



**HAL**  
open science

## Motion Coordination of a mobile manipulator for contact transition tasks

Vincent Padois, Jean-Yves Fourquet, Pascale Chiron

► **To cite this version:**

Vincent Padois, Jean-Yves Fourquet, Pascale Chiron. Motion Coordination of a mobile manipulator for contact transition tasks. 10th IEEE International Conference on Methods and Models in Automation and Robotics, Aug 2004, Miedzzydroje, Poland. pp.967–972, vol. 2. hal-00624411

**HAL Id: hal-00624411**

**<https://hal.science/hal-00624411>**

Submitted on 19 Sep 2011

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## MOTION COORDINATION OF A MOBILE MANIPULATOR FOR CONTACT TRANSITION TASKS

V. PADOIS, J.-Y. FOURQUET and P. CHIRON

Ecole Nationale d'Ingénieurs de Tarbes, Laboratoire de Génie de Production,  
65000 Tarbes, FRANCE, vpadois, fourquet, pchiron@enit.fr

**Abstract.** This work is devoted to complex missions planning and execution in Robotics. Robotics has evolved from an industrial, repetitive framework to application domains with much more variability of tasks, with increasing complexity in uncertain environment. This is clearly the case for Service Robotics e.g. but even industrial robots have now to work in environment not totally calibrated for the task they have to perform. The result is that the classical decomposition in static ordered local tasks cannot apply in presence of such a variability. It has a poor dynamic performance and cannot cope with uncertainties. Our work is organized around a complex mission: “*Go to the blackboard and write*” for mobile manipulators that have capabilities of locomotion and manipulation. It is a simple and intuitive example of a complex mission that relies on different sensors, exhibits different operating modes and needs to switch between different feedbacks and set-points. Our approach is based on Hybrid Dynamical Systems. It is focused on dynamical sequencing of control laws that ensures good transients, robustness and allows to update the mission at every transition from one mode to another. Simulation have been realized with *matlab Simulink* and *Stateflow* toolboxes and experimental validation is developed within the *GenoM* controller on the  $h_2$ bis nonholonomic mobile manipulator.

**Key Words.** Mobile manipulator, non-holonomic systems, redundancy, contact transition, speed and force control.

### 1. INTRODUCTION

This work deals with complex missions in mobile manipulation robotics. For many years, research community in robotics has proposed numerous solutions allowing to solve specific tasks. Textbooks and journal papers describe methods that allow e.g. to move the end-effector in free space or to exert an interaction force on the environment. Missions that have to be realized in service robotics for instance are naturally more complex. They are made of many distinct phases that have to be chained dynamically. Nonetheless, the approach generally adopted when considering a complex problem is to decompose it in a sequence of elementary subproblems, and then to solve independently each subproblem. This approach has the merit to permit the study of each step of the sequence in a simple way since it disregards the other steps. It has furnished a large library of methods and algorithms for each specific tasks and is particularly suited when the environment can be adapted to the task and when this task is

repetitive enough to deserve *ad hoc* tuning. These features are usual in an industrial framework that requires a low versatility of the robotic system.

Now, new directions, both in service and manufacturing robotics, lead to embed these techniques in missions where uncertainty and variability are much more important. Wheeled locomotion, for instance, naturally produces positioning uncertainty. Environment is more *natural* (less calibrated) and tasks are less repetitive. At the same time, it seems pertinent to build the solution from the library of classical methods by chaining them dynamically. So, it is necessary to adapt and combine existing strategies for local tasks in order to realize complex missions with good transients.

Even if the objectives of our work are more general, the work presented here is organized around one kind of mission:

*From an imposed end-effector location, a free space motion is followed by a trajectory tracking over a sur-*

face along which a normal force is imposed.

and around one kind of system: A nonholonomic mobile manipulator built from a serial arm mounted on a wheeled mobile platform. This system is equipped with a force sensor that measures contact forces at the end-effector.

This application is sufficiently rich to point out problems and features of a more generic complex mission in robotics. It comes from some recent industrial developments that aim at moving manipulators around a large size part rather than moving it.

