MOBILE ROBOTS ON BUILDING CONSTRUCTION SITES : SPECIFICATIONS BASED ON TASKS REQUIREMENTS AND GEOMETRICAL ANALYSIS

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SUMMARY

For the last two years, a French research project aimed to define the specification of construction robots, with regard to the mobility requirements. Mechanical aspects, as well as motion planing and positioning function were carefully examined, for a panel of building construction basical operations. Conclusions are carried out for construction robot future development.

Keywords : mobile robot, specification, building, construction tasks, mechanical morphology, motion planing, positioning systems

1. INTRODUCTION

During the eighties, a great attention was paid to productivity improvements in the manufacturing industry, as well as, more recently in non manufacturing industries such as the building construction activity.

In this domain, numerous research works dealt with robotics as a mean for increasing productivity in the public work and building activities. These research works led to the developpements of several experimental robots, mainly in Japan, but also in USA and Europe and particularly in France.

These first approaches were tremendously helpful to identify precisely further research fields covering wide disciplines from advanced technical topics to sociological and economical ones.

Among technical aspects, the mobility function, is an essential feature of the future on-site construction robots. One can easily be convinced by reading the proceedings of the yearly dedicated congress, held since 1984. In addition with the technical interest on this subject, a few hours stay on a building construction site prove the high genericity of the mobility function and its economic weigth (workers movements, materials displacement, ...).

Considering this context, the French team previously in charge of the SOFFITO project, the first experimental mobile robot in Europe for building operations, launched a study supported by the French Ministery for research. The goal was to specify the characteristics of the mobility function for building robot, with regard to technical and economical constraints of construction site.

In this paper, we first report on these main constraints; the methodology is presented as well as resulting conclusions and future developpements.

2. THE ROBOTIC APPROACH IN CONSTRUCTION

The first research work in the field of construction robot started in Japan at the end of the seventies decade. During the last ten years, the attention of many people from several countries proved the growing interest paid to this subject.

Significant steps were made which led to the realisation of prototypes assessing the technical feasability. These robot are generally dedicated to specific tasks (mortar spraying, painting, concrete leveling and smoothing, ...). No satisfying answer was drawn out of these experiments and the discussion is still open about the present economical interest.

There still subsists a wide gap between these "pioneer"-like developments and the building construction operations on-site. It also exists a wide variety of construction sites due to numerous building methods. A global reflexion is merging, which aims at gathering professionals (architects, materials, tools, builders, ...) toward a concerted approach.

A synthesis of these previous works brings to the fore the necessity to consider the construction process as a whole, in order to analyse the interaction between construction methods and automation techniques.

This main idea which can look simple for skilled roboticians used to manufacturing applications, leads in the construction field to theoretical developpements named "constructability".

The major stake of these research works is to design "constructive systems", involving robot, in order to build better, cheaper and under improved working conditions. On this last point, it should be notice that the building activity is responsible for about one third of working accident deaths and is so the most dangerous one.

3. THE SOFFITO ROBOT : ACCOMPLISHMENTS AND EXPERIENCE

From 1986 to 1988 , the SOFFITO project aimed at illustrating the potential interest of the robotics techniques for construction operations. It demonstrated to the building professionals that available techniques, developed for other purpose, are likely to be used to perform tasks on construction sites, most of these tasks being presently manualy executed.

It is also an opportunity to incite investigations among professionals in order to evaluate the effectiveness of these techniques to improve work conditions and increase quality and productivity of work.

For experimental purpose, among building operation, the SOFFITO robot performed a finishing task: painting spraying. This choice resulted of technical availability and economical considerations, but SOFFITO was not designed as a "painting robot". It was designed as a minimum experimental robot to perform tasks in building sites, including therefore all basic functions nessecary to execute constructions operations (especially mobility).

From the experiment and after a long demonstration period to robotic or building professionals, it was concluded that :

- available techniques can be used to build an experimental construction robot. Tasks executed inside or outside the building can be considered ;
- future construction robot will probably never replace manpower on sites. The situation on-site is too complex and cannot be predicted and a human operator will be essential ;
- the present performances and their likely improvements allow an economical approach of the use of the SOFFITO robot. Between the present situation and fully autonomous machine, a great number of steps have to be taken. It is also clear that the automation of construction operations will need new designs of construction processes. Manual processes only suit for manual work.

The SOFFITO project gave the bases for more systematic studies on the design and the use of mobile robots on sites.

