A TEST CASE OF COMPUTER AIDED MOTION PLANNING FOR NUCLEAR MAINTENANCE OPERATION

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Needs for improved tools for nuclear power plant maintenance preparation are expressed by EDF engineering. These are an easier and better management of logistics constraints such as free spaces for motions or handling tasks. The lack of generic or well suited tools and the specificity of nuclear maintenance operation have led EDF R&D to develop its own motion planning tools in collaboration with LAAS-CNRS, Utrecht University and the software publisher CADCENTRE within the framework of the three years Esprit LTR project MOLOG [1].

EDF users needs will be summed up in the first part of the paper under the title « Motion feasibility studies for maintenance operation» and then compared to the current industrial offer in the « Software's background »'s part. The definition and objectives « Towards motion planning tools » follows. It explains why maintenance preparation pertains to automatic motion planning and how it makes studies much simpler. The « MOLOG's Benchmark and first result »'s part describes the test-case used to evaluate the MOLOG project and gives an outlook at the results obtained so far.

MOTION FEASIBILITY STUDIES FOR MAINTENANCE OPERATIONS

Nuclear maintenance operations often require humans, cranes, tooling, transport devices, or even specific handling or cutting device like robot arm to work altogether in highly cluttered environment with large amounts of machinery, piping, and tanks. Thus motions or handling operations may become critical. This leads engineers to split up such tasks into elementary ones, each of them involving one handling device, one component to remove, to storage or to install and necessary tooling which lies and moves in the same environment.

Then a first critical aspect of the maintenance preparation is to check that each new elementary task is feasible which basically means that the initial and final positions can be connected by a collision free motion which respects the kinematics capabilities of the device. Most elementary tasks are well known but consequent studies must be undertook as soon as a non-trivial one occurs (unforeseen maintenance operation, upgrading and retrofit of major parts of installation or dismantling). These studies enable to minimise the potential civil engineering modifications (to enlarge the way), to optimise the cutting operations (of a too big component to remove) and potentially to check the design of specific devices. Such studies could take several months.

The second critical aspect is the sequencing and the overlapping of the standard elementary tasks. These kind of studies appear at the stage of standard maintenance preparation. The free space of infrastructure and machinery is in most cases minimised to lower the cost of civil engineering. This makes that any change or unforeseen circumstances in the tasks organisation could lead to geometric conflicts (like occupation conflict, way closure or device allocation conflicts) or more generally prevent any motion of one task from achievement.

Thus a three dimensional representation of the installation armed with computer aided motion design software seems as a necessity along the whole life cycle of the installation in order to evaluate the feasibility of new maintenance task or to diagnostic conflicts in tasks organisation. It is also an explicit mean of communication and negotiation between all the partners involved in a maintenance operation.

SOFTWARE’S BACKGROUND

The current offer of industrial software for representation and studies of nuclear installation can be broken out in two main categories: Computer Aided Design (CAD) for civil engineering and Computer Aided Motion (CAM). Each category partially covers the needs for maintenance preparation and have their own logic which make themselves difficult to use as a basic support for the studies mentioned above.

CAD software for civil engineering are aimed at 3D layout representation of large and complex installations like power plants, chemical installations and offshore platforms. They often include a collision checker and a virtual navigation tool in the 3D model which allows to visit the installation and to quickly change the viewpoint of the infrastructures. While for many years this category of software has been the only one able to represent large and complex installations as nuclear power plant buildings, they are far from fulfilling the uses needs for motion simulation, with two main drawbacks. The first one is data organisation. In CAD tools the 3D model is basically a collection of static objects segmented according to civil engineering professions which does not coincide with an assembly or disassembly logic. The second one is that CAD tools are mainly aimed at managing static layouts. Rigid bodies can only move interactively once at the time. This drawback forces the user to describe the state of the operation at any time with the position of all movable rigid bodies. This work could also be very redundant as soon as a mechanism like handling device appears. For example the polar crane of the reactor building can roughly be modelled by three rigid bodies *i.e.* 3 x 6=18 positions and orientations parameters although we know that three parameters are enough to describe it at any fixed time. The static description of the operation states has to be restricted to a discrete set of times which does not guarantee the absence of collision between two states. Whenever achieved, this work can be highly time consuming : several weeks for an elementary task and months for a complete maintenance operation. Furthermore real animation of the result of this work is mostly unavailable.