We made the choice of a description based on switching among a finite number of modes that are linked to different set-points, control laws and events to detect. This approach falls into the description of robotic missions by the Hybrid Dynamical Systems formalism. The emphasis is made on the dynamical nature of the sequence of elementary modes and is to be compared with the State of the Art essentially focused on static chaining of primitives [10].

## 2. STATE OF THE ART AND MAIN ISSUES

In the literature, contributions concerning the motion in free space of the end-effector location, denoted by  $\xi$ , are clearly separated from the ones dealing with constrained motion for which contact force  $\mathcal{F}$  is imposed together with  $\xi$ . In the first ones, it is assumed that no contact force can occur whereas the second category considers that the contact is realized from the beginning. Many modeling issues – at dynamic and kinematic level – and related control schemes can be found in reference textbooks [14, 13, 8].

Contact transition problems from free space motion to constrained motion have been emphasized very early [11]. Nonetheless, only a little number of authors has actually studied this topic (e.g [9, 7, 17]). These works are mainly concerned by stability issues and impact modeling. Recently, Yu and Pagilla [19] have presented a method that allows to cope with geometric uncertainties of the contact surface location. Doh *et al.* [4] have also proposed a specific control law that aims at avoiding large bounces during hard contact transitions.

This kind of mission has specific features, some of them being “critical”. Compared with other hybrid dynamical systems, there are different facts that make it very demanding.

So the main points, and problems, are :

- The contact transition is instantaneous and systems dynamics change very suddenly. Hence, in the planning process, this change must be carefully planned. Then, due to unavoidable uncertainties in measures, this plan will not be verified. Uncertainties must be relatively low since impact causes instantaneous damages. Then, the plan and the control law must be updated in real-time. Here are the main problems: measured

peak force due to impact may be very steep and high. Since, the force control law become active after the detection of a threshold value at sampling times, the transient may be very poor. So, contrary to other systems with various operating modes, the detection of change in dynamics must be very short. And, the control law must be chosen depending on the first measured values on the transient. Applying a classic force control scheme in this transition phase will not insure good dynamic performance and stability is not the only concern. The problem is to use information received during the transients in the best way in order to avoid exciting nonlinearities and unmodeled dynamics.

- There is always a need to update the plan using the measures during the execution since uncertainties are always present. In fact, a mobile manipulator relies on proprioceptive (odometry and encoders) and exteroceptive sensors (fixed or moving cameras, laser rangefinder). On one hand, due to the slipping of the wheels on the floor, proprioceptive information is not really safe. On the other hand, exteroceptive measures are subject to various estimation or quantization effects. Thus, it is necessary to update the real position of a part of the environment, a wall e.g., from a force threshold detected at the end-effector. Then, if the wall must be followed, its location is updated when impact occurs.
- Position control and force control schemes are characterized by different desired values for stiffness and damping. A very stiff controller is needed for accurate positioning and tracking in free space whereas a softer controller may be interesting in force control.

In fact, there are different means to adapt planning and control strategies and considering the mission as a whole reveals additional tunable parameters and “degrees of freedom”

- At planning level, redundancy can be exploited: A particular configuration can be chosen for a given end-effector location and a particular generalized velocity can be chosen for a given end-effector desired velocity or force. Time evolution of variables may be adapted to the sequence of tasks and the decomposition of the global mission is not unique.
- At control level, control laws structure and parameters may be chosen from the local nature of the mission.

Finally, the result must be interpreted. Of course, stability and convergence to the desired set-points must be ensured but these are not the only concern.

The execution of the different local tasks must be slightly disturbed by the dynamic chaining within the mission. So, transients is certainly the main concern.

### 3. STRUCTURING AND PLANNING THE MISSION

In our approach a mission is described by:

- $k$  modes for which a particular set-point and an associated control law are applied,
- a switching pattern that describes the order in which local tasks are sequenced.