4. THE PROFESSIONAL ENVIRONMENT

In a traditional activity such as the building construction field, no evolution can be proposed without considering the organisation and the way of working of the profession. Some essential figures are nessecary to get a clear idea of the professional context. These figures are valid for the French situation :

- the building industry is one of the most important in the total French activity, regarding either the number of workers (1 035 000) or the volume of (449 billion francs in 1989) ;
- every contruction project involves a wide number of contractors and sub-contractors in charge of specific operations, for the whole realisation of the project. Generally, each contractor is independant and has its own methods and practices and tools. Such an organisation, which does not facilitate the use of common tools for generic operations, has also many drawbacks on communication and technical exchanges between building constructions sub-contractors, and misunderstanding occurs very often ;
- in the building industry, 295 000 company employs less than 10 salaries, making up to 40% of the total volume of activities. This atomization makes very difficult the technology transferts towards building professionals. Nevertheless, even if these companies have limited investment capabilities, they can support significant financial effort, as far as the economic benefit of a machine has been proved in real operating conditions.

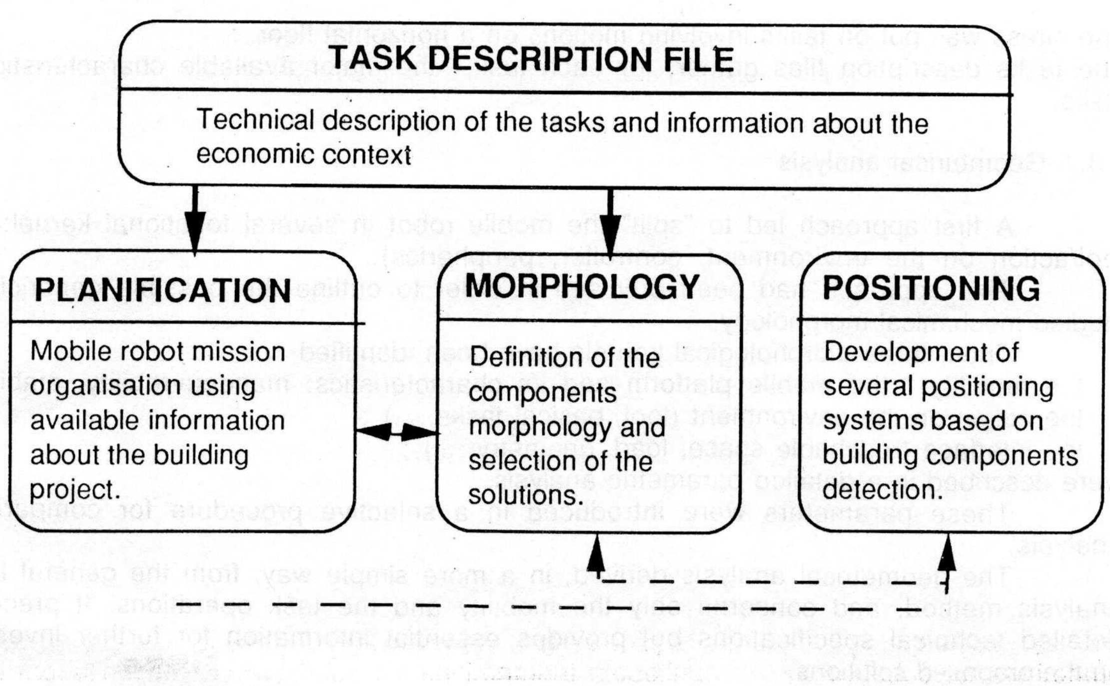
5. ORGANISATION OF THE STUDY

5.1. General approach

The study on building robot mobility dealt with 3 majors topics :

- the mechanical morphology of future mobile robots for building construction site, in order to define machine architectures suitable with building construction constraints ;
- the interaction between the building construction techniques and the use of automated tools or robots on the site, especially for the positioning requirements ;
- the control and the programming of the mobile robots having to move in a structured but evolutive environment (in both time and space).

In order to ensure the coherency of the study, each of these reflexions refers to a common set of tasks describing files.



5.2. Task analysis

The know-how of an on-site building worker can be considered as an expert knowledge on the task performed. It is possible to gather the qualitative characteristics of a particular task (elementary operations, chronology, relations with other operations, ...), but, on the opposite, it is very diificult to reach a quantitative description of the operating mode, as these features are highly dependent upon the experience and the know-how of the worker.

The lack of quantitative data on the building construction tasks is mainly caused by the oral and practical transmission of the know-how, which does not require formal description.

