelerometers, gyroscope, compass, rate sensors and wheel encoders for localization; laser scanner, proximity sensors and sonar ring for obstacle avoidance will be considered. In addition, research work on the development of on-line navigation system, global path planning and the complete system integration will be carried out.

Following sections will elaborate more about the various modules of the AGV.

OVERVIEW OF THE TEST-BED

One of the ultimate goals is to create an autonomous robot. Such robot will accept high-level descriptions of tasks and will execute them without further human intervention. In achieving this goal the designers have to face challenging and rich computational and mechatronic issues. Indeed, the development of a test-bed itself is rich in research and development.

When developing an AGV for outdoor applications, one of the major concerns is its mechanical design. The low

weight structure and the load distribution are very important, which directly affects the performance of the vehicle. In our approach (see Figure 1), the vehicle body is of hybrid design, possibly consisting of supporting aluminum structure, which is light and very rigid, and a perspex outer skin. Low air drag coefficient can effectively reduce aerodynamic resistance of the body. In general, it is more difficult to reduce the air drag coefficient as the vehicle length is shortened [1]. However, it can still be reduced through a good balance among the following features [1]: tapering of the front and rear ends, flat under-floor design and adoption of an undercover.

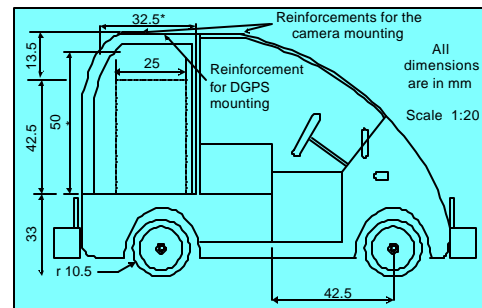


Figure 1: The Vehicle Structure

Another major issue in developing an AGV is the design of appropriate computer architecture. The overall computer architecture proposed for the navigation system is as shown in Figure 2. There are three single board computers (PIII, 650Mhz) forming a Local Area Network (LAN) provides the required computing power. *Processor A* acts as the host computer and it communicates with the remote computer via a wireless Ethernet (within 150m radius) as well as via a radio modem (more than 150m radius). Remote computer is used for data monitoring and control. *Processor B* is dedicated to provide high computing power required for image processing. *Processor C* does all low-level data acquisition and control.

Developing the technologies necessary for autonomous robot is a formidable undertaking with deep interviewed ramifications in automated reasoning, perception and control. It raises many important problems such as: what sensors to be utilized, how to fuse them in order to achieve the best solution to various navigation problems, how to achieve motion planning and how to obtain the best control of the robot. Therefore, this test-bed can be utilized in the future for the researchers in Nanyang Technological University, who wish to develop their own strategies in various modules of out door mobile robot. The engineers in the industry may approach this vehicle to investigate and develop their special requirements. Further, any other research institution, industry or university may have a

chance to purchase this mobile robot in order to carry out their own research.

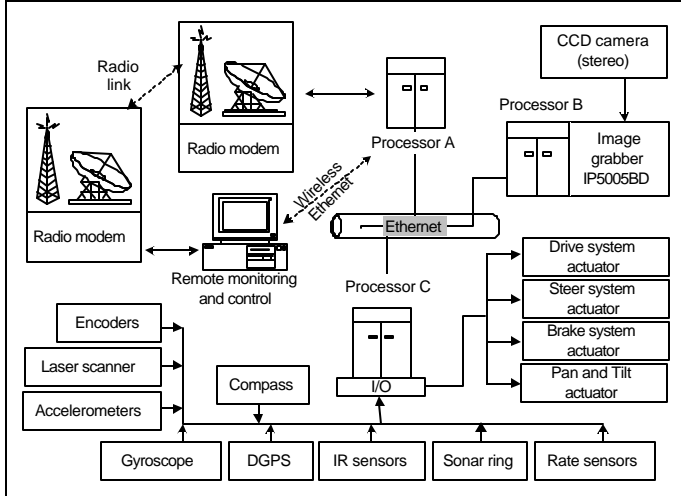


Figure 2: Computer Architecture for the Navigation System

SENSOR MODULE [2-8]