It is a hybrid dynamical systems description and the simulation tool is *Simulink* and *Stateflow* toolboxes from *Matlab*. A *Stateflow* diagram is a finite state machine. States correspond to modes and transitions are activated by events: time elapsed or detection of a sensor threshold value. The structure is somewhat generic in the sense that strategies can be modified independently for each local tasks without modifying it.

At the planning level, every local task is characterized by:

- the type of task : Point To Point, Continuous Path (with or without imposed final time), contact task,...
- initial and final values for location and, depending on strategies and type of local task, initial and final velocities or forces,
- eventually, the control law to apply.

Each task is inserted in the global plan by entering:

- the occurrence order,
- the threshold value for the beginning of its execution.

From these data, the planner introduces transition phases between the tasks and provides the desired time evolution of controlled variables.

### 4. UNCERTAINTIES, PLANNING AND EXECUTION

We consider that data are naturally corrupted with errors: drift of the odometry system, exteroceptive sensors resolution, errors of the estimated parameters of both the robot and the environment. Thus, transition from a task to the following one occurs asynchronously but in a predictable time (or space) interval. Any large drift in the transition date corresponds to an anomaly that cannot be interpreted as the result of these uncertainties.

From the *a priori* data, the planner defines an ideal start date, a final date and a time interval around these values. During the execution, the triggering signal for

the following task must occur within the time interval defined around the final date: if nothing is detected during this interval, the system is set in error mode. In normal execution, the date of the triggering signal defines the beginning of a transition time interval of a given duration. At the end of this duration, depending on information received concerning the transients, execution proceeds normally to the following updated task or is turned again on error mode.

### 5. MODELING AND CONTROL: REDUNDANCIES, IMPACT AND KINEMATICS

#### 5.1. Modeling

The joints we have to control are driven through a velocity loop with high ratio gear reduction and we consider relatively low velocities motions. So, dynamical effects are not taken into account for joints set-points in the planning process. It is well know that kinematic control schemes perform well in this case. So, we have chosen to rely on kinematic control schemes. However, contact forces involves a physical modeling based on dynamics since the interaction forces  $\mathcal{F}$  maps the torque vector  $\Gamma$ . So, dynamic modeling has been used for impacts and load modeling.

When dealing with nonholonomic mobile manipulators, relations between redundancy, instantaneous kinematics and nonholonomy have to be studied carefully. In the literature, very few works consider the generic modeling of mobile manipulators and many authors decompose the task for the two subsystems: the wheeled platform on one side, the arm on the other. Nonetheless, different authors are considering the mobile manipulator as a whole [15, 18]. Among them, Bayle et al. [3, 1, 2] have proposed a generic modeling.

Kinematic control schemes used for  $n$ -link holonomic manipulators are based on instantaneous kinematics:

$$\dot{\xi} = J(q)\dot{q} \text{ with } J \text{ a } m \times n \text{ matrix}$$

where  $q$  is the  $n \times 1$  configuration vector,  $m$  is the dimension of the task space,  $\dot{q}$  is the  $n \times 1$  vector of generalized velocities. The control vector  $u$  is then the vector of generalized velocities in the holonomic case. In the nonholonomic case, since generalized velocities are constrained,  $u$  must be chosen in another way [1]. Nonetheless, most of the existing techniques can be used by considering the so-called *instantaneous posture kinematic model* (IPKM).

$$\begin{aligned} \dot{\xi} &= \bar{J}(q)u \\ \dot{\beta} &= \zeta \end{aligned}$$

where  $\bar{J}$  is a  $m \times \bar{n}$  matrix,  $u$  a  $\bar{n} \times 1$  vector of independent control variables that map the admissible end-effector velocities (with  $\bar{n} < n$ ).  $\beta$  is the vector

of steering velocities and  $\zeta$  the associated control vector when there are steering wheels. When there are no steering wheels, the IPKM comes down to:

$$\dot{\xi} = \bar{J}(q)\mathbf{u} \text{ with } \bar{J} \text{ a } m \times \bar{n} \text{ matrix}$$

In the planar example depicted on the Figure 1,  $\mathbf{u}$  can be chosen as e.g  $\mathbf{u} = (v \ \omega \ \dot{q}_{a_1} \ \dot{q}_{a_2})^t$  (or  $\mathbf{u} = (\dot{\theta}_r \ \dot{\theta}_l \ \dot{q}_{a_1} \ \dot{q}_{a_2})^t$ ) where  $v, \omega, (\dot{\theta}_r, \dot{\theta}_l)$  are respectively the linear and angular velocities of the platform (the right and left wheel velocities), and  $q_{a_1}, q_{a_2}$  are the generalized coordinates of the arm.

