An integrated hardware/software platform for both Simulation and Real-Time Autonomus Guided Vehicles Navigation

Luca Baglivo
Mariolino De Cecco
Francesco Angrilli
CISAS, Center of Studies and Activities for Space
Via Venezia 1, Padova, 35131 Italy.
Phone +39-049-8276795; Fax +39-049-8276785
E-mail: mariolino.dececco@unipd.it

Francesco Tecchio
Angelo Pivato
ItalProject S.r.l.
Via L.Da Vinci, 35015 Galliera Veneta, Italy

KEYWORDS
Simulation, AGV, potential field control.

ABSTRACT

This paper presents an integrated hardware/software platform for the simulation of real-time Autonomus Guided Vehicles (AGV) navigation. The platform employs the same software architecture and code actually running onboard the real-time hardware to perform off-line the control and navigation simulation. By means of this approach it is possible to optimise the control parameters, simulate the logistics or the achievement of the path planned and also make the vehicle actually run with the same all-in-one software. This method allows to reduce development time necessary for debugging, optimising control algorithms and identifying system and/or control parameters; the same software is exploited also for variables flow control and for monitoring the whole state of the system.

The above platform was used for the optimisation of AGV potential field control for real-time obstacle avoidance.

INTRODUCTION

The intense competition in manufacturing requires materials handling systems that are agile and capable of reconfiguration, in order to have manufacturing environments highly reconfigurable and responsive to accommodate product, factory and process changes. Modern AGV can exploit such capabilities as far as their autonomy is maximised; in this way the traditional disadvantages of rigid (wire guided) AGV-systems are overcome.

More flexible AGV systems employ more flexible measurement systems such as inertial-odometric, triangulating laser sensors (Kam et al. 1997) and more flexible control algorithms such as trajectory control and potential field control for unexpected obstacle avoidance and the navigation in partially-structured environments (Graf et al. 2001, Ge and Cui 2002, Tsourveloudis et al. 2001).

The augmented flexibility obviously increases the system complexity, so that it becomes difficult to optimise the entire algorithm and/or parameters on an h/w basis; or by means of standard control design tools: non-holonomic systems are challenging from the control point of view, as they are globally controllable but not locally, and they are not feedback stabilizable by continuous time invariant feedback control laws (Brockett 1983). On the other side, simulation environments require to develop the simulation, to write it in the specific language, to validate it, to optimise the algorithm and to translate the result in the proper real-time software environment. Part of the above phases can be avoided if the simulation and the h/w environment are the same. For this reason it was developed an h/w and s/w platform that uses the same code for the simulation of the entire AGV functionalities and for the real-time control (simply enabling the h/w interfaces with the drivers and the sensors or the simulation engine).

Recent developments in simulation tools for manufacturing have improved production engineering development and the tools are being adopted more and more widely in industry. For the development of AGV systems this has not yet fully been exploited. Several studies and works on simulation concerned more with logistic and concurrent handling aspect of AGV systems than with the pure control aspect (Verbraeck et al. 2000, Saanen et al. 2000), but it is an essential part of AGV design which asks more time for development.

Traditional methods of s/w simulation involve modelling, identification, validation and use of the simulation structure for control or other specific purposes. The proposed method adds a first step where it is designed the whole software architecture that will embody both the simulation and the real-time control and a final step where the same platform is used for the RT control.

An alternative approach achieving a real-time simulation is indicated in (European Space Agency 2004): it consists in a real-time test bench interfaced with the system in order to simulate environment, kinematics, dynamics, sensors, etc. By this architecture part of the system h/w is replaced by an RT h/w simulator. It has a valuable application for space tests when it's impossible or very expensive to test system in the real environment on earth.

Simulation has been used in this multifunction software since the development phase of controlling the AGV

Proceedings 19th European Conference on Modelling and Simulation
Yuri Merkuryev, Richard Zobel, Eugène Kerckhoffs © ECMS, 2005
ISBN 1-84233-112-4 (Set) / ISBN 1-84233-113-2 (CD)

drivers. The software workframe has been gradually upgraded according to development phases. An advantage is that a problem that occurs on h/w control situation can be analysed in a simulation mode, and the simulations can also be used to test different solutions before they are implemented in the real system. A feature of this simulation system is the opportunity to switch the control software in simulation mode simply excluding the hardware interface (real sensors) and enabling the simulation engine which emulate system’s kinematics and dynamics by means of sensor’s virtual outputs.