First aimed at robotics engineering, Computer Aided Motion (CAM) software are widely used in automotive, aeronautics and more recently in animation, medical or ergonomics. Thanks to their mechanism (kinematics) design capability they allow describing a scene using the minimal set of needed parameters (three in the example just above). This set is called a configuration or similarly a point in the configuration space. A unique trajectory in the configuration space represents all the physical trajectories of one or several rigid objects in the workspace. Using configurations easily enables simple continuous motion design. Whenever inverse kinematics capacities are available, tools are proposed to help the user to find specific configurations like grasps or poses, which allows to design complete handling tasks. Armed with this, a user can define continuous motion with two different strategies:

1. Fix initial and final desired configurations and modify the nature of the trajectory which links them until it does not remain any occurrence of collisions.
2. Build an ordered list of configurations and fix the way to link them two by two to design the complete collision free trajectory.

Both strategies are of course of equivalent complexity and, in non trivial motion design, force the user respectively to use too many parameters to describe the nature of the trajectory or to use a too large succession of stage points. Problems thus arise for the user faced to laborious trial/error procedures. The problem of automatic design of collision-free trajectories, also called motion planning, was born [2] to avoid such situations during CAM design, but industrial application is being a long time coming.

The reason of this delay is due to the inherent complexity of the problem which was investigated and understood during the two last decades. The computation of the first strategy based on trajectory’s automatic definition between two given configurations (for example deduced from an obstacle avoidance potential field) leads to analytic singularities or it looses its generic nature that makes it unusable for easy and interactive motion design. The second strategy is more adapted to a generic algorithmic treatment but also leads to singularities called combinatorial explosion. This means that the computation time can be quickly damning.

TOWARDS MOTION PLANNING TOOLS

Such singularities can now be identified and putted off in the computation thanks to the recent development of probabilistic methods [3, 4, 5, 6, 7]. These methods are quick and generic and thus enable industrial application in the motion planning area. These methods are one of the fundament of the MOLOG project.

The price to pay for their use is that the answer of the question « Are we sure that it doesn't exist any collision free motion in this cluttered environment to achieve a task ? » is an estimation. Anyway, if these methods find a solution of the motion planning problem, this solution is exact. Otherwise if the estimation of non-feasibility is high, it often means that the motion is very complex (for example with too many manoeuvres or with an high collision risk) and makes it ever in practice impossible.

Furthermore these methods enable a two step computation. During the first step which does not require the presence of the user, the topological properties of the configuration space are captured, just like a roadmap does for car traffic, but in a high dimensional configuration space. During the second step, the user specifies an automatic query in the roadmap and can refine the results using the optimisation tools (currently path length minimisation) and quickly produces different trajectories.

