THE COMPUTER INTEGRATED ROAD CONSTRUCTION PROJECT

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Abstract

This paper is about the "Computer Integrated Road Construction" project, which is a Brite-EuRam III funded project, lasting 1997-1999, aiming at introducing a new generation of control and monitoring tools for road pavements construction. These new tools will bring significant improvements in terms of management of the work and control tasks by providing computer aided assistance to the various operators, and by creating a digital link between design office and job site.

The first part of the paper gives the background of the project, which gathers seven European partners, from five different countries. The objectives of the project are then given, in general and for each of the two targeted products, one for the compactors (CIRCOM) and one for the asphalt pavers (CIRPAV).

Then, the two prototypes which are under development are described, each of them being decomposed into three main sub-systems : the ground sub-system, the on-board sub-system and the positioning sub-system. The main specific features of each sub-system are emphasised.

After the state of progress of the developments are finally presented the expected benefits of the project's products to the different (direct and indirect) users : road contractors, road owners, as well as the different social and environmental impacts. The paper ends with the links existing between CIRC and other European projects.

1. BACKGROUND

The European development plan for the construction of motorway infrastructure forecasts the building of 20,000 km of highways and motorways within the next 10 years. The financial stakes linked to this project are significant : each km built costs on average 6 MECU. About 20 to 25% of the overall budget is dedicated to pavement construction. European building and civil engineering industry faces an international market in which the demand for quality control and productivity improvement is becoming increasingly necessary.

The "Computer Integrated Road Construction" (CIRC) project, n° BE-96-3039, is supported by the European Commission, under the Industrial & Materials Technologies Programme Brite-EuRam III. It aims at demonstrating the interest of new tools, based upon the application of state-of-the-art information technologies to the road construction sites.

Seven partners are involved in the project, each providing complementary skills and abilities :

- ITMI division of CAP GEMINI France, main activity: information systems, project role: Co-ordinator, Prime contractor, developer and integrator of positioning systems.
- The Laboratoire Central des Ponts et Chaussées (LCPC), France, main activity: engineering expertise and research within the field of civil engineering, project role: project initiator, trials and project consulting.
- TEKLA OY, Finland, main activity: geographical information systems, project role : development of mission planning and control system, development of interface to CAD system.
- University of Karlsruhe (IMB *or:* Institute for Construction Management and Machinery), Germany, main activity: construction machines and management, automation in building and civil engineering works, project role: development of on-board control systems.
- University of East London (UEL), Great Britain, main activity: metrology, project role: development of the laser-based positioning system.
- EUROVIA, France, main activity: road and motorway construction, project role: requirements specifications, experimental work-sites.
- National Land Survey (NLS), Sweden, main activity: geography and geodesy research and expertise, project role: work-site surveying consultant.

Alongside this consortium, an End-Users Club has been created. This group, managed by the partner Eurovia, 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 (Dynapac, ABG) and over 30% of the European road construction (Eurovia, Colas, Dragados y Contructiones).

2. OBJECTIVES

2.1 General objective of CIRC products

The CIRC project aims to develop precision systems for the real-time control and monitoring of the work performed by road construction equipment. These systems, to be integrated, in a first step, into road construction machines like compactors or pavers, will rely on CAD (Computer Aided Design) data established during the design phase, and on on-site measurements acquired in real-time during the construction work.

CIRC products will provide integrated ready made solutions for operator assistance, for machine control and for quality assessment, ensuring, for the first time in the road construction industry, a global numerical link between design, work and control.

The project relies on two major technological approaches :

- the first one is the use of state-of-the-art real-time positioning technologies, such as phase-differential Global Positioning System (GPS) or 3D laser-based technology, which is the only solution capable of giving in elevation the required accuracy for the pavement upper layers,
- the other is the real-time use of CAD data on the machines as a reference geometrical data base for all the operations.

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.

2.2 Functional objectives for 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. 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.

So, the main objective of CIRCOM is to assist the driver in this task, so that he can perform the exact number of passes, at the right speed, everywhere on the surface to be compacted. This assistance is based upon an ergonomic man-machine interface (MMI), where simple graphical data and information are displayed to the operator. 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 system with an accurate and continuous localisation of the machine. "Accurate" in this case means 10 cm in both transversal and longitudinal directions, "continuous" means that it should work everywhere on the site, whatever the environment.

When installed on several machines (generally, 2 to 4 compactors work together on big sites) CIRCOM, in its multi-compactors version, will be able to manage the data base globally for all the machines. That is to say that each driver will have the knowledge of the work achieved by his colleagues and will be able to take it into account during his own work.

