MOCONT LOCATION MODULE: A CONTAINER LOCATION SYSTEM BASED ON DR/DGNSS INTEGRATION

Joseba Landaluze, Victoria del Río, Carlos F. Nicolás, José M. Ezkerra, Ana Martínez
IKERLAN Research Centre, Arizmendiarrieta 2, 20500 Arrasate/Mondragon, The Basque Country (Spain)

Keywords: DR/DGNSS, DR, GPS, DGPS, inertial navigation system, location system

Abstract: The problem of identifying and adequately positioning containers in the terminal yard during handling with Reach Stackers still remains to be solved in an appropriate manner, while this is extremely important in making the identification and positioning operations automatic. A precise knowledge in the Terminal Operating System (TOS) of such data in Real Time would have considerable economic impact on the logistic treatment of operations. The MOCONT system sets out to provide a solution to this lack. In particular, the MOCONT Location Module establishes the position of the container in the yard while it is being handled by a Reach Stacker. This system is based on the integration of the Differential Global Navigation Satellite System (DGNSS) with a Dead Reckoning (DR) inertial system. This article presents the general characteristics of the MOCONT Location Module, its structure, and the structure of data fusion, besides some results obtained experimentally.

1 INTRODUCTION

The problem of localising the containers in the yard of container terminals had been partially solved for terminals equipped with huge machines, such as Rubber Tyre (RTG) and Rail Mounted Gantry Cranes (RNG) or even Straddle Carriers, but is still a problem for those terminals equipped with Reach Stackers or Front Loaders. Moreover, the automatic identification of containers on board the handling machine is still a problem remaining to be solved.

The European projects MOCONT ("Monitoring the yard in container terminals", IST-1999-10057) and MOCONT-II ("Monitoring the yard in container terminals – Trials", IST-2001-34186), aimed at providing a system to track the containers in the yard in Real Time. The projects aimed at developing a system that automatically identified containers and localised them when moved by small machines, called Reach Stackers.

This paper presents the Location Module of the MOCONT system, developed in said European projects, and more particularly, the development of the inertial navigation system or Dead Reckoning (DR) system. The Location Module is based on the integration of a Differential Global Navigation Satellite System (DGNSS) and an inertial DR system. Data are integrated by means of a Kalman Filter. This system reckons the position of the vehicle at all times, improving estimates supplied by the DGNSS. The exact position of the container is determined by means of a transformation of coordinates from the vehicle body since the length and angle of inclination of the boom are known. The system is particularly useful when the GNSS does not supply quality data or is interrupted, due to few satellites being accessible, multipath phenomena or due to working inside container canyons or in dark areas. The DR inertial system is able to continue estimating vehicle position with precision for short time intervals, with bounded errors, until GNSS signals with sufficient quality are available.

In the literature, different structures of inertial systems appear for land vehicles. The most common case is the use of a sensor for rotation speed of yaw angle and odometric information obtained from vehicle wheels (Aono, 1999; Ramjattan, 1995). Other redundant sensors are often used to help, each being different depending on the type of vehicle and application in question (Aono, 1999; Zhang, 1999). In some cases, especially in vehicles for agricultural purposes, a digital compass or a geomagnetic direction sensor are used instead of a yaw angle speed gyroscope (Benson, 1998; Zhang, 1999). In order to avoid errors, which may be introduced by odometric sensors on wheels due to slipping, Sukkarieh (1999) proposes an Inertial Measurement Unit (IMU), comprising three accelerometers, three

Landaluze J., del Río V., Nicolás C., Ezkerra J. and Martínez A. (2004).
MOCONT LOCATION MODULE: A CONTAINER LOCATION SYSTEM BASED ON DR/DGNSS INTEGRATION.
In *Proceedings of the First International Conference on Informatics in Control, Automation and Robotics*, pages 227-234
DOI: 10.5220/0001132802270234

