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TOWARDS COMPUTER INTEGRATED ROAD CONSTRUCTION

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ABSTRACT

Two noticeable events will speed-up the development of road construction robotics :
- the recent availability on the market of adapted localization systems,
- the increasingly developing utilization of computer aided design in the study of road construction projects.

Currently, no links do exist between the design studies and the construction work involving digital data which could be used for programming automated equipment.

In this paper, the authors first describe a homogeneous family of equipment units as compared to the control and localization problems, i.e. : the levelling/profiling units.

Then, after having described the existing or draft localization systems and the CAD tools currently used in France, the authors describe a simulation model of an operator assistance system for levelling/profiling machines.

This moke-up unit allows introducing the various concepts required for the achievement of a CIC system, and the research axis to be developed to reach that objective.

1 - INTRODUCTION

Robotization of Public Work equipment constitutes one of the acknowledged means *[MON-89]* of improving the **quality** of the work and **safety** of the working personnel on the work sites, and **productivity** of the workshops.

The LCPC, which develops methods and testing/monitoring equipment units in the field of road construction applications, has elected, since a few years, to follow that direction.

Three major guidelines direct the envisaged researches : **localization** in external land site, **assistance to control**, and **modelisation** of equipment operation.

The current work is aimed at prefigurating how these three research directions will be integrated in a joint CIC project.

2 - THE FAMILY OF LEVELLING/PROFILING EQUIPMENT

Amongst the equipment units involved during the construction process of a road, some of them can be grouped in a same family which has been named "family of road levelling/profiling equipment".

These units are characterized by :
- a task, consisting in **achieving, in a single run**, the levelling of a road, either by adding, or removing, a single layer,
- the need of being controlled according to **four degrees of freedom** (X, Y, Z axis, and transverse inclination or rolling) with high accuracy requirements,
- a relatively slow speed which determines the progress speed of the whole work site (from 3 m/mn to 6 m/mn in Europe).

This family includes :
- **the finisher,**
- **the slip-form paver,**
- **the autograde,**
- **the milling machine.**

These units consist of a drive and steering **chassis**, most often mounted on caterpillars, and sometimes on tyres, itself supporting a levelling **tool**, free to move relative to the chassis. This tool can be :

- a smoothing and pre-compacting **screed** (two degrees of freedom) in the case of the finisher
- a sliding **mold** (three degrees of freedom) in which concrete is vibrated and formed in the case of the slip-form paver
- cutting **screws** (two degrees of freedom) in the case of the autograde
- a **rotor** provided with teeth in the case of the milling machine.

The operating principle of these units is simple :

- the chassis moves along the longitudinal profile of the road, and is either manually guided by a driver (finisher and milling machine), or wire-guided in direction (slip-form paver and autograde) at as constant speed as practically possible,
- the tool is adjusted in position in the space by cylinders made integral with the chassis (two, three or four depending on the machine), the control being either manual, or automatically elaborated from a mechanical or ultrasonic feeler following a wire representing the reference profile.

In both cases, the **control process of the tool** is identical :

positioning both extremities of the tool in the space according to a reference curve which may be represented by an equation of the following form : $Z=f(X,Y)$ or $Z=f(s)$, where s is the curviline abcissa representing the advance of the unit along the road.

It can be easily realized how this process can be automated by programming these reference curves in the control system of the unit, and utilizing the X and Y information data of the localization system for elaborating the local elevation references *[PEY-90]*.

Another more rational and safer approach could be proposed, and corresponds to that which has been used in the work presented herein :

1 - on a CAD system, the data describing the project is established in a frame which is perfectly defined for the whole work site,

2 - the said data is loaded in the automatic control system of the equipment at the beginning of the work, at the same time as the working program,

3 - when the unit is set to work, it automatically calculates the local surface of the project to be achieved, using the X-Y position of the tool which is measured by means of its localization system,

4 - finally, the machine generates the control commands to its cylinders and monitors the actual elevation and attitude position of its tool, using the information supplied by the same localization sensor.

Remark : control of the actuators (operation 4 hereabove) can be easily performed by a human operator using information data elaborated by the system under the form of a control aiding function.

We are even confident that this must be an absolutely necessary intermediate stage.

Concerning the automation of the **steering control** of the equipment, this is even more easy to formalize as it consists in following a plane trajectory of the form : $X=X(u)$, $Y=Y(u)$, using the actual position supplied by the localization system.

3 - THE CAD SYSTEMS

3-1 Introduction

Computer Aided Design of road projects (road CAD) has now become operational.

The development of road CAD leads to **organize the whole data processing line** linked to the design and achievement of road construction projects.