The second objective of CIRPAV is to record the actual work achieved by the roller, in terms of trajectory followed and number of passes on every point of the trajectory, 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.

2.3 Functional objectives for CIRPAV

Two main functions will be ensured by CIRPAV, from the machine operation point of view :

- to assist the driver in his task of maintaining the paver on its correct trajectory at the right speed, thanks to an ergonomic man-machine interface where both reference trajectory and actual position will be displayed,
- to assist the screed-man in his task of controlling accurately the position and cross-slope of the screed either through a state-of-the-art automatic control system or through dedicated displays indicating the commands to apply manually.

For these two goals, CIRPAV will provide all the position and attitude information of the tractor and of the screed which are necessary, with the respective accuracy required, that is to say ± 3 cm in both transversal and longitudinal directions, and ± 1 cm for the height component.

The third main objective of CIRPAV, from the site manager's point of view, is to record the actual work achieved by the paver, in terms of trajectory followed, altimetry and cross-slope on every point of the trajectory, in order to feed the site data base and to perform a global quality control at the site level.

Apart from the contractual progress reports (6-month, annual, mid-term, final...) which are due to the Brite-EuRam administration and from the technical notes, specifications, minutes and reports which have been and are being issued by the different partners, the main deliverables of the project will be the two CIRCOM and CIRPAV prototypes.

Each of them is decomposed into three sub-systems (Figure 1) :

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

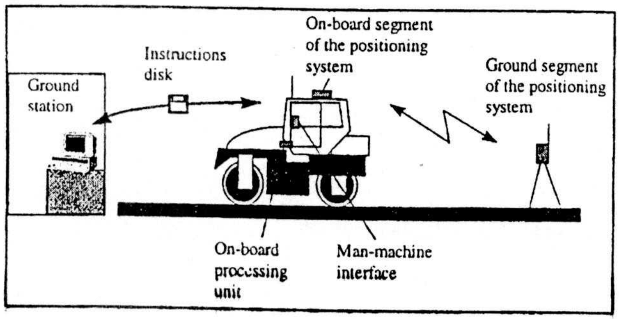

Figure 1 : global architecture of CIRCOM

3.1 CIRCOM prototype

The role 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 role of the positioning sub-system is to locate precisely and in real-time the compactor by using state-of-the-art Global Positioning System (GPS) technology, in real-time kinematic (RTK) mode as well as dead-reckoning sensors (Doppler radar, encoder and fibre-optical gyrometer). To get the best of all the instruments, an extended Kalman filter has been designed, running at the rate of 25 Hz.

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.

3.2 CIRPAV prototype

The role of the ground sub-system is to :

- provide the paver with geometric data about the work-site, coming from CAD data, as well as guidelines for operation,
- compute paving results and make some statistics about the work achieved.

The role of the positioning sub-system is to locate precisely and in real-time the paver and its screed For that purpose, different sub-systems are currently developed and studied, in order to provide the best possible solution, with regards to the kind of site. Mainly two technologies will be addressed :

- a novel 6D laser-based technology, capable of generating continuously and automatically sets of 6 spatial co-ordinates (« LaserGuide » system from University of East London), with an excellent accuracy in terms of elevation,
- the RTK-GPS technology, as for CIRCOM, combined with inclinometer measurements, for less demanding paving works in terms of elevation accuracy.

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

- memorise and compute instruction data, position data, work achieved,
- automatically control the height and the cross slope of the screed (if the operator chooses the " automatic control " mode),
- manage two man-machine interfaces (MMI) which assist the driver and the screed-man in their work.

3.3 The ground sub-system software

The two products will be different, but the core of the ground sub-system will be common to CIRCOM and CIRPAV. The most innovative feature of this software is the structure of the data base itself which is 3-dimensional, meaning that all the elements of the project, as well as the trajectories, are stored as 3D polylines in a vector data base.

An example of ground sub-system's window is given in Figure 2.

