A NEW GPS-BASED GUIDING SYSTEM FOR COMPACTORS

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Abstract

The paper is about a novel operator-aiding system, specially designed for the road compactors, in the frame of a European project called "Computer Integrated Road Construction". After having recalled the main objectives, which are closely related to the mechanical quality of the road, the paper gives a general overview of the system, composed of three sub-systems : the ground sub-system, the positioning sub-system and the on-board sub-system. Then each sub-system is described, from requirements, design and realisation points of view. A special emphasis is given to the description of the Man-Machine-Interface which is of high importance for the success of the project. In the conclusion are indicated the conditions of presentation of this product, during the Munich BAUMA fair, and the development of the second product of the project is mentioned.

1. INTRODUCTION

The CIRC (Computer Integrated Road Construction) project aims to develop precision systems for the real-time control of the positioning of road construction equipment [1].

CIRC products will provide integrated ready made solutions for operator support, for machine control and for quality assessment. They will ensure a numerical link between design, work and control

The CIRC project is supported by the European Commission (Brite-EuRam III N° BE-96-3039) and started at the beginning of 1997 for three years.

The project relies on two major technological approaches. The first one, for positioning, is the integration of GPS (Global Positioning System) technology. The other is the real-time use of CAD data on the machines as a reference geometrical data base for all the operations.

Due to the implementation of better resource management, CIRC systems will generate about a 5% gain on the budgets linked to compacting and paving. These savings permit a rapid return on investment.

Seven partners, among which are three industrial companies, are involved in the project, each providing complementary skills and abilities :

- CAP GEMINI France, ITMI Aptor division,
- Laboratoire Central des Ponts et Chaussées (LCPC), France,
- TEKLA OY, Finland,
- Karlsruhe University (IMB institute), Germany,
- University of East London (UEL), Great Britain,
- EUROVIA, France,
- National Land Survey (NLS), Sweden.

Alongside this consortium, an End-Users Club has been created. This group gathers several companies and organisations directly interested in the operation of the CIRC system. The role of this club is to participate in the specifications of requirements and facilitate the integration of CIRC products into the European market. Major companies of the road building world are members of this club, which represents over 50% of the European equipment manufacturing and over 30% of the European road construction.

The consortium will develop during the project two different versions of CIRC systems for the first two target machines : CIRCOM for compactors and CIRPAV for pavers.

2. MAIN OBJECTIVES OF CIRCOM

In road layers compaction, it is essential that the right level of energy should be transmitted to the material, with a uniform distribution. This energy, as far as the settings of the compactor do not vary, depends directly from the number of runs, or passes, of the machine (figure 1). Until now, only the memory of the operator was used as a record to control the prescribed number of passes, inducing frequent defects in the achieved structure, given the extreme difficulty to perform this control in the site conditions.

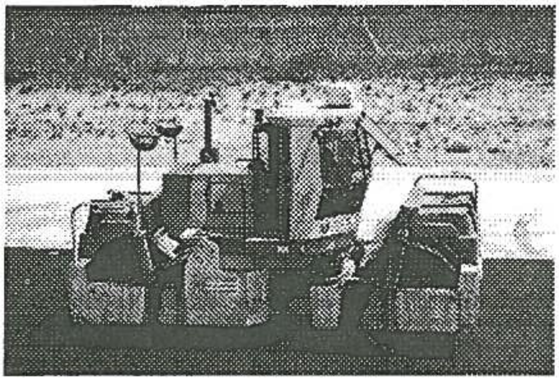

Figure 1: A compactor at work on a motorway site.

So, the main objective of CIRCOM is to assist the driver in this task, by helping him to perform the exact number of passes, at the right speed, everywhere on the surface to be compacted. From this improvement of quality in terms of level and uniformity of density, will result significant gains at the level of the life-time of the road, the operating time of the equipment and the saving of material.

To perform this task, it is essential to provide the operator and the system itself with an accurate and continuous location of the machine. "Accurate" in this case means between 5 cm and 20 cm in both transversal and longitudinal directions. "Continuous" means that it should work everywhere on the site.

The second objective of CIRCOM is to record the actual work achieved by the compactor, in terms of trajectory and number of passes on every point, in order to feed the site data base and to perform a global quality control at the site level. So, the contractor should be able to get an immediate snapshot of the "as-built" in terms of compaction.

The main operational constraint of the CIRCOM system is at the level of the ergonomics of the man-machine interface that must absolutely remain very simple and user-friendly given the current low educational level of the operators.