System studies have been conducted and, whereas the core of these applications still remains the geometrical modelization of road projects, many peripheral applications establish links between the CAD system and the needs of the geometers, project designers and work executives *[CRA-90]*.

Two project modelization levels are currently existing :

- a level grounded on a project description in terms of **"red line"**, build-up from a number of

geometrical primitive data (arc of a circle, clothoïds, paraboles, ...) and transverse profiles,
- a level grounded on a **surface description** of the project, generally under the form of a set of triangular facets.

The first level is close to the concepts used by the project designer, whereas the second, which is more universal, features more flexible utilization and is better adapted to the acquisition of the natural ground or to the description of parts of complicated constructions : interchanges, crossings, branches.

3-2 CAD and design

Concerning the **project design** phase, the tools are all adapted to the work of the project designer :
- the designer commences his work from a digital representation of the natural ground,
- he successively determines, with the possibility of performing fast to and fro movements *[GER-90]*, the plane axis and longitudinal profile,
- then, he determines his crosswise profiles,

(during these phases, he may handle his project through objects of which he has thorough knowledge : clothoïds, arcs of circles, segments of straight lines, paraboles, typical transverse profiles),
- from these elements, he may run modules which verify whether the constraints of the project and design standards are adhered to,
- finally, he outputs the elements of the project, i.e. both those which are necessary for consulting the contractors, and those necessary for conducting the work.

As a general rule, the current development of the products are aimed at strengthening the design aiding role of this range of tools :
- as wide interactivity as practically possible,
  - increased graphical performances,
  - reference to road concepts,
  - integration of standards and rules,
  - integration of the know-how.

This is, for example, the direction taken in the ARCAD project of the SETRA (Service Technique des Routes et Autoroutes) *[DEB-90]*.

3-3 CAD and construction

During the **achievement** phase, these tools are used in a more restrictive manner.

The reason is linked to the on-site working methods which require a site set-up phase during which many markers are installed.

The coordinates of these markers are obtained from the project design study.

Concerning **control of the achieved work**, a survey phase is necessary as none of the available equipment units is equipped with a real time job follow-up system.

The data thus recorded can be re-entered into the CAD system for calculating the cubatures and for work acceptance purposes.

3-4 Expected evolution

It is obvious that, account taken of the richness of the information data handled by these systems, improved utilization of the data could be imagined on the work sites, i.e. :

real time control of the construction equipment.

This paper is aimed at initiating this approach toward **"Computer Integrated Construction"** (CIC)

4 - THE LOCALIZATION SYSTEMS

It has been seen in section 2 hereabove, how the machine integrated localization system is important in the automation process.

Indeed, it is from the information supplied by the localization system that the equipment will program and monitor its own work.

For almost four years now, the LCPC has been conducting researches, experiments and developments in this field *[PEY-89]*.

Many system configurations and several technologies may be envisaged depending on the type of work to be achieved.

Since our former communication at the 7th ISARC held in BRISTOL *[LEC-90]* in which we summarized the essential techniques which could be used as well as their advantages and drawbacks, noticeable evolutions have been experienced :

- the **"SIREM"** system, invented by the LCPC and also presented at STUTTGART last year *[LEC-91]*, is now available in the form of an operational prototype which has demonstrated at the end of 1991 that it had reached its objectives (accuracy along the Z axis : 5 mm, along X and Y axis : 10 cm, rolling and pitching : 0.03°, yawing : 0.2°),
- since 1991, an industrial product is available on the market (**"AXYLE"**, manufactured by the SERCEL company) which allows 1 to 8 mobiles to be localized in a plane by micro-wave telemetry, also featuring an accuracy in the range of 10 cm, but with distances between mobile and beacon as great as 10 km,
- some industrial companies, specialists in **GPS** receivers (SERCEL, ASHTECH), are currently developing real time localization systems, the announced accuracy ranges of which (between 1 cm and 10 cm on all three axis depending on the implemented techniques) might upset the field of available products in the forthcoming years.

Nevertheless, despite the recent increasing rate of new developments, no system has been hitherto utilized in operating condition on a real work site, but several projects currently in progress should be operating on experimental work sites within two years.

Concerning the localization of levelling/profiling units, the accuracy requirements are in the order of : 5 mm along the Z axis, 10 cm along the X and Y axis, 0.05° in terms of rolling and pitching, and 0.2° as far as yawing is concerned.

In the foregoing, we have assumed that the equipment under consideration was equipped with a system of the SIREM type, i.e. capable of providing 6 degrees of freedom concerning the mobile on which the equipment is fitted.