In previous works it was analysed the calibration problems of the vehicle kinematics (Durrant-White 1994) whose parameters, coupled with the identification of the dynamics, allows to simulate the vehicle behaviour in the real environment. After validation of the kinematics- dynamical model, it was added a second layer of software for the real-time obstacle avoidance in semi-structured environments by means of potential field methods.

An important feature of the platform is the possibility to monitor also the state of the system and manage possible faults and warnings.

H-S/W RT SIMULATION METHOD

The steps that the proposed h-s/w RT simulation method involve for the navigation control design are the following:

1. design of the software structure that embodies all the drivers and functionality for the Real-time system control;
2. mathematical modelling of the system plant;
3. system plant parameters identification;
4. system plant model validation;
5. use of the system plant model for navigation control design and related parameters optimisation [s/w mode];
6. experimental verification [h/w RT mode].

Traditional methods of s/w simulation involve the steps 2,3,4 and 5. The proposed method adds a first step where it is designed the whole software architecture that will embody both the simulation and the real-time control. A final step is added where the same platform used for the mathematical/numerical simulation development is used for the RT control.

The important advantage is that the control algorithms do not need to be implemented on another application for their simulation purpose. It is sufficient to launch the single application disabling the libraries that achieve the hardware I/O control and enabling the simulation engine libraries developed ad hoc, which calculate virtual output of sensors on the basis of the system’s model implemented in the simulation engine.

The disadvantage is that a s/w platform developed for RT control purposes requires more time to develop the simulation engine than platforms developed for numerical or control purposes. However several companies, like for example National Instruments, are adding tools that enable the simulation in parallel to the control.

1. Software structure design

As illustrated in Figure 1 the software (written in LabView$^{®}$) has three hierarchical levels of control: the upper level is the planning one, at a lower level are the path control and task control algorithms (including the potential field method), the lowest level is assigned to the drivers control loops, the fastest ones. The last two tasks can exhange data with two possible systems: the hardware system, which is the real one and it is essentially made up of drivers and sensors, or the simulation engine, which embodies a model of the driver system. The application can run in real-time mode on the embedded AGV system as well as in the host client PC in simulation mode. By the same interface the user can choose to launch the application in simulated mode or in hardware mode: in the first case the software runs only on the client computer; if the interface selection switch is set on hardware mode the application runs in real-time on the on-board server computer and sends data to the user interface on the client computer.

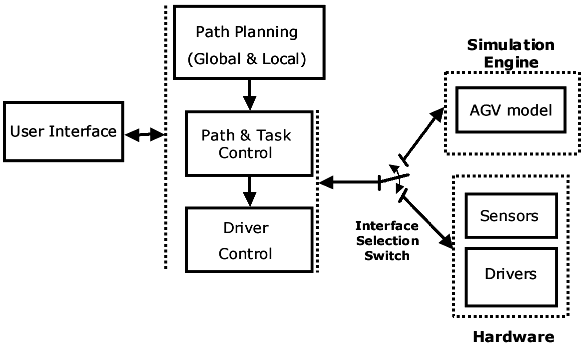


Figure 1: Block diagram description of the system.

Measured Position
X [m] 0.172
Y[m] 0.000
Attitude [rad] 0.000
Steering Position [rad] 0.00
Xinit 0.100
Yinit 0.000
Init Attitude [rad] 0.000

Figure 2: Control Panel example in the user interface

2. Mathematical modelling of the system plant

This section shows the kinematics of a three-wheeled vehicle like the ones that are often used in industrial environments for pallets handling and transport. Two encoders are used on the driver wheel: one to measure the steering angle, the second to measure the angular velocity.

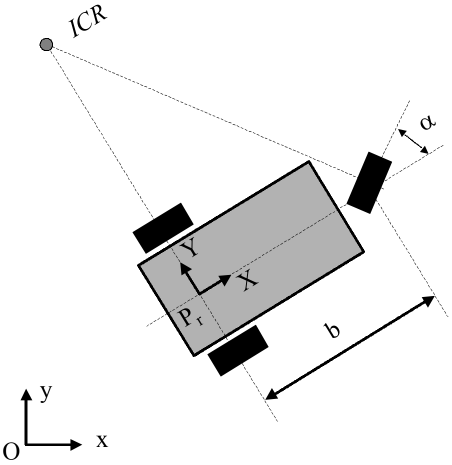


Figure 3: Kinematics scheme of a three-wheeled AGV

The Figure 3 showns the kinematics scheme of a three-wheeled AGV. The angular velocity ω refers to the driving wheel. The attitude δ is meant to be the angle between the absolute reference system xOy and the mobile reference system XP_rY. The position Pr is defined by the vector (x,y,δ) which also takes the attitude of the mobile robot into account.
The kinematics behaviour is always controlled by two wheels. Therefore, one wheel bears slippage if it is not perfectly aligned with one of the other two. The discrete form of the inertial-odometric navigation equations is the following:

$$\begin{cases} x_{k+1} = x_k + \dfrac{2\pi}{n_{TOT}} \cdot n_k \cdot R \cdot \cos(\alpha_k + \alpha_0) \cdot \cos(\delta_k) \\ y_{k+1} = y_k + \dfrac{2\pi}{n_{TOT}} \cdot n_k \cdot R \cdot \cos(\alpha_k + \alpha_0) \cdot \sin(\delta_k) \\ \delta^E_{k+1} = \delta^E_k + \dfrac{2\pi}{n_{TOT}} \cdot n_k \cdot R \cdot \sin(\alpha_k + \alpha_0) \cdot \dfrac{1}{b} \\ \delta^G_{k+1} = \delta^G_k + T_C \cdot G(V^G_k) \\ \delta_{k+1} = DF(\delta^E_{k+1}, \delta^G_{k+1}) \end{cases} \tag{1}$$

Equation (1) is the characteristic which makes it possible to estimate the AGV's position and attitude. The steering motor is controlled in position and its model, used by the simulation engine, is a first order transfer function inserted in the PID control loop (Figure 4). The motor is in fact controlled in velocity by a dedicated driver and the motor-driver behaviour in the position control chain is that of a delay.

- α_s, α_m are respectively the angular setpoint for steering axis position and its measurement.
- κ, τ are the costants of motor-driver first order tranfer function.

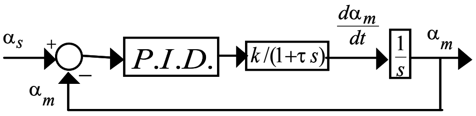


Figure 4: Control scheme of the steering motor system

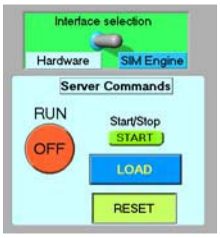
The control variable for the driving motor is the angular velocity and its control scheme is similar to that of the steering motor system.

3. System plant parameters identification

The kinematics model calibration is discussed for example in (Durrant-White 1994, Borenstein and Feng 1995,1996): similar methods were implemented.
The motor model parameters identification was obtained by means of simple step input methods.

4. System plant model validation

Tests were made to validate the simulation kinematic and dynamical model of the system.



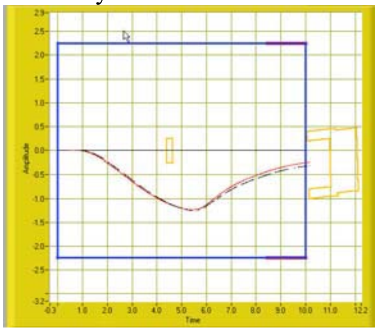


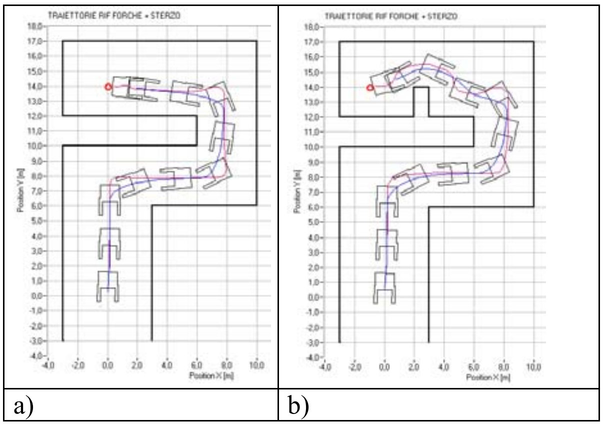
Figure 5: The Hardware/Sim Engine switching
Figure 6: Comparison of Simulated trajectory (dotted black) vs Real one (continuos red)

In Figure 6 is presented a comparison between a simulated trajectory and a real one showing a good correspondence. The example is related to an unexpected central obstacle avoidance task.