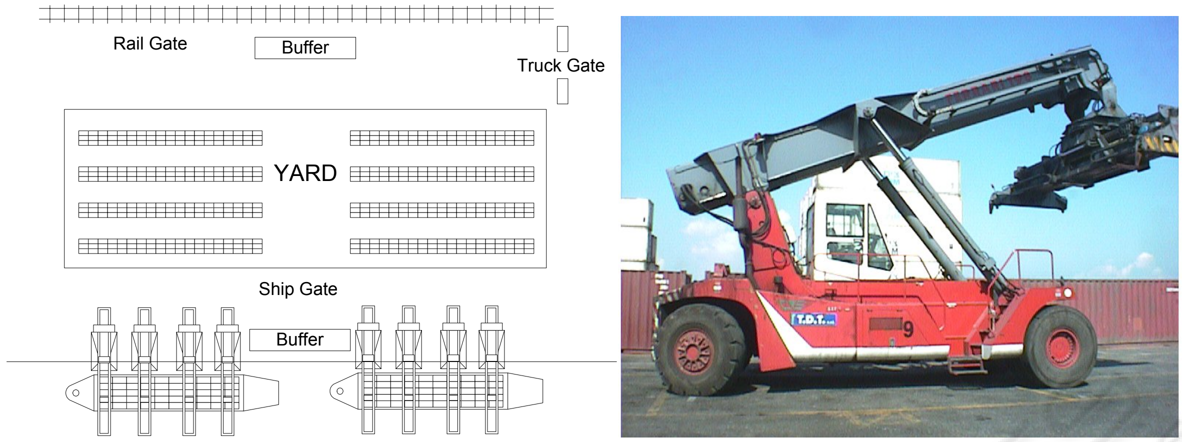

Figure 1: Overall scheme of a container terminal and Reach Stacher container handling machine.

gyroscopes and two pendular gyroscopes, by which vehicle acceleration and yaw and tilt rotation speeds are obtained. Rogers (1999) presents an inertial system consisting of a low cost fibre optic rate gyroscope and of a radar ground speed sensor.

Due to the specifications of the MOCONT project, according to which it was not possible to change the structure of the Reach Stacker machines and nor was it possible to install encoders in the wheels to obtain odometric information, initially a structure based on a triad of accelerometers and a triad of solid state gyroscopes was selected. Although this set up may be valid for on-road vehicles, once field data were obtained for a Reach Stacker in normal work tasks, it was concluded that this set up was not valid for such a machine; due to the low speeds and considerable degree of vibration to which this machine is subject during operations, the accelerometers did not provide information on machine movements on the yard, and only the yaw rate ant tilt rate gyroscope signals could be used (Landaluze, 2003). Therefore, a sensor structure similar to that proposed in (Rogers, 1999) was chosen. Finally, since a subcentimetric receiver was replaced by a submetric receiver, and taking into account the "non-collocation" between the Reach Stacker chassis sensors and the GPS antenna, fitted on the highest point of the Reach Stacker boom, sensoring was completed with a digital compass.

This paper firstly presents an overview of the MOCONT project, followed by an explanation of the structure of the Location Module in the MOCONT system. Then follows a description of the DR inertia system and the Kalman Filter implemented. Lastly, some experimental results are shown, as well as a statistical evaluation of the results obtained by the Location Module of the MOCONT system in the course of the MOCONT-II project.

2 OVERVIEW OF THE MOCONT SYSTEM

The MOCONT project was presented as a new landmark in the application of telematics in intermodal transport, especially in the control of container terminals. The main objective of the project was to develop a system to identify the position of containers in the yard in Real Time. Although said follow-up problem had already been partially solved in the case of large loading and unloading cranes (Rubber Tyre RTD, Rail Mounted Gantry Crane RMG, Straddle Carriers), this was and is a problem in terminals with Reach Stacker machines. It was in these machines, therefore, where the project comes to bear (Figure 1).

The Reach Stacker is an off-road machine used to handle containers in the terminal yard. It is characterised by a small body with an extensible boom (the arm) mounted over of the operator cabin. It is equipped with a spreader, namely the handling device used to pick and keep containers by the machine itself. The Reach Stacker can stack up to the fourth height (up to the fifth height in case of empty containers).

Taking into account the main objective of the project, the MOCONT system should perform the following operations:

- Identify the container, reading the identification code when picked up by each Reach Stacker.
- Follow each movement of the container in the terminal yard while being handled by the Reach Stacker, recording (i.e., the position of the container in the yard – row, column, height) where the container is picked up or released.
- Inform on the position of the container and its identification without the intervention of human operators.