These 6 degrees of freedom are essential for being able to calculate, at any time, the transformation matrix between the mobile frame and the so-called "absolute" frame which is in fact the reference frame.

Remark : in the case of another system which would not supply angular information (i.e. a single GPS antenna) it could well be imagined that the said system is equipped with sensors of the inclinometric type in order to be brought in line with the SIREM system.

5 - THE MOKE-UP OPERATOR AIDING SYSTEM DEVELOPED BY LCPC

5-1 Functional description of the application

The moke-up system developed by LCPC *[COR-91]* is aimed at demonstrating that digital control of levelling/profiling equipment can be envisaged in a relatively near future.

The requirements relating to the application to be achieved were : **a machine moving on an unknown surface has to control its levelling/profiling tool and, for that purpose, has two types of information available : its position within an absolute coordinate reference system, and the project (surface) to be achieved, defined within the same reference system.**

The position is available at any time and the project is described both in terms of plane and elevation under the form of successive sections.

In terms of plane, each section corresponds to a red line arc (X(s), Y(s)).

In terms of elevation, the project stands as a succession of transverse profiles and a linear interpolation law between the said profiles.

The application must yield the plane tangent to the project in the vicinity of the tool, within the equipment coordinate reference system.

From that information, the machine is able, within its own coordinate reference system, to control its tool so that it is set tangent to the project and will thus "profile" the surface to be achieved.

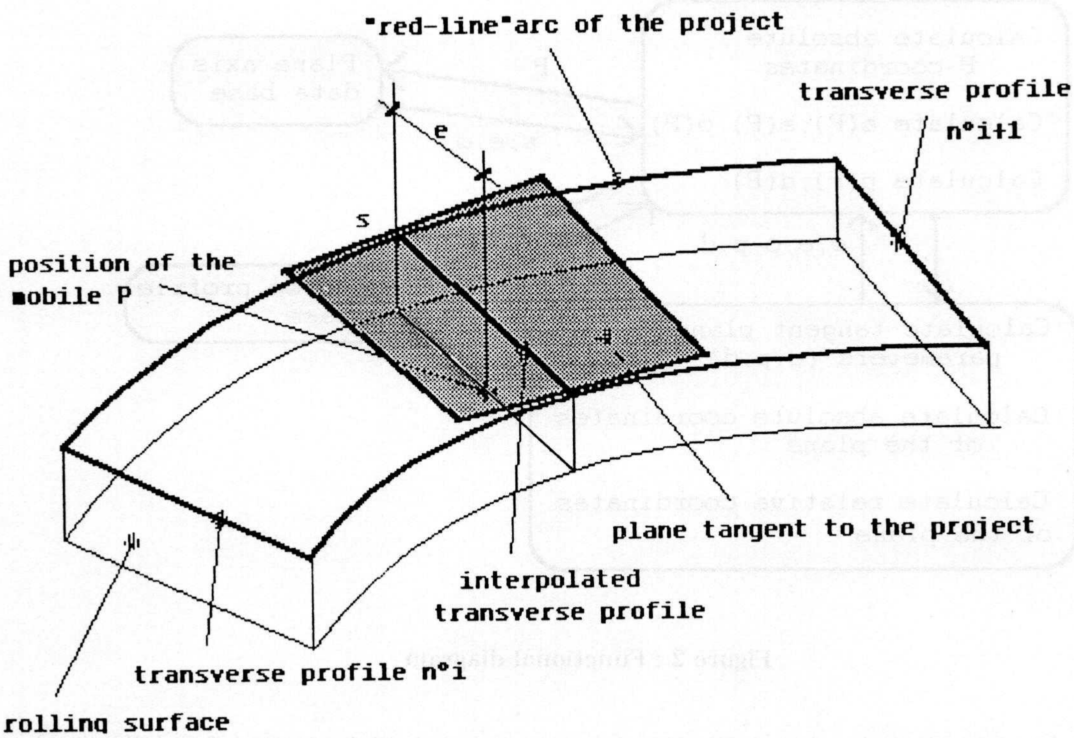

Figure 1 : Plane tangent to the project

The application has been designed under the form of communicating modules having the architecture shown on figure 2.

When the application is interrogated for knowing the tangent plane within the equipment reference system :

- it actualizes the position of the machine (Re),
- it determines the absolute position of point P linked to the tool,
- it searches the plane section in which point P is located and obtains, in response, the curviline abcissa (s) along the red line and the distance of point P relative to the red line (e) and the orientation of the red line (o) at this location,
- knowing s and e, the machine will then search the two transverse profiles surrounding point P and, applying the linear variation law, it will calculate the axial slope (p) and cross slope (d) coefficient at point P.
- it calculates the tangent plane in the absolute coordinate reference system from the orientation, axial slope and cross slope coefficients (o, p, d).
- it transforms in the relative space of the machine, the characteristics of the tangent plane.