The feasibility of the CIRCOM concept had already been established, thanks to the demonstrator called MACC, which has been developed and patented by the LCPC. This demonstrator has been experimented using various positioning solutions, the last one, which has been chosen as the main positioning technology in the CIRC project, being real-time kinematic GPS, capable of centimetre accuracy [2].

3. OVERVIEW OF THE CIRCOM SYSTEM

CIRCOM is designed as a hierarchical system. It is decomposed in three sub-systems split up into several modules.

The 3 sub-systems are the following (see figure 2):

- ground sub-system (GSS),
- positioning sub-system (POS),
- on-board sub-system (OB).

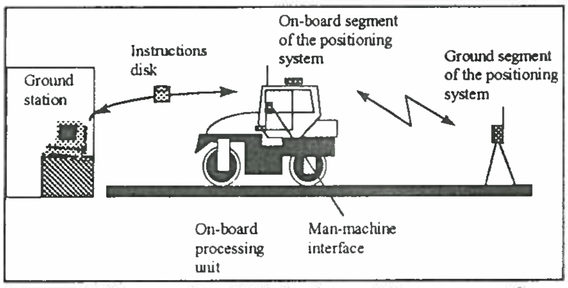

Figure 2 : Global architecture of CIRCOM.

The aim of the **ground sub-system** is to :

- provide the compactor with geometric data about the work-site, coming from CAD data, as well as guidelines for operation,

- compute compacting results and make some statistics about the work achieved.

The aim of the **positioning sub-system** is to localise precisely and in real-time the compactor by using Global Positioning System (GPS) technology as well as dead-reckoning sensors.

The role of the **on-board sub-system** embedded on the compactor is to :

- memorise and compute instruction data, position data, work done, and to

manage a Man Machine Interface (MMI) which assists the driver in compacting.

From a hardware point of view, CIRCOM comprises three units called "boxes" (see figure 3) :

- the driver box includes the interfaces with the driver, i.e. the screen, the reduced keyboard and the PCMCIA disk drive. It is to be positioned in an ergonomic way and is removable.

- the computer box includes the acquisition and computation electronic boards as well as the power supply regulator. This unit is placed at a safe location in the compactor.

- the roof box includes the RTK GPS (Real Time Kinematic Global Positioning System) devices: processing unit, radio-modem and the antennas for GPS and radio-communication of position corrections.

Moreover, dead-reckoning sensors are connected to the computer box (see section 5).

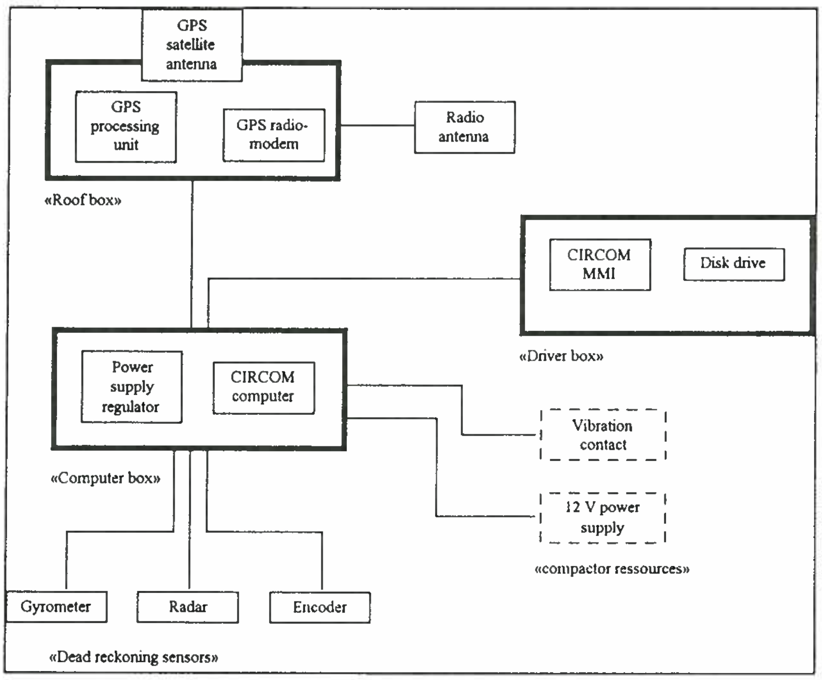

***Figure 3** : Hardware architecture of CIRCOM.*

4. GROUND SUB-SYSTEM

4.1. Requirements

The main challenge of the ground sub-system is to establish a link between the design and the construction of the road. Indeed, the data provided by the road CAD systems are directly processed in order to bring to the on-board sub-system the appropriate information about the work-site.