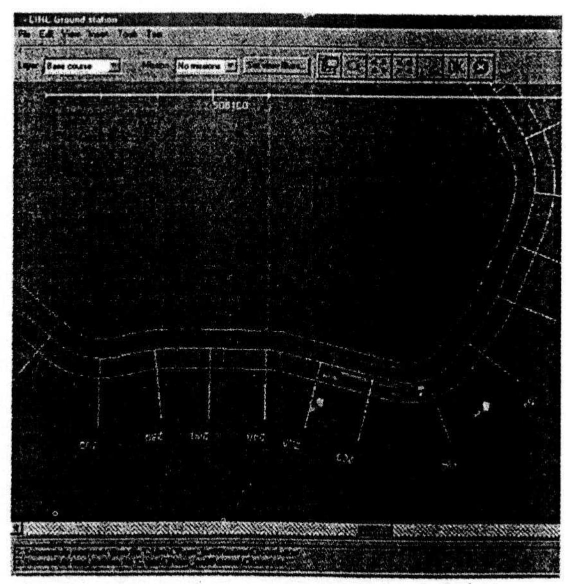

Figure 2 : the ground sub-system MMI

4. PROGRESS AND ACHIEVEMENTS

The CIRCOM prototype has been developed during the first half of the project in his mono-machine version. Experimentation trials have been done on the Eurovia A84 motorway work-site in Villedieu-Les-Poêles (Normandy, France) at the beginning of September, 1998 (Figures 3 and 4). These trials were programmed in order to :

- finalise the experimentation (assessment of all the technical functionalities),
- carry out the site-oriented trials necessary to assess the operational functionalities.

These trials were successful and shown that the main functions required were fulfilled, in particular the performances of the positioning system, even inside GPS shadow zones, thanks to its innovative fusion between GPS and other sensors measurements.

The multi-compactors functionalities are currently under development, other field trials, similar to the first ones will be organised next summer, involving at least three different compactors. During these new trials, that will be carried out during several weeks, will be assessed :

- multi- compactors functionalities,
- global gains in terms of quality brought by CIRCOM in comparison with the manual mode.

Fig. 3 : the compactor used for the full-scale trials

Figure 4 : the on-board MMI during compacting operation

The CIRPAV prototype is currently in the development phase. The system design is completed, now each sub-system is being designed in a detailed way and developed by the appropriate partners.

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

- <u>unit tests</u> : 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.
- <u>integration tests</u> : to verify that the CIRPAV system as a whole has a valid functioning. This phase will include static and dynamic tests on a test vehicle.
- <u>experimental tests</u> : to verify the performances of some of the modules/sub-systems of the CIRPAV : robustness and accuracy of the positioning sub-system, ... They will be carried out on a real paver on test tracks of the CER at Rouen, France.
- <u>validation tests</u> : to verify that the CIRPAV 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 October 1999.

Figures 5 and 6 present the mock-ups of the two MMI which are under design for the driver and for the screed-man of the paver.

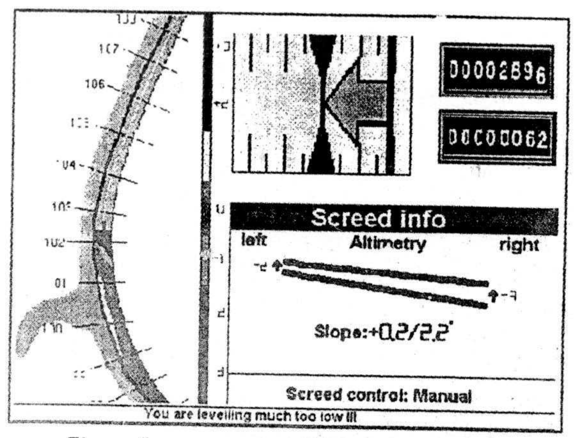

Figure 5 : prototype of CIRPAV driver's MMI

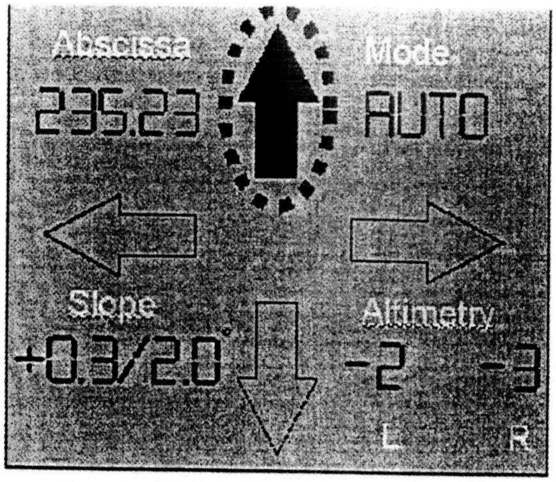

Figure 6 : prototype of CIRPAV screed-man's MMI

5. BENEFITS TO DIFFERENT USERS

5.1 For the road contractor

The main expected economic gains for the road contractor are at four levels :

- saving of tedious labour cost,
- saving of equipment use,
- material saving,
- improvement of quality.