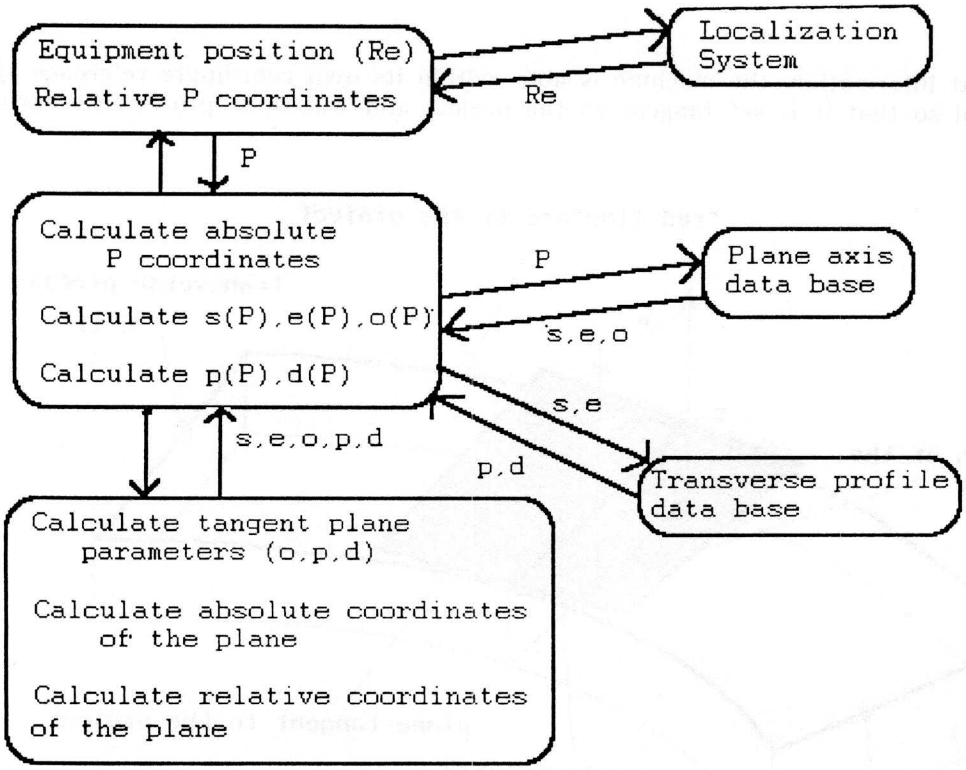

Figure 2 : Functional diagram

It can be seen that the description level has been retained in terms of **red line** and **cross profile**.

This description is well suited to the usual sections of the projects.

It this case, the description is relatively compact and closer to the road design standards.

In order to be able to use these modules in real time, we have developed project data access sub-modules acting as buffers.

As the machines proceed at relatively slow speed, they seldom change from section and never "jump" any section. Therefore, if the successive sections are connected together, it is never necessary to re-read all the data of the project (except at starting-up or for correcting an error).

Information e (distance of the tool relative to the red line) and o (red line orientation) corresponds to intermediate calculation parameters necessary for applying the interpolation law between two cross profiles.

These are also essential parameters for controlling the machine.

Indeed, it should be realized that, on future worksites, the project data will not be materialized on the site.

In such conditions, these parameters will play a fundamental assistance role in machine direction steering.

5-2 User's interface

In the foregoing, we have described the functions and the inputs/outputs of the various modules of the moke-up system. Its heart consists of the data file construction modules, the project section research modules, and modules calculating the tangent plane from which the reference instruction to be transmitted to the tool is generated.

At the current stage of the research, and prior to installing the system on an actual machine, we have been willing to illustrate the work hitherto achieved by integrating these modules in a

simulation environment allowing the achieved work to be visualized in an operator's friendly manner.

On the computer screen shown on the picture below, a number of blocks and windows can be seen.