More precisely, the ground sub-system is in charge of the following functions.

1. To import information from the road CAD system
2. To plan the mission of the compactors
3. To export the geographical database as well as the mission to the compactors
4. To import achieved work from the compactors
5. To compute statistics about the achieved work

4.2. Design and development

1. CIRC systems are designed to import data from the main CAD software thanks to a standard format called CIF (CIRC Input Format) that CAD developers agree to implement. Two major CAD software developers have already agreed to provide CIF files. Specific CIRC interfaces, that allows the ground sub-system to read and translate usual files, may also be developed if necessary.

2. The ground sub-system will also allow the contractor to define the kind of compaction for each layer of the road, including the type of machine and the target number of passes.

3. As this sub-system will be common to different kinds of machines equipped with CIRC systems, the road representation will also be the sale, whatever the number of dimensions the machine need for its control. This means that the geometrical description of the road structure will be 3 dimensional, under the form of 3D polylines.

4. The work achieved by the compactor will also be stored as 3D polylines, representing the actual trajectories of the machine, in a vector database. The database is basically a list of points in 3D space with time stamps. In this way no information about road construction process is lost. Another advantage is that vector description follows new trends in road design CAD software, so both the road design and its realisation can be described in similar way. The same medium allows to bring back to the ground computer the data about the achieved work, mainly the number of passes per area of the road, for further exploitation.

5. It will be possible to process the data about the performed work in order to provide the contractor statistics about the work of each machine, the histogram of compaction of the road and so on. The ground sub-system will allow to display these results in a useful and friendly way.

The ground sub-system is a PC located in an office of the contractor. It is generally not on the work-site but several kilometres from it. The large storage disks are PCMCIA hard drives. Their credit card format allows them to be easily transported between the office and the work-site once or twice a week.

5. POSITIONING SUB-SYSTEM

5.1. Requirements

The positioning sub-system is a key component of the complete CIRCOM system. In the MACC demonstrator, localisation was performed by a RTK GPS unit alone. The main drawback of this solution was that, in some cases, no localisation data was available. Indeed, the GPS must be able to track at least four satellites to compute its location. In the presence of buildings or trees, the system may fail. . Of course, when the machine passes under a bridge (it happens every 1 or 2 km on a highway), the system will not work.

In order to alleviate this problem, it was decided to use additional sensors to allow dead-reckoning localisation during these phases. What performances are desirable for this dead-reckoning ? The idea was to consider that the most common difficult situation would be that of passing under a bridge. In the worst case, this bridge supports a 2x2 lane road and crosses the work-site with a 45° angle. Taking into account the re-initialisation time of the GPS after a masking and the speed of the compactor, the distance travelled is approximately 100 m. Considering that the desired localisation accuracy is 20 cm in these zones, the precision of the dead-reckoning localisation should be better than 0,2 %.

5.2. Choice of the sensors

Due to the constraints of the work-site and to the high reliability demanded, the use of an external odometer is not acceptable. Moreover, the conditions of use are particularly difficult : the material on which the compactor moves is hot (more than 100° when laid on the road) and tends to stick to the roads. For these reasons, we finally chose the following additional sensors : a fibre-optic gyrometer and two distance/speed sensors. Two different kind of distance/speed sensors were chosen : a simple encoder in the drum of the compactor and a contactless Doppler radar in front of the drum. The reasons why these two different kind of sensors are required are simple. At very low speeds, Doppler radars do not work at all, and this happens often since the compactor repeatedly stops and reverses its speed. On the other hand, the encoder is not sufficient because, when the compactor is back to its normal speed, powerful vertical vibrations are applied to the cylinders for compacting, causing slippage ratios as high as 30%, so the true ground speed measured by a radar becomes essential.

Figure 4 shows the sensors set-up of the compactor.