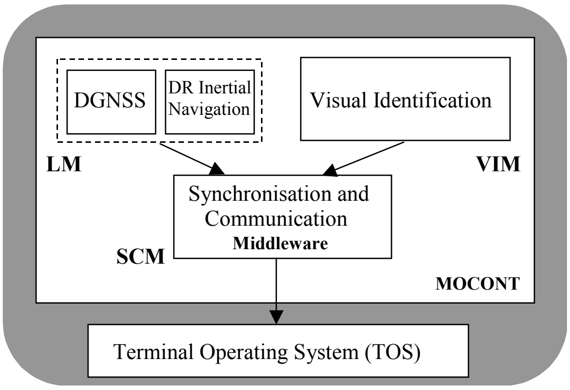

Figure 2: MOCONT functional architecture.

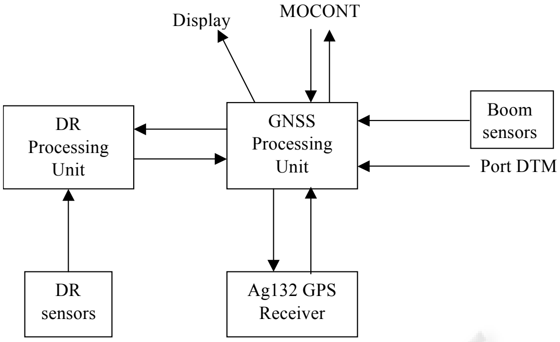

Figure 3: Scheme and flow data of the Location Module.

- In Real Time, update the position of any container handled by a Reach Stacker in the Terminal Operating System (TOS).

In order to obtain the objectives proposed, the MOCONT system incorporates three different modules (Figure 2): the Location Module, the Visual Identification Module and the Synchronisation and Communication Module. The Location Module determines the position of the container in the terminal yard; the Visual Identification Module reads the container's identification code; the Synchronisation and Communication Module acquires the identification and position data on the container and informs the TOS.

3 STRUCTURE OF THE LOCATION MODULE

The Location Module consists of two subsystems: the DR subsystem and the DGNSS subsystem. This last one has two different parts: the GPS receiver and the GNSS Processing Module.

In the final MOCONT Location Module Trimble's Ag132 GPS receiver is used at the heart of the GNSS and, therefore, of the location system, for the positioning of the Reach Stacker. The Ag132 GPS receiver combines high-performance GNSS reception with radio-beacon DGNSS capability in a single durable waterproof housing, ideal for use in the yard environment. The receiver uses differential GNSS to provide sub-metre accuracy.

Differential GNSS requires two or more receivers. One receiver, called the reference or base station, is located at a known point to determine the GNSS measurement errors. This could be housed on the roof of the main administration buildings, to allow easy access and constant monitoring. An unlimited number of AgGPS receivers, sometimes called rovers, collect GNSS data at unknown locations onboard each Reach Stacker. Over a radio band, the reference station broadcasts correction values, which are applied to the Ag132 GPS receiver positions. Errors common at both the reference and rover receivers and then removed from the solution.

The performance of the Ag132 GPS receiver is improved by direct GNSS augmentation with height aiding. Height aiding improves the solution by enhancing satellite visibility, and reducing the positioning challenge from a three-dimensional to a two dimensional problem. Using a DTM of the port and the current location of the Reach Stacker, an interpolation algorithm provides an accurate measure of the current ground height. With knowledge of the Reach Stacker geometry, the boom extension and boom inclination, the height of the GNSS antenna on board the vehicle, and indeed the height of the container carried by the Reach Stacker, can be continually computed.

In addition, the Location Module provides complimentary DR augmentation for periods when GNSS positioning with height aiding is not possible. The DR subsystem consists of a Processing Unit and some DR sensors, by means of which the Reach Stacker position is continuously estimated. The GNSS Processing Module continually provides the DR subsystem with the current position from the Ag132 GPS receiver (in projected UTM coordinates) and some indication of the quality of that position fix (by means of a covariance matrix of the computed parameters). In return the DR subsystem continually updates the GNSS Processing Module with the best estimate of the current position.