5. Navigation control design and parameters optimisation [s/w mode]

The potential field method used for the task of obstacle avoidance is similar to the VFF method of Borenstein (Borenstein and Koren 1991). It is very simple to be implemented and it is efficient for local obstacle avoidance if its parameters are well tuned. The main disadvantages of this method are three: the parameters are difficult to be tuned; it suffers of local minimum problems and oscillations in narrow passages. For the last two problems some technics were developed in order to eliminate local minimum and oscillations. The problem of tuning parameters is fully simplified by the simulation tool and the effect of changing parameters is verified simply by switching to hardware mode. Since this potential field method doesn't take into account the dimensions of the vehicle it was developed an algorithm for avoiding lateral and rear collisions with obstacles.

Another problem of the potential field method is the lack of attitude control which is very negative for transpallet industrial vehicles in the load and the unload phases. By means of the h-s/w method it was possible to develop a method in order to solve also this problem while maintaining the other potential field method features untouched.

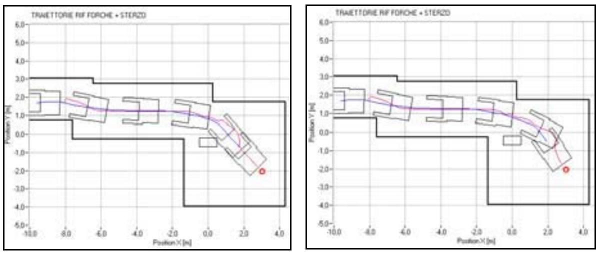


a) b)

Figure 7: Simulation example: a) corridor without obstacle; b) when an obstacle appears. Trajectories of rear wheels' center and of steering axis are shown

In Figure 7 is shown the result of a simulation of the AGV performing a path in a corridor, first without obstacle and then with an unexpected obstacle appearing before approaching the target. This is a final result after parameter optimisation was utilised to solve problems of narrow passages inducing oscillations and of collisions with lateral object due to non-point shape of the vehicle.

The Figure 8 shows the first of the above problems and its solution before and after the introduction of the control corrective algorithms and their optimisation .



a) with collision b) without collision

Figure 8: Solution to the Problem of Lateral Collisions

6. Experimental verification [h/w RT mode]

The simulation software was used for testing a potential field method for local obstacle avoidance in partially structured environments. Before the algorithm was implemented in the actual AGV control software, it was simulated for debugging purpose, then simulation of control was used in order to optimise control parameters, finally the method was tested on the AGV.

In Figure 9 we present a frame sequence (read from left to right and from top to bottom) showing an obstacle avoidance test carried out to compare simulation results with real ones. The task showed is the same simulated in Figure 6.

CONCLUSION

In this paper, an integrated h-s/w platform has been proposed for both the simulation and the real-time implementation of Autonomus Guided Vehicles navigation. By means of this approach it is possible to employ the same software architecture and code for simulation purposes (control algorithm debugging and optimisation of parameters, path planning simulation) as well as for the real-time control on an embedded AGV system. The steps that this proposed h-s/w RT simulation method involve for the navigation control design are : design of the software structure; mathematical modelling of the system plant; system plant parameters identification; system plant model validation; use of the system plant model for navigation control design and related parameters optimisation [s/w mode]; experimental verification [h/w RT mode]. This method was successfully used for achieving the autonomous navigation of an industrial transpallet.

Figure 9: The result of the Real Implementation of a potential field method for Obstacle Avoidance

Clarification

Only for academic purposes the following clarification is reported:
Baglivo implemented the h-s/w RT simulation and developed the obstacle avoidance algorithm, 40% of the whole work is assigned to him.
De Cecco conceived the integrated hardware and software method and the system modelling, 40% of the whole work is assigned to him.
Angrilli organised and supervised the research project both from managerial and technical point of view, 10% of the whole work is assigned to him.
Tecchio and *Pivato* organised and supervised the research project from the industrial point of view, 5% of the whole work is assigned to each of them.

The research was partially funded by a ministerial grant under the 46 law.