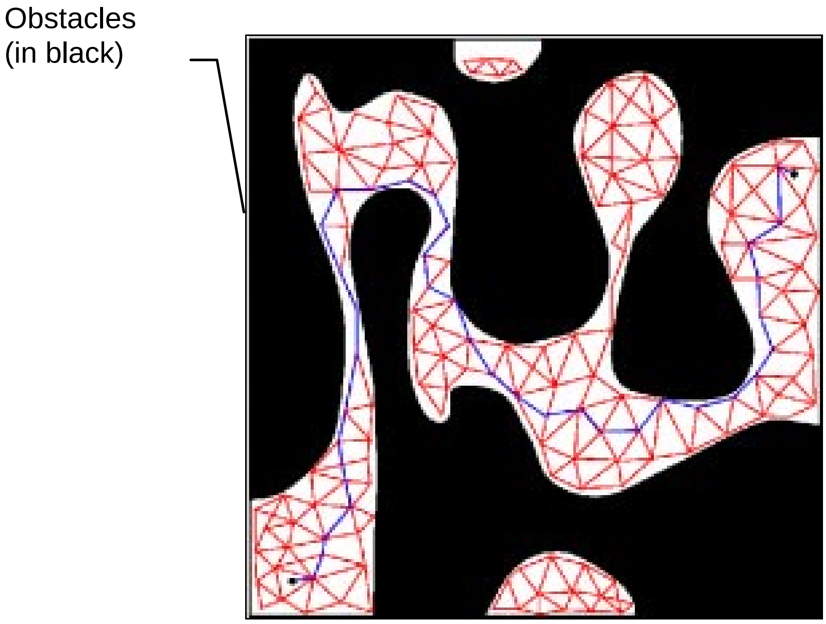

Figure 1: Roadmap and trajectory

A specific effort for the Man Machine Interface (MMI) and for an intelligent management of the calculation time has been done to ensure collaboration between algorithms and engineering experience. Using such motion planning tools, the maintenance preparation can use the procedure shown on fig. 2 below.