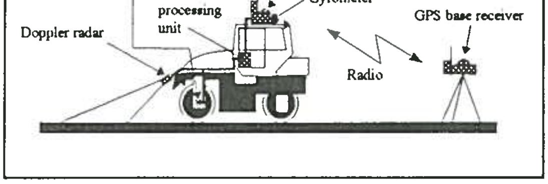

Figure 4 : Positioning sensors set-up of CIRCOM

5.3. Design of the fusion algorithms and results

The basis equations are those of the dead-reckoning localisation. They are used repeatedly (at 25 Hz) using the measurements of the yaw rotation speed provided by the gyrometer and of the speed provided by either the radar or the encoder. When a position measurement provided by the GPS is available (at 1 Hz), the current dead-reckoning estimated position is updated to prevent it from drifting. When the GPS is masked, the dead-reckoning algorithm is simply repeated. The updating of the estimated position is performed using an Extended Kalman Filter [3]. The time delay if the GPS, also called latency, was taken into account in the estimation phase of the filter. Many tests have been performed on various trajectories. For all standard trajectories, the required precision of 0,2 m has been obtained for more than 100 m. Figure 5 shows the kind of result we obtained on a typical compactor trajectory : absolute error (solid line) and precision indicator (dotted line).

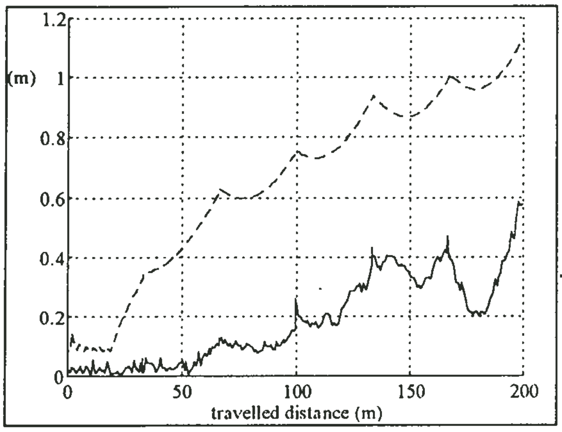

***Figure 5** : Absolute error and precision indicator*

6. ON-BOARD SUB-SYSTEM

The On-board sub-system (BS) is, besides the on-board segment of the positioning system, the main part of the CIRCOM system that is mounted on the compactor. For descriptive reasons this system is split up into its two main components:

1. The on-board data processing unit.
2. The man-machine-interface (MMI) including a graphic display and a reduced keyboard.

The tasks of the On-board data processing unit generally include the following three tasks:

a) Processing of the data provided by the Ground sub-system.

b) Processing of the Positioning sub-system data.

c) Up-dating of the database with data about the work-execution of the compactor.

In the following we will mainly describe the MMI which has the task of displaying the data required by the machine operator and the processing of the operator's inputs .

6.1. Requirements

The detailed requirements for the on-board subsystem and its man-machine-interface were defined by the main end-user Eurovia and the end-users club. Generally spoken, the MMI has to take into consideration that a machine operator seldom has an extended background about the handling of a computer and must not loose watching his environment.

Hence the display has to be intuitive,

readable "at a glance" without confusing the machine driver, not too detailed concerning the representation of the worksite and with a limited amount of information. The inputs by the operator must only be possible at a safe machine state, i.e. at very low speed or the machine being stationary.

Concerning the normal daily use of the system it has been chosen to visualise to the operator:

– a scaled map including the boundaries of the road, the axe and the profiles and the state of compacting in real time (with a zoom adjustable by the driver),

– the compactor's position on the map and the limits of the surface to be processed by the compactor, taking into account the following requirements :

. the driving direction is presented permanently in vertical direction on the map,

. the accuracy of the display does not allow the driver to drive his machine only by referring to the map,

– the number of required *and* already performed passes for the actually processed surface,

– the compactor's actual *and* required speed,

– warning/alarming messages in case of inappropriate handling of the machine,

– for vibrating rollers: desired compacting mode, static or vibrating.

The main inputs are possible via a keyboard where one key represents exactly one functionality of input. They will be devoted to:

– the updating of the required passes by the operator due to a change of previous compacting, available compacting machinery behind the compactor respectively,

– the zooming and scrolling of the MMI-map.

– the setting back of the map into default state, after zooming and scrolling, using a "home key".

6.2. Design and development

The on-board system is implemented on a PC 104 hardware architecture using Ethernet link to the positioning system and PCMCIA link to a static memory for data transfer to the ground system.

For the MMI a 10,4" coloured display and a reduced keyboard is used. The display (640x480 pixels) is mounted page oriented.

Figure 6 shows in grey-scale the different units of the normally coloured display.

1. *MMI-map:* on the left-hand side, with a thin frame around it, is shown the part of the road being processed, with profiles and axe. The compactor is always presented in the lower third of this screen segment, its driving direction remaining vertical and the road scrolls up and down when the machine moves down and up. The road is rotated accordingly to the change of the machine's yaw angle. Different colours are assigned to the different numbers of passes upon the whole processed surface.