References

Borenstein J. and Koren Y. 1991, “Potential Field Methods and Their Inherent Limitations for Mobile Robot Navigation”, In *IEEE Proceedings of the IEEE Conference on Robotics and Automation*, Sacramento, California, April 7-12, 1991, pp. 1398-1404

Borenstein J. and Feng L. 1995, “UMBmark: A Benchmark Test for Measuring Odometry Errors in Mobile Robots”, *SPIE Conference on Mobile Robots*, Philadelphia, October 22-26, 1995

Borenstein J. and Feng L. 1996, “Measurement and Correction of Systematic Odometry Errors in Mobile Robots”, *IEEE Transactions on Robotics and Automation*, Vol. 12, No 5, (Oct) 1996.

Brockett R. 1983, “Asymptotic stability and feedback stabilization”, *Differential geometric control theory*, Vol. 27, pp 181-208, Birkauser, 1983.

Durrant-Whyte, H. 1994. “Where am I? A tutorial on mobile vehicle localization”, *Industrial Robot*, Vol. 21, No. 2, pp. 11-16.

European Space Agency. 2004. *Multi-mission Hybryd Navigator Breadboard*, TEC-ECN-GPS-IMU 2510/2004 Issue 01

Ge S.S. and Cui Y.J. 2002, “Dynamic Motion Planning for Mobile Robots Using Potential Field Method”, In *Autonomous Robots* 13, 207–222.

Graf B., Hostalet Wandosell J. M. and Schaeffer C. 2001. “Flexible Path Planning for Nonholonomic Mobile Robots”, *EUROBOT* September 19 - 21, 2001, Lund, Sweden.

Kam M., ZHU X. and Kalata P. 1997. “Sensor Fusion for Mobile Robot Navigation”. In *Proceedings of the IEEE*, Vol. 85, No. 1 (Jan) 1997, pp. 108-119.

Saanen Y.A., Verbraeck A. and Rijsenbrij J.C. 2000 “Simulation as a Control Device over Physical Systems”. In *Proceedings ASIM2000*, (Berlin, March 2000) ASIM/SCS, 2000.

Tsourveloudis N. C., Valavanis K. P. and Hebert T. 2001, “Autonomous Vehicle Navigation Utilizing Electrostatic Potential Fields and Fuzzy Logic”, In *IEEE Transactions on Robotics and Automation*, Vol. 17, N. 4, August 2001.

Verbraeck, A. et al. 2000: “Simulation as a Real Time Logistic Control System: AGV Control with Simple++”. In *The New Simulation in Production and Logistics – Prospects, Views and Attitudes*. Mertins, K., Rabe, M. (eds.). Berlin, Germany, 2000. pp. 245-255.

AUTHOR BIOGRAPHIES

LUCA BAGLIVO was born in Tricase (LE, Italy) in 1978. He studied mechanical engineering (automation) and obtained his degree in 2003. He is a Ph.D scholar toward the Research Doctorate in Space Science, Technology and Measurement in Mechanical Engineering Dept at University of Padova. His interests include AGVs, sensor fusion, simulation and robotics. His e-mail address is: luca.baglivo@unipd.it

MARIOLINO DE CECCO was born in Pescara (Italy) in 1969. He studied Electronic Engineering and obtained his degree with first-class honours at the University of Ancona. He obtained the PhD degree in ‘Mechanical Measurement’ at University of Padova and a. He is researcher of the CISAS. His current interests include mechanical measurements, sensor fusion, vision systems, signal processing, linear and non-linear control, adaptive control, space qualification and procedures and system simulation. He has been qualified as professor.

FRANCESCO ANGRILLI is full professor of Mechanical and Thermic Measurements at Padova University, Italy, he is also director of the Center of Studies and Activities for Space CISAS "G. Colombo" of the Padova University; Director of Post-graduate courses for Research Doctorate in Space Science and Technology principal investigator in a number of researches sponsored by C.N.R., A.S.I, ESA, PMI and Private Industries; he has been member of tecnical team and program manager for a number of space missions. He is the Author of more than 140 papers published in italian and international journals.

FRANCESCO TECCHIO was born in Cittadella (PD, Italy) and he attended the University of Padova where he studied mechanical engineering and obtained his degree in 1996. Since 2001 he has been working at the Italproject srl where he is now leading the AGV (Automatic guided Vehicle) project in the field of end line packaging.

ANGELO PIVATO was born in Galliera V.ta (PD) .
He studied mechanical technology and applied himself to research and innovations in the packaging sector.
He is the chairman of the company Italproject srl (specialised in the design & manufacture of automatic packaging systems).