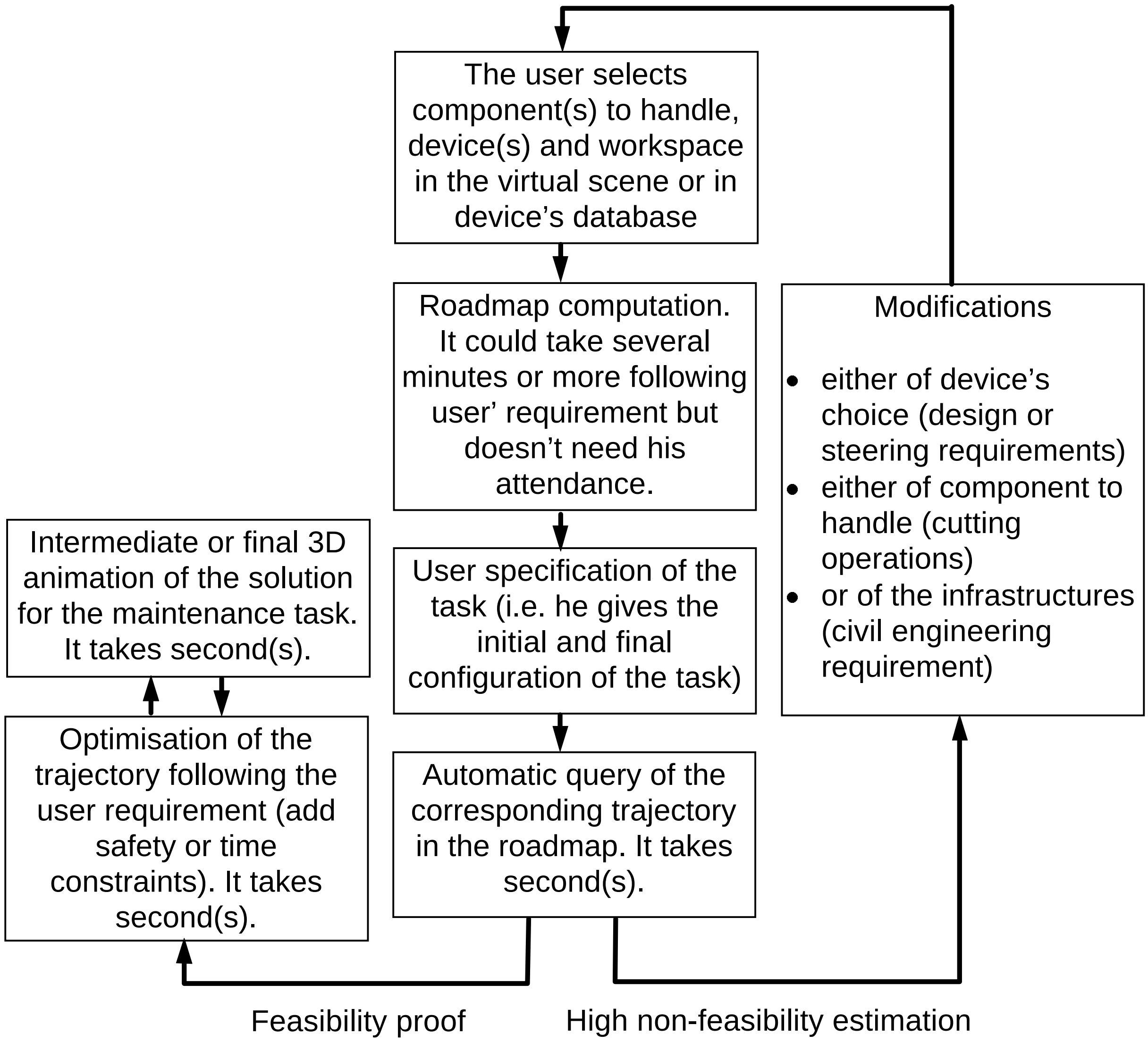

Figure 2: Procedure of a maintenance preparation using the MOLOG Motion planning tool.

Some high level capacities of CAM Software like grasp or pose definition or more generally changes of the kinematics structure during the motion are currently integrating in the MOLOG motion planning tools. We talk thus about handling planning.

1. The user chooses one piece to remove in the virtual scene by picking it and specifies the device and the storage position of that piece.
2. The handling planning tool automatically produces the trajectory of the handling device which comes from its park position, grasps the object, transports it to its storage position and finally goes back to its park position.

Useful extensions of the problem appears when several pieces are selected or when one single piece must be handled by several devices. These extensions enable automatic tests of tasks overlapping if time optimisation is desired.

MOLOG’S BENCHMARK AND FIRST RESULTS

We have used a quite difficult operation as test-case to evaluate the potential relevance of automated path planning for the preparation of maintenance operations inside complex industrial installations. This test case comes out from a real life study made at EDF a few years ago during the layout design of a new nuclear power plant. Using just CAD system (without CAM or Motion planning tools), it required several weeks of studies [8].

The purpose was to check the feasibility of moving a supplying water turbo pump with a crane located in the engine room of a nuclear power station. The complete exchange operation consists in taking all components of the turbo pump off (turbine bonnet, turbine, main pump and second pump also called booster). We focused on the turbo pump bonnet which is the biggest component and thus the hardest collision free motion to find among piping and other obstacles.

The travelling crane come above the block and put it on the floor. Thanks to the MOLOG motion planning software, computing the roadmap (the possible collision-free trajectories of the crane carrying the bonnet) took less than one minute and to find one short trajectory avoiding the complex piping and linking the desired initial (bonnet on the turbine) and final configuration (bonnet on the ground) took less than 10 seconds. (see some snapshots of the animation result below).