On the right-hand side, we find the

following indicators, from top to bottom.

2. *Passes indicator:* shows the number of passes already done for the compactor's actual position. Furthermore it shows the ideal number of passes.

3. *Speed indicator:* informs the driver about required and actual speed.

4. *Watch.*

5. *Alarm information:* highlighted only if an indication of extraordinary states of the vehicle is necessary, e.g. if the compactor is too slow for effective compacting.

6. *Vibration indicator* (for vibrating rollers only): indication if static or dynamic processing is obligatory, highlighted green if vibration state is as desired, red if not.

7. *Information line* for different status information.

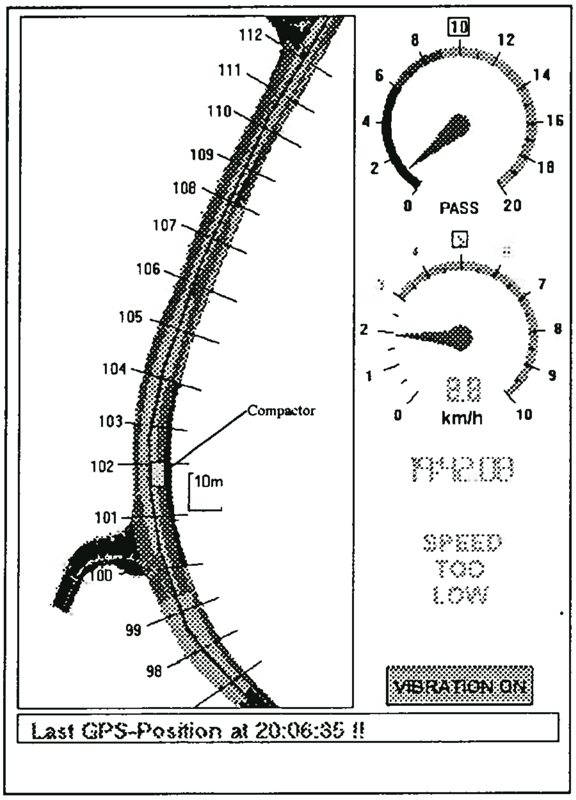

***Figure 6** : MMI display in grey scale*

7. DEVELOPMENT STATUS

CIRCOM is currently in the development phase. After the system design, each sub-system is being designed in a detailed way and developed by the appropriate partners.

In the next steps, CIRCOM will be tested following four procedures :

1. the aim of the **unit tests** is to verify that each of the sub-systems has a correct functioning. These tests will be carried out on each of the three sub-systems separately.

2. the aim of the **integration tests** is to verify that the CIRCOM system as a whole has a valid functioning. This phase will include static and dynamic tests on a test vehicle.

3. the aim of the **experimental tests** is to verify the performances of some of the modules/sub-systems of the CIRCOM : robustness and noise immunity of the radio, accuracy of the positioning sub-system, ... They will be carried out on a real compactor on test tracks of the CER at Rouen, France.

4. the aim of the **validation tests** is to verify that the CIRCOM realises all the functions required by the user in a satisfactory way. They will be performed on a regular work-site from Eurovia. This last step is planned for June 1998.

8. CONCLUSIONS

At the moment this paper is being written, the first CIRC product is about to be presented at the biggest European construction machinery fair, the BAUMA, in Munich. This product will be the first totally integrated system, devoted to a civil engineering task, capable of managing the total process, from the design office up to the quality control of the work achieved. The presentation will be organised with the co-operation of one of the biggest road equipment manufacturers in Europe.

From a scientific point of view, the development of the real-time positioning sub-system has undoubtedly been the one which has needed the greatest effort in terms of research, given the stringent specifications required.

The result of this research is a novel device, using state-of-the-art GPS and optical fibre gyrometer as main sensors and advanced Kalman filtering techniques, for the first time on a civil engineering machine.

A simple, intuitive and user-friendly MMI has been designed, supporting all the operational functions that have been specified by the future end-users of the device.

The research and developments inside the CIRC project will continue upon the second contemplated product which will be devoted to the profiling machines such as pavers or graders. For those machines,

the most challenging functions will be again the positioning functions. This time, will be addressed the accurate 3D positioning of the tool, "accurate" meaning this time at centimetre level for the height component. The presentation of this second product, called "CIRPAV" will correspond to the end of the project, i.e. end of 1999.

9. REFERENCES

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