A key requirement for autonomous navigation in an unconstrained and uncertain environment is that the system be capable of sensing the surroundings to determine where the AGV is at present (localization) and where it is moving. This is in order for the AGV to be able to respond intelligently to a changing situation or environment. As is the case with many autonomous navigation systems, all the sensors are placed on board the vehicle. Sensory modules on board the actual vehicle include optical encoders, rate sensors, accelerometers, gyroscope, compass, DGPS, CCD color camera, laser scanner, sonar and proximity sensors. The sensors provide complementary information as regards the internal state of the vehicle and the current state of the environment. Therefore, a proper sensor fusion algorithm can be developed in order to find localization and obstacle information.

The vision system is used for the purposes of localization and local navigation. For the purpose of outdoor navigation, two novel lane detection algorithms have been developed. In one approach, the lane edges are detected directly on camera image and then those edges are converted into real world coordinates (see Figure 3). Catmull-Rom spline-based lane model and a free-form snake-based (FFSB) algorithm [7], which describes the perspective effect of parallel lines, has been developed. In the other approach, it is assumed that the lanes are on a flat ground and first; the camera image is projected on to the ground image and then detection of the edges on the ground image. In this algorithm, deformable templates are used and circular arc is applied to describe the lane shape with a limited range.

Differential Global Positioning Systems (DGPS) are gaining widespread popularity as a navigational aid, especially in providing absolute position information. We developed a position estimation system by utilizing information from different sensors, viz. DGPS, rate gyroscope and odometers via extended Kalman filtering technique.

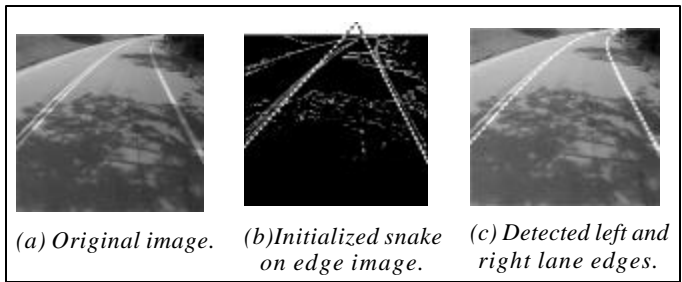


Figure 3: Experimental Results of FFSB Algorithm

VEHICLE AND CONTROLLER MODULE [9-12]

Autonomous control is an important function of the AGV. The main function of the control system is to track a desired path specified by the local navigation system as accurately as possible. The problem of control is compounded by the fact that the model dynamics are highly non-linear and of a higher order. Further, model parameters are either unknown or uncertain, and also subject to variation due to changing load and environmental conditions. Detailed and accurate kinematic and dynamic models of the non-holonomic AGV were developed for the purposes of designing and testing of suitable controllers and navigational strategies. Despite the model complexity of the AGV, linear PD/PID control methods have been applied yielding adequate performance at slow speeds. To enhance performance, several non-linear methods are being investigated, including input-output feedback linearization and the sliding mode control.

Considering the complexity of the vehicle dynamics and high non-linearity, the difficulty of obtaining the actual vehicle dynamic parameter values, the variability of certain model parameters and the human knowledge available on speed and steering control, fuzzy control methods are also being investigated [12]. The experimental results of such a fuzzy control scheme, which consists of a Lateral Fuzzy Controller (LAFC) and a Fuzzy Drive Controller (FDC) is as shown in Figure 4.