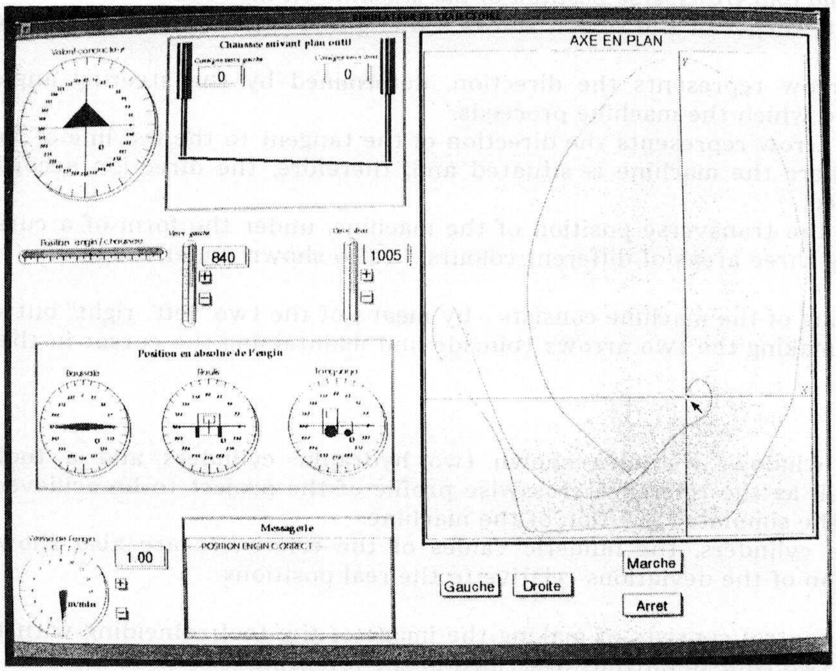

Figure 3 : Picture of the screen

Some are of the **"simulation"** type and will not be needed on a screen installed on an actual machine. Others are of the **"control assistance"** type and prefigure the type of interface which might exist between an automated machine and its driver.

Simulation :

- *Machine displacement*

We have created a window which visualizes the plane profile of a road under construction on which the machine is assumed to be moving and corresponding, obviously, to the "project" data files used in the simulation.

Under this window, there are four buttons respectively intended for starting and stopping the movement of the machine, and for direction steering (to the left or to the right) of the dummy machine travelling on the road.

In the lower left corner of the screen, an analog and a digital speed indicating dial, and two speed setting buttons are shown.

Finally, the window in the left-hand central part of the screen is used for displaying, under graphic form, the three angles of attitudes (yawing, rolling, pitching) of the machine depending on its position on the road.

Thus, using these control and monitoring functions, the dummy machine can be piloted on the selected project and its position in the horizontal plane as well as its absolute attitude in the space can be displayed in real time.

- *Tool control*

Under the window representing the position of the tool described in the following, we have simulated the manual control levers of the tool by buttons allowing to control the elevation and lowering movements of the hydraulic cylinders carrying the tool.

Control assistance :

- *Directional guiding and transverse position of the machine on the road*

The upper left corner of the screen shows a dial graduated in degrees, and incorporating two arrows :

- the first arrow represents the direction, determined by the steering angle of the wheel, according to which the machine proceeds,
- the second arrow represents the direction of the tangent to the red line of the project at the location where the machine is situated and, therefore, the direction according to which it shall proceed.

A display of the transverse position of the machine, under the form of a cursor moving on a scale incorporating three areas of different colours, is also shown under the dial.

Correct guiding of the machine consists - by means of the two "left -right" buttons described in the foregoing - in making the two arrows coincide and maintaining the cursor in the centre position of the scale.

- *Tool position*

In the last window, we have shown two hydraulic cylinders and a tool fixed at both extremities, as well as the reference crosswise profile of the project to be achieved, elaborated by the system, from the simulated position of the machine.

Close to the cylinders, the numeric values of the references are also shown, with colours changing in function of the deviations relative to the real positions.

The correct control consists of making the image of the tool coinciding with the image of the project, using the two control buttons described in the foregoing.

6 - CONCLUSION

The work represented herein is modest, but has the merit of highlighting the research fields in which advance must be done before reaching the stage of industrial CIC.

- **Machine automation** :

. control laws depending on the type of machine and type of work *[GOU-91]*.

- **Evolution of CAD systems toward CIC** :

. surface representation with realistic display,
. interaction between design and construction,
. standardisation of the data files,
. real time functionalities.

- **Man-Machine interface** :

. reliable and simple ergonomic display of the information data required for driving automated or robotized machines,
. safety functionalities,
. man-machine communication and monitoring.

These researches and developments cannot be efficiently conducted by a single team.

The diversity of the involved fields requires **close collaboration between a pluridisciplinar teams of researchers and industrial undertakings**, jointly operating **around a major project.**

The LCPC is currently looking for technical and financial partners, for conducting a project of this type.

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