5.1.1 Saving of tedious labour cost

This saving will mainly be effective for CIRPAV.

For paving works, respecting a reference profile, the job site cost devoted to the manual levelling and preparatory tasks is very high with the traditional methods (wire and pegs or laser towers). For the base or sub-base layers spreading (in order to guide the pavers), these tasks are estimated, to amount to 10 % of the total cost of the work.

The main objective of CIRPAV is to lower this cost percentage below 5 % and to improve the level of quality achieved for the road (evenness). Computation have been made by EUROVIA, showing that a 80 kEuro CIRPAV could be paid off thanks to this saving on a single 30 km long highway work site.

5.1.2 Saving of equipment use

This saving will mainly be effective for CIRCOM.

The use of CIRCOM can reduce the number of machines used on the job site, thanks to a significant reduction of the overlapping surfaces travelled by the machine, thus enabling the contractor to do the same job with a reduced number of machines. This increase of productivity can amount, at the level of the compacting task, up to 25 %. In terms of saving, a simple calculation shows that two CIRCOM of 45 kEuro each could be paid off by two 20 km long highway work sites

5.1.3 Improvement of quality

In a zone where the quality of levelling or evenness on site is not sufficient, the controller of the work site can either oblige the road constructor to repair the zone by placing a supplementary reprofile layer or by milling the course or decide a cut in its payments. In both cases the economic impact on the work site is heavy.

The improvement of quality is obviously one of the main goals of the CIRC Project. It will benefits to all the users and customers, but particularly to the contractor, when talking about the saving of money linked with the suppression of supplementary works for repairing.

5.2 For the contractor and the road owner

5.2.1 Material saving

The dispersion of the layers thickness will decrease with the use of CIRPAV. From a statistical point of view, the risk of over/under thickness is reduced. It can then involve a reduction of the theoretical thickness which is established during the design phase, taking into account that risk, while keeping the same mechanical resistance. The savings are estimated to 5% on the consumption of materials.

Such a saving corresponds to important economic gains (around 3 500 Euros / km on a 2 x 2 way highway pavement site) which will be shared between contractor and owner.

5.3 Safety, social and environment impacts

5.3.1 Safety

The safety impact is significant. It is mainly expected at the level of the human labour that will be saved in the tasks of laying out and maintaining the physical references and in the task of checking the achieved work. All these tasks are performed around the running machines and are consequently very dangerous.

5.3.2 Social

Using high-technology products such as the CIRC systems will bring a significant valorisation of the road works which are traditionally considered as dirty, dangerous and tedious. It will reduce low-level and repetitive tasks such as manual levelling of stakes, manual installation of wire ropes, manual checking of the thickness, etc.. CIRC systems will bring to the machines operators ergonomic computer aids that will considerably improve their hard working conditions. Together with an enhancement of job satisfaction, using devices such as CIRC systems will bring to the labour various opportunities for education and training, increasing that way the traditionally low technical level of the work sites labour.

5.3.3 Environment

Road pavement materials available on the work site are produced through a long chain of production involving mainly :

- extraction of raw materials from the natural environment (stones and oil),

- separate processing of these materials in order to obtain aggregates and bitumen,
- mixing process of the two constituents in order to obtain asphalt concrete,
- transportation phases between the processing phases, mainly with lorries.

All these phases are much energy-consumer and pollution-producer, despite the stiffening of the regulation and the industrials efforts. Savings at the level of pavement materials will involve savings at every level of this chain and thus a significant reduction of the corresponding pollution. Moreover, the lower demand for raw materials will involve a better preservation of the environment

6. LINKS WITH OTHER PROJECTS

6.1 Targeted Research Action networks

The CIRC project is affiliated to two Targeted Research Action networks:

- European Friendly Construction Technologies (EFCT),
- European Thematic Network on Extractive Industries (EUROTHEN).

The reason to participate in both networks is that they are complementary. EFCT deals with the same application sector (construction) but with poor technical synergy whereas EUROTHEN seems to offer better technical benefits in a different sector (mining).

The project manager of the CIRC consortium attended the 1st EUROTHEN workshop (Athens, Greece, 12-13 January , 1998) and presented a paper.

A representative of the CIRC consortium attended the 2nd EFCT workshop (Bruxelles, Belgium, November 16-17, 1998).