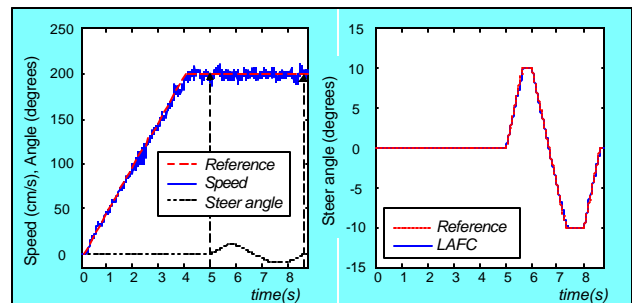


Figure 4: Experimental Results of FDC and LAFC in Simultaneous Operation.

NAVIGATION MODULE [13-15]

The navigation module is implemented using a behavioral approach [14]. That is, each of the complex local navigational tasks that need to be carried out is analyzed in terms of primitive behaviors and expressed as an aggregation of such behaviors. A fuzzy logic approach to

behavior synthesis and integration has been adopted. The fuzzy behavioral methodology provides a natural means of incorporating human navigation skills in terms of linguistic information. The fuzzy behaviors which are considered to be necessary include, *Wall-Curb Following*, *Obstacles Avoidance*, *Obstacles Contouring*, *Narrow Path Maneuver*, *Cornering*, *Route Following* and *Wandering*. Each of the behavior is synthesized based on appropriately fused sensory data received from the complementary sensor devices. The traveling profile of the AGV performing a *left curb following* and *right turn* at a junction is as shown in Figure 5

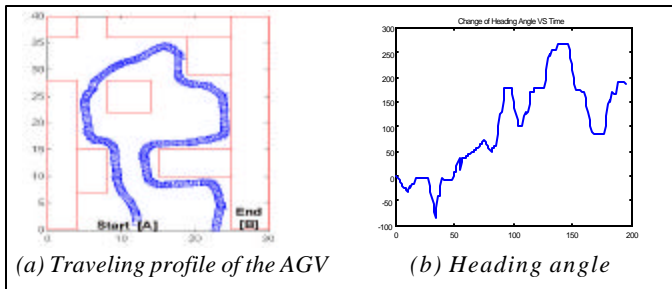


Figure 5: AGV Navigation using IR Sensors.

A novel behavior fusion method for the navigation of AGV in unknown environments also investigated. The proposed navigator consists of an Obstacle Avoider (OA), a Goal Seeker (GS) and a Navigation Supervisor (NS). The fuzzy actions inferred by the OA and the GS are weighted by the NS using the local and global environmental information and fused through fuzzy set operation to produce a command action, from which the final crisp action is determined by defuzzification. Simulation shows that the navigator is able to perform successful navigation tasks in various unknown environments, and it has smooth action and exceptionally good robustness to sensor noise [15].

CONCLUSION

There are many factors that need to be taken into account in the development of an autonomous navigation system for outdoor AGVs. Among them, the design of the vehicle structure, computer architecture, actuation system, its control and utilization of various sensors play an important role. Further, it is important that the autonomous navigation system be intelligent to act both reactively and proactively to the changing environmental conditions. The realization of such an architecture involves the development of subsystems for sensing, path planning, localization, local navigation, and path control. A judicious choice of good sensors for determining the internal state of the AGV and the state of the environment is of paramount importance. This is, especially in an outdoor environment, due to many factors such as weather, changing environmental conditions, road conditions, etc., a few sensors acting independently may not be adequate. Thus, an array of sensors needs to be used with appropriate sensor fusing technology. Advanced non-linear control methods are a necessity in the controller development as AGV kinematic and dynamic models are extremely non-linear and complex. A local navigation system based on a behaviorist decomposition of tasks is

highly suited given the complexity of the problem of local navigation in the presence of environmental uncertainty and modeling difficulties. The use of a fuzzy logic approach to behavior synthesis and coordination has the advantage of representing and handling uncertain and imprecise knowledge about the environment through sensors. Further, a fuzzy approach provides a natural means of incorporating human navigation skills in terms of linguistic information.

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