The GNSS Processing Module will then pass the position information to the driver and the rest of the MOCONT system.

The GNSS Processing Module, which interfaces with the Ag132 GPS receiver, the DR subsystem,

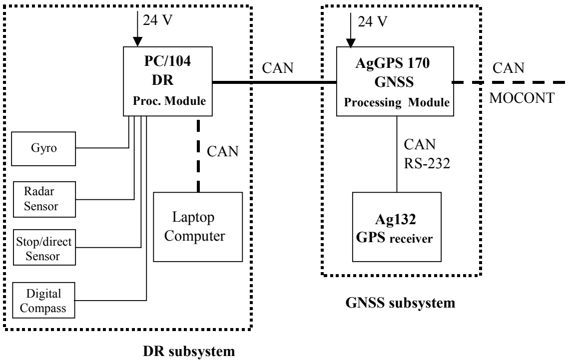

Figure 4: Elements of the Location Module.

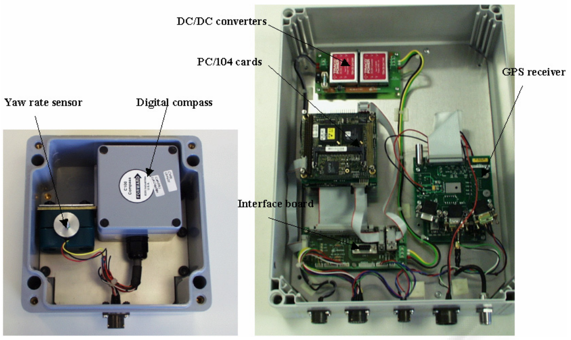

Figure 5: Heading box and Location Module box.

the boom sensors and the Synchronisation and Communication Module, has been developed using the robust and compact AgGPS 170 Field Computer. The AgGPS 170 is designed to withstand the environmental extremes that are typical of the container port environment.

A scheme of the Location Module, with its components and the flow of data, is shown in Figure 3 and Figure 4. As can be observed, the communication between the two subsystems of the Location Module is by means of a CAN bus. The communication between the GNSS subsystem and the Synchronisation and Communication Module is also by another CAN bus (Figure 4). The values measured by the boom sensors are supplied by the MOCONT middle-ware through this bus.

4 DR SUBSYSTEM DESIGN

4.1 Description of the DR subsystem

Although initially different sensorings were tested for the DR subsystem, a sensor structure similar to that proposed by Rogers (1999) was finally selected. Likewise, replacing the MS750 subcentimetric GPS receiver in the final structure of the Location Module with an Ag132 submetric receiver, made it necessary to complete sensoring in the DR subsystem with a digital compass. As a result of these changes, the final structure used for the DR subsystem was as follows:

- The DR Processing Module, which consisted of a sandwich of three PC/104 boards: a CPU based on a 233 MHz Pentium Processor, an I/O data acquisition board and a 2-channel CAN communication board.
- The DR sensor set. This included the following sensors: a solid state gyroscope to measure the speed of rotation around the yaw axis; a radar technology Ground Speed Sensor, which provided the forward/backward speed of the vehicle; a stop/direction sensor, in order to detect if the vehicle is stopped or not, as well as the movement direction of the vehicle, forward or backward; a digital compass, to measure the vehicle heading angle.

Figure 4 shows the main elements of the Location Module and the structure of the DR subsystem. A laptop computer was used to monitor and configure the DR subsystem, as well as to collect raw data. Most of the elements of the DR subsystem were included in two boxes, the Location Module box and the Heading box, as they appear in Figure 5.

4.2 DR/DGNSS integration

Although different data fusion algorithms were tested, a kinematical Kalman Filter was finally chosen due to its simplicity and the good results obtained. For the navigation equations, it is assumed that the vehicle is moving on a tangent-plane, as it was a point, so the positioning involves locating the vehicle in cardinal directions: N-S-E-W. Figure 6 shows the local level geographic navigation and the

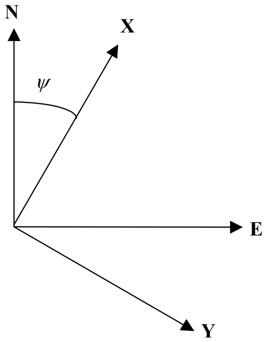

Figure 6:Local level geographic and body frames.