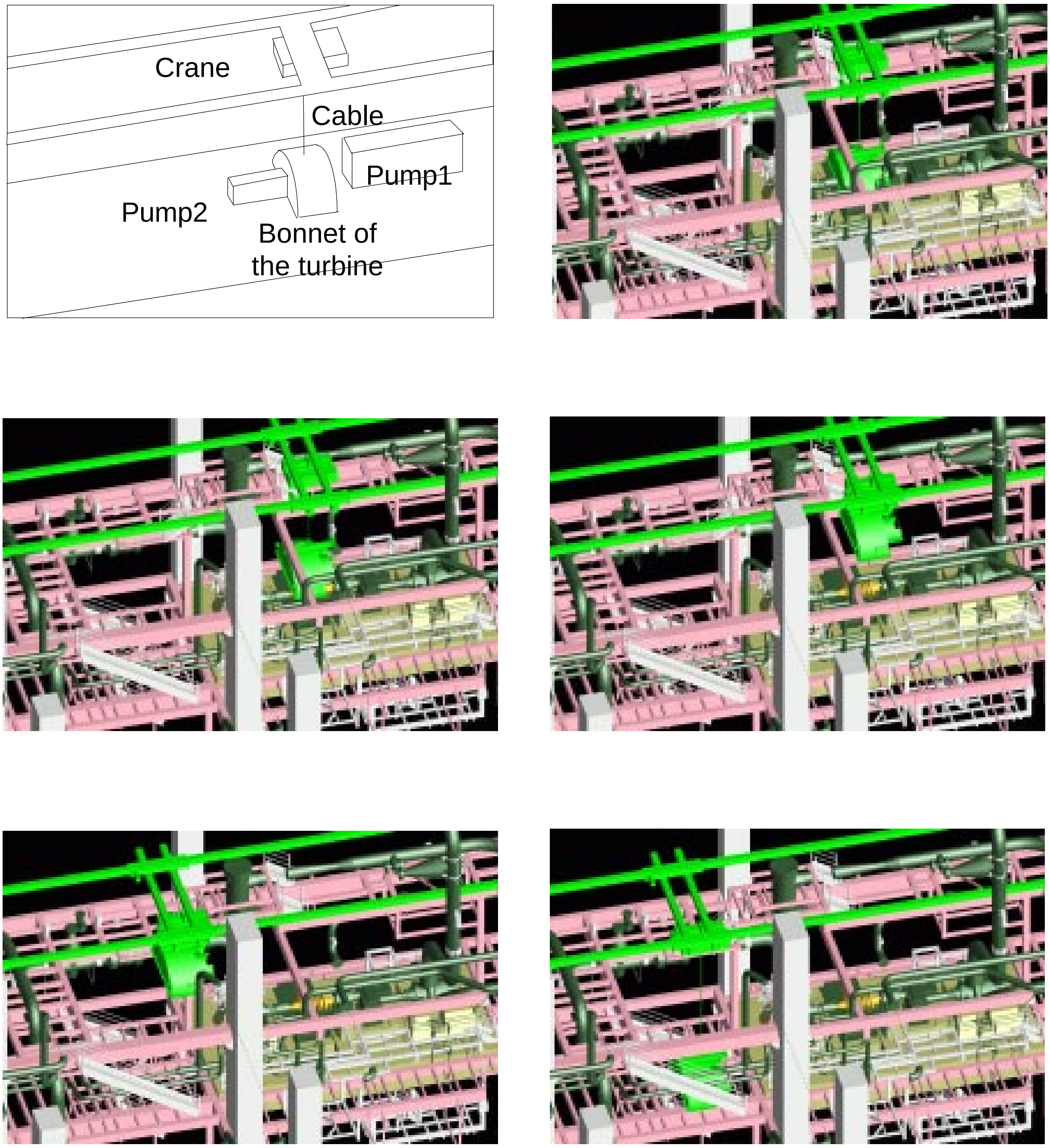

Figure 3: some snapshots of the animation result of the turbo-pump handling using MOLOG Motion Planning Tool in the CAD system PDMS [9].

CONCLUSION

The development of Motion Planning tools inside usual CAD system enables a real simplification of the feasibility studies for nuclear maintenance preparation. We have proven that the MOLOG motion planning tool can be used in very complex environments. Roadmaps are a very efficient way to capture the structure of a large set of motions. Among this set some trajectories are particularly well suited. This leads the way of nuclear specific optimisation tools in order to help the user to choose one of them. Other constraints than geometric or kinematic ones could thus be taken into account. These constraints could be broken out into two main categories:

- Safety constraint (like security distance to obstacles, dangerous zone to avoid as much as possible)
- Time and task's organisation constraints.

Integrating some high level capacities of CAM Software and such nuclear specific optimisation tools are the next steps of the project.

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