Nevertheless, it is possible to work on the mobility problem because this study requires a reduced set of input data which can generally be quantified (weight, forces, type of material,...).

A set of tasks, representative of the whole building operations has been selected, according to the two technical criteria :

- task requiring a physical contact between the tool and the environment ;
- task requiring or not simultaneous motions of the mobile platform and the tool ;

and an economical criterion :

- relative handwork consumption to perform the task.

	simultaneous motions of tool and mobile plaform	non simultaneous motions
tool in contact	painting spraying mortar spraying	painting spraying handling
tool without contact	floor cleaning sanding concrete leveling concrete smoothing waterproofing drawing	drilling indoor components assembling (plaster blocks)

The stress was put on tasks involving motions on a horizontal floor.
The tasks description files gather, for each task, the major available characteristics of the tasks.

5.3. Geometrical analysis

A first approach led to "split" the mobile robot in several fonctional kernel: mobility, tool/action on the environment, controller, peripherics).

This approach had been precised in order to outline the possible genericity of the studied mechanical morphology.

Then, three morphological kernels have been identified :

- the mobility (the mobile platform and its characteristics: manoeuvrability, stability,...) ;
- the action on the environment (tool, basical tasks, ...) ;
- the interface (reachable space, load, geometry, ...) ;

were described in a detailed parametric analysis.

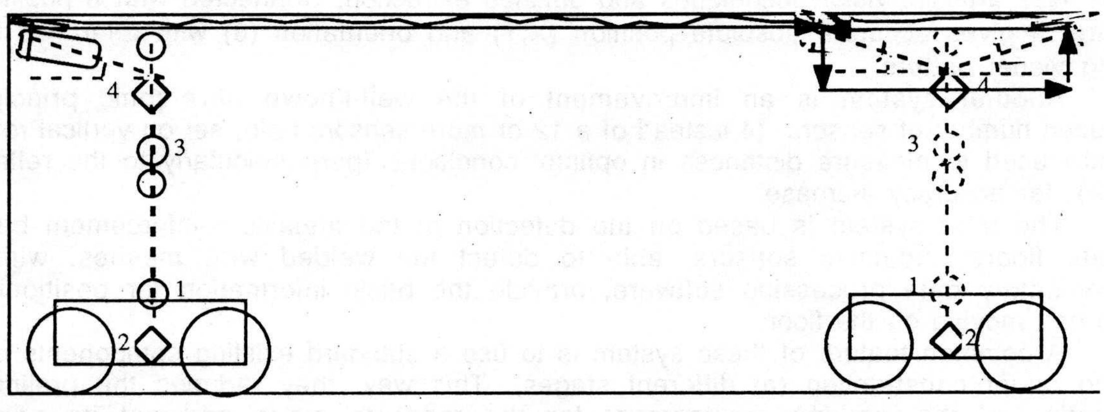
These parameters were introduced in a selective procedure for comparizon and analysis.

The geometrical analysis derived, in a more simple way, from the general fonctional analysis method, and concerns only the mobility and the task operations. It precedes the detailed technical specifications but provides essential information for further investigations on the proposed solutions.

The geometrical analysis aims, at first, to identify the suitable cinematic structures, which could lead up to future industrial development (assuming favourable economic and social conditions). Then, through a gathering of the solutions for all the considered tasks, some multi-usable solutions can be drawn out, after increase in the characteristic dimensions of the task. Ultimately, a sort on the selected solutions, gives generally a generic morphological structure which allows to perform various tasks by changing only the tools.

The working method is based on the three following phases :

- a study of the basical movements of the tools, described in a reference linked to the environment (task level). This approach includes the tool pre-positioning stage, the task performing movements and the final stage ;
- a analysis of the various articulated blocks, able to ensure the tasks realisation through the necessary degree of freedom, available either from the tool or the mobile platform or through an interface ;
- the proposals of several mechanical architecture suitable for the whole system (mobile paltform + interface + tool), with respect to the main constraints expressed. The best solutions are selected according to four performance criteria: easy to install, easy to control, suitable for performing the task, ratio simplicity versus machine manufacturing cost.



Example of mechanical morphology solution (tool and interface) for concrete ceiling smoothing

5.4. Navigation and positioning

For the first generations of robot, it was necessary to arrange the working environment and to modify the tools. The technical solution implyed the simplification of the tasks which reduced the versatility of the robots. The recent needs for flexibility require additional capabilities from the robots, which are :

- improvement of relational capabilities of the machines, with both the human operator (man-machine interface, MMI) and the working environment (sensing). On this topic, the working site is a particular context which can be learnt through the use of specific sensors. Positioning problems can be ranged in this domain.
- increase of understanding, through logical and reasoning functions, to provide the machine with self-decision capabilities. Among others, navigation aspects require to be able to solve such problems.