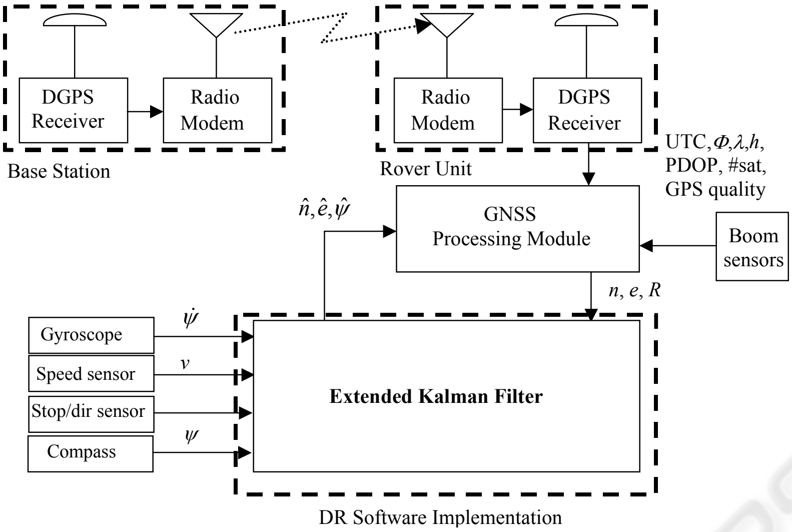

Figure 7: DR/DGNSS integration scheme.

body reference frames. It is assumed that the only transformation between these two frames is via the heading angle ψ.

The DR navigation system implements a distance travelled (integrated velocity) and a travel direction. The distance travelled is referenced to the body frame, which is then transformed into a local level geographic navigation frame through the angle ψ. This implementation assumes that other vehicle attitudes, i.e., roll and pitch, are sufficiently small as to be ignored.

The body referenced velocity is represented as a nominal velocity v, defined such that the X-component is along the primary direction of travel, plus velocity errors as a result of speed sensor scale factors ε_v.

The computed body referenced velocity is represented as

$$v_B = v + v \cdot \varepsilon_v \tag{1}$$

where v is the measured or estimated vehicle velocity.

Assuming that the body to navigation frame transformation and body-referenced velocity are approximately constant over a small time interval, the sampling time, it can be written:

$$\begin{aligned} \dot{n} &= v_B \cdot \cos\psi = v \cdot \cos\psi + v \cdot \varepsilon_v \cdot \cos\psi \\ \dot{e} &= v_B \cdot \sin\psi = v \cdot \sin\psi + v \cdot \varepsilon_v \cdot \sin\psi \end{aligned} \tag{2}$$

where $\dot{n}$ and $\dot{e}$ are the velocities in the local frame and v is the measured vehicle velocity.

The heading angle rate could be expressed as follows:

$$\dot{\psi} = \alpha_\psi \cdot V_\psi + \varepsilon_\psi \cdot V_\psi + b_\psi \tag{3}$$

where

α_ψ : gyroscope gain
ε_ψ : gyroscope scale factor error
b_ψ : gyroscope bias
V_ψ : measured gyroscope voltage

The speed sensor scale factor error ε_v, the gyroscope scale factor error ε_ψ and the gyroscope bias b_ψ are modelled as random-walk processes. From equations (1), (2) and (3) the continuous-time state-space realisation for the DR/DGPS is deduced:

$$\begin{aligned} \dot{\underline{x}} &= f(\underline{x}, \underline{u}) + \underline{w} \\ \underline{y} &= h(\underline{x}) + \underline{v} \end{aligned} \tag{4}$$

where $\underline{u} = \begin{bmatrix} v & V_\psi \end{bmatrix}'$, $\underline{x} = \begin{bmatrix} n & e & \varepsilon_v & \psi & \varepsilon_\psi & b_\psi \end{bmatrix}'$ and $\underline{w}$ and $\underline{v}$ are random variables. The augmented state equations for the DR subsystem can be stated in direct form or in terms of residual errors, and therefore the structure of the Extended Kalman Filter can be deduced, the measurement vectors being:

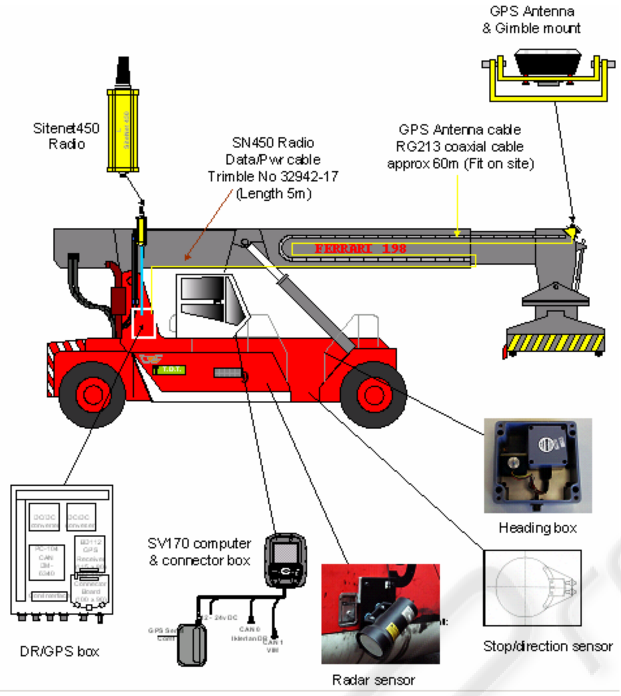

Figure 8: Installation of all elements of the MOCONT Location Module on a Reach Stacker.

$$\underline{u}(k) = \begin{bmatrix} v \\ V_{\psi} \end{bmatrix} \quad \text{with a frequency of 200 Hz}$$

$$\underline{z}(k) = \begin{bmatrix} n \\ e \\ \psi \end{bmatrix} \quad \text{with a frequency of 2 Hz}$$

Figure 7 shows the DR/DGNSS integration scheme. As outputs of the prediction steps of the Extended Kalman Filter, a vehicle position estimate is obtained with a frequency of 200 Hz, although the correction of state estimate is applied with a frequency of 2 Hz.

5 EXPERIMENTAL RESULTS

Figure 8 shows how all the MOCONT Location Module elements are fitted in a Reach Stacker. In the course of the MOCONT project, a system prototype was tested at the Terminal Darsena Toscana (TDT) in Livorno (Italy). In the MOCONT-II project, however, the system was implemented on 8 prototypes tested intensively over a six-month period at the TDT and at the VTE terminal in Genoa (Italy), taking a considerable number of data for statistical analysis.

The main objective of the Location Module is to locate precisely the container in the terminal yard. The yard is the surface of the terminal dedicated to the container storage. It is subdivided into modules, each one composed of corridors (carriageways used to move containers within a module and between different modules) and groups of slots. A group of slot is referred to as a lane. Lanes are numbered using capital letters, starting from A. One slot is uniquely identified within a lane by its yard coordinates: row, column and height (Figure 1). Therefore, the container position in the corresponding slot should be accurately estimated. During the project MOCONT-II more than 5600 container position messages were collected. Results presented in the Final Public Report (MOCONT-II, 2004) led to the conclusion that the performance of the MOCONT Location Module was 99.7% of correct localisation resulting from the wide set of trials carried out.

The advantages of the DR subsystem are highlighted during the work inside container canyons, and generally, in the work near high stacks of containers which, on the other hand, are the most important moments for the correct position identification as this is when the Reach Stacker is picking up or releasing a container in a given slot.

Figure 9 shows typical results of a Reach Stacker handling a container. It corresponds to data collected in Livorno, where the cases of container canyons were quite common. The figure shows the GNSS estimate for the position of the vehicle chassis and the estimate conducted by the DR subsystem, which

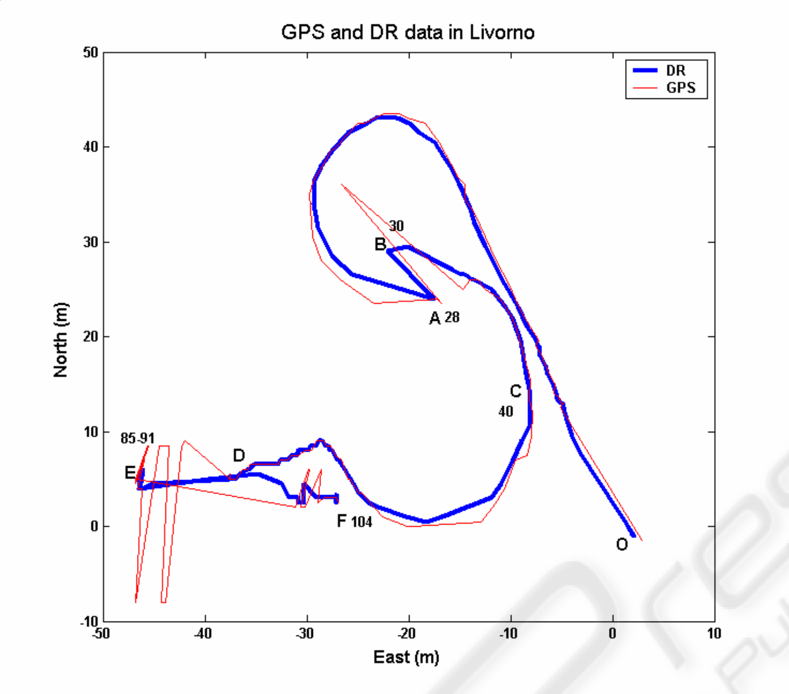

Figure 9: Example of experimental results at the TDT terminal in Livorno.

is transmitted to the GNSS on a frequency of 2 Hz. North and east relative position components, with respect to the starting point O, appear. The vehicle moves forward from the origin O to point A (instant 28 s). It then moves backward to point B (instant 30 s) from where it moves forward once again to point E (instant 85 s), after having passed through points C (instant 40 s) and D. It is at point E until instant 91 s, when it then moves backward to point F (instant 104 s). Covariance is not very good (always greater than 1), but also, between points C and D, it is approximately 3. As shown in the graph of Figure 9, when the covariance of the GNSS estimate is relatively low (about 1), the DR estimate continues to be in line with that of the GNSS. When the value of the covariance is large, particularly in the D-E-F stretch, the DR estimate is based mainly on the information provided by its own sensors.

In Figure 10 a detail of results obtained in Genoa is shown. In Genoa true container canyons rarely appeared, but sometimes the influence of high stacks of containers was evident, as in the case shown in the figure. The movement of the Reach Stacker starts at the point O, point considered as the origin of coordinates. The vehicles moves forward to point A (instant 12 s) and it is stopped at that point until instant 74 s, when it then moves backward to point B (instant 78 s). The Reach Stacker is at point B until instant 106 s. Then it goes forward to point C (instant 110 s) and after 17 s at that point the vehicle moves backward to point D (instant 130 s). After 11 s it continues going backward to point E (instant 153 s), changes movement direction and moves forward to point F (instant 188 s) and then it continues its travel. As it can be deduced from the figure, the Reach Stacker performed operations with containers at points A and C. A container was picked up from a slot at point A and then it was released in other slot at point C.

The GNSS data covariance was very bad from instant 6 s until instant 78 s and from instant 106 s until instant 110 s (east covariance value higher than 3.5 and north covariance value higher than 9). Therefore, from point A to point C the GNSS estimates have poor quality, as it can be observed in Figure 10, but DR estimates show very well the movement carried out.