5.4.1. Navigation

In order to solve the working operation of a robot on-site, it is helpful to provide it with all available information about the organisation of its vicinity. The topology of the site is frequently available through the designer map of the building, and can be used as a basic knowledge for environment modeling.

A general method for environment modeling has been developed, using standard physical building components, referenced and linked to each other (wall, doors, posts,...). The model issued from this method is used by both the planner and the execution controller. The environment modeling, planning and execution softwares have been developed using an objectoriented language (LAP) and PROLOG.

The environment description was coupled with logical reasoning structure which manage the motions with regard to the task requirements and the external constraints (position, unknown obstacle detection,...).

The planning software was implemented on an experimental mobile robot. The performed tests have shown that an important work remains to get enough expert knowledge to provide the robot with all necessary information for task execution and motion control.

5.4.2. Positioning

Three general purpose systems for robot positioning have been developed. Based on different principles, they all used a specific structurant component of the building under construction. None of these system under development and qualification can today pretend to meet every positioning requirements (accuracy, phases of the construction process,...) of a mobile robot, but they can be combined to extend their application field.

A first system is based on the visual detection of building components such as floor tiles. it uses artificial vision techniques and outlines extraction. Connected with a positioning software, it gives accurate absolute position (X,Y) and orientation (θ) with reference to an existing visual pattern.

Another system is an improvement of the well-known ultra-sonic principle ; Aareduced number of sensors (4 instead of a 12 or more sensors belt), set on vertical rotating axis, are used to measure distances in optimal conditions (perpendicularly to the reflecting surface), for accuracy increase.

The third system is based on the detection of the metallic reinforcement bars in concrete floors; inductive sensors, able to detect the welded wire meshes, with the complementary data processing software, provide the basic information for positioning a mobile cart moving on the floor.

A common feature of these system is to use a standard existing components of the building under construction (at different stages). This way, they reduced the preliminary preparation of the working environment for the robot to move and get its position. Nevertheless, some of these systems may require particular attention during construction operations or components manufacturing. This is particularly true for the inductive positioning system which need an accurate knowledge of the metallic mesh in the slab for realistic sensor information and computation. This can be reached through improvements in both manufactured product quality and on-site assembling tasks.

6. RESULTS AND FUTURE DEVELOPMENTS

The studies performed in the framework of this research program provide significant information about the realisation of the mobility function for on-site building construction machines :

- it appears difficult, under present economic and technical conditions, to design a generic mechanical morphology suitable for a wide range of building construction operations. Most of building tasks require dedicated tools and specific machines; the technical obstacle, if not insurmontable, is not the major one with regard to the professional practices which are to use own machines instead of sharing common ones ;
- in the field of navigation, it is now clear that the information available at an early stage of the the building design (map on computers issued from CAD systems) provide an essential knowledge for robot navigation programming in the construction site environment. Complementary data may be required, such as the task realisation parameters (operating mode, ...), and the characteristics of the mobile machine (manoeuvrability, ...). The development made in the field of navigation and path planning allow to think that techniques are today available. Some lack still remain and main efforts should deal more with the knowledge about the tasks and their formal description than with computer science advanced techniques (IA, object oriented langage, ...) ;

- in order to avoid either heavy preparation of the working environment or expensive techniques incompatible with the building context and economic constraints, further developments should be made towards positioning systems based on building components and their particularities. Experimental results drawn out of this study aim to prove the technical feasibility and the interest of this powerful approach, not limited to building construction applications.

The building traditional practices, the actual assembly methods, the use of non-standard products and the packaging of the materials are the major hindrance to strong automatisation of the building construction tasks. A global reflexion must be started, gathering all building professional in a profitable partnership, to identify the most automation adapted construction methods.

One should not expect everything from increase automatisation or robotisation. Such developments should take place among complementary professional oriented actions (training, information, ...), in a general approach, involving all the building partners, and could meanwhile lead to higher quality and rigour in the building activity.

The research works under progress, aiming at improving the communication between the numerous professionals which participate in the construction process, are parts of this general evolution. In the meantime, many efforts from components and materials manufacturer to enhance the performances of their products, contribute also to reach such an objective. The CIC (Computer Integrated Construction) is the federating name of this approach in wich all building partners should be involved.