6 CONCLUSIONS

Analysis of a large number of experimental data obtained in the course of the MOCONT-II project has proven the success of the MOCONT Location Module in tasks involving tracking the position of containers in terminal yards while these are being handled by the Reach Stackers, recording the slot (row, column, tier), where the container is picked up or released. Integration of the Differential Global

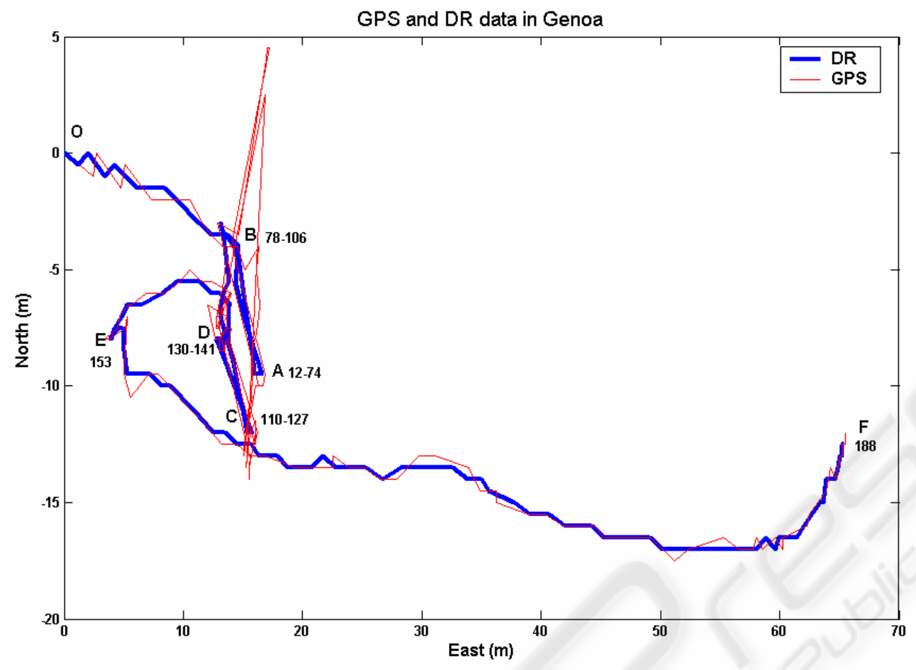

Figure 10: Example of experimental results at the VTE terminal in Genoa.

Navigation Satellite System (DGNSS) with a Dead Reckoning (DR) inertial system has been demonstrated to be effective in estimating the position of the vehicle and of the container. Positioning is effective even when working in container canyons, on the condition that it be for a limited movement time of some 40 s. Apart from the general characteristics of the MOCONT system, the structure of the MOCONT Location Module has been presented as well as the data fusion diagram. Likewise, typical experimental data and the final evaluation of effectiveness are also presented.

ACKNOWLEDGEMENT

The material in this paper has been partially funded by the European Union under the scope of the Information Society Technologies programme (research projects MOCONT: IST-1999-10057 and MOCONT-II: IST-2001-34186).

REFERENCES

Aono, T., K. Fujii and S. Hatsumoto. 1999. Positioning of a Vehicle con Undulating Ground Using GPS and Internal Sensors. *T. SICE, vol. 35, no. 8, pp. 1004/1001*.

Benson, E.R., T.S. Stombaugh, N. Noguchi, J.D. Will and J.F. Reid. 1998. An evaluation of a geomagnetic direction sensor for vehicle guidance in precision agriculture applications. *ASAE paper 983203*.

Landaluze, J., V. del Río, A. Milo, J. M. Ezkerra and A. Martínez. 2003. Desarrollo de un sistema de localización DR/DGPS para vehículos "off-road". *5ª Semana Geomática. Barcelona, 11-14 febrero.*

MOCONT-II. 2004. *Final Public Report*. www.mocont.org.

Ramjattan, A.N. and P.A. Cross. 1995. A Kalman Filter Model for an Integrated Land Vehicle Navigation System. *Amy 1995, vol. 48 (no.2), pp. 293-302.*

Rogers, R.M. 1999. Integrated DR/DGPS using Low Cost Gyro and Speed Sensor. *ION National Technical Meeting.*

Sukkarieh, S., E.M. Nebot and H.F. Durrant-Whyte. 1999. A High Integrity IMU/GPS Navigation Loop for Autonomous Land Vehicle Applications. *IEEE Transactions on Robotics and Automation, vol. 15, no. 3.*

Zhang, Q, J.F. Reid and N. Noguchi. 1999. Agricultural Vehicle Navigation Using Multiple Guidance Sensors. *FSR'99 International Conference on Field and Service Robotics.*