For a mobile manipulator, due to nonholonomic constraints, it is necessary to distinguish geometric from kinematic redundancy [1]. Geometric redundancy is related to the  $n$ -dimensional vector made of the three parameters  $x, y, \vartheta$  defining the location of the platform and the  $n_a$  generalized coordinates  $q_{a_1}, q_{a_2}, \dots, q_{a_{n_a}}$  of the  $n_a$ -link arm (see Figure 1.) When  $m < n$ , the system is redundant at geometric level and redundancy provides the capability to choose a particular configuration among those realizing a prescribed location  $\xi$  of the end-effector. When  $m < \bar{n}$ , the system is redundant at kinematic level and redundancy provides the capability to choose a particular kinematic control vector  $\mathbf{u}$  among those giving the prescribed end-effector velocity  $\dot{\xi}$  by using the relation :

$$\mathbf{u} = \bar{J}^+ \dot{\xi} + (I - \bar{J}^+ \bar{J})\mathbf{z}$$

where  $\bar{J}^+$  is any generalized inverse of  $\bar{J}$  and  $\mathbf{z}$  any  $\bar{n} \times 1$  vector.

These choices can be exploited to optimize the contact transition but also during any local task. In this way, we can increase manipulability during free space motion and minimize the impact forces at the contact transition. This latter point can be considered from several viewpoints: in a manner similar to that of Walker [16, 17], where it can be seen that impact forces are related to the configuration-dependent inertia matrix of the robot. In that case, it remains to choose the best configuration among those realizing the given value for the location at the contact transition. It can also be considered by following a joint trajectory that helps to adapt the impedance [6] of the controlled system at the contact.

## 5.2. Control strategy

The control law has to cope with sudden changes of load at the contact. In the same way, dynamics are different with and without contact interaction. So, we use different control laws for the different phases of motion: in free space, in the transition phase and in contact task. In free space motion, a classic kinematic control scheme is used where different criteria may be optimized in the redundant case. A hybrid position-force kinematic control scheme [12, 8] has been developed in the constrained case. In order to work at

a kinematic level, the force measured by the sensor is transformed into a displacement through the definition of an estimated stiffness.

## 6. TESTBEDS, SIMULATION AND RESULTS

The objective is to perform automatic safe contact transition for the h<sub>2</sub>bis mobile manipulator at LAAS-CNRS (see figure 2) where the task to realize is “*come to the blackboard and write*”.

Simulation results have been realized on a planar system made with the same unicycle-like platform model and a two link arm (see Figure 1). The kinematic control schemes have been tested over a complete dynamic model including actuators, transmission and under the assumption that the environment characteristics are partially known: uncertainties on the stiffness have been added, together with measurement noise and nonlinear contact characteristics. Of course, the results depends on many factors in this kind of mission :

- operational velocity and configuration at the impact,
- sampling time, date of impact w.r.t. sampling time,
- bandwidth of the force measurement,
- stiffness of the contact.

The first two are intimately related to the uncertainties on the real position of the environment. So, worst cases are obviously when:

- uncertainty is important so velocity at the contact may also be high,
- contact occurs immediately after the sampling time so detection will occur a sampling period after,
- force measurement bandwidth is low so detection of contact will be delayed,
- stiffness is high so (contact may be damaging and) peak force is high at the transition and integral based control schemes will have bad transients.

The task to realize is depicted on the figure 3. The end-effector has to follow a free-space trajectory ( $x(t)$  and  $y(t)$  are imposed) until it reaches a wall. Then, it has to follow a trajectory along this wall applying at the same time a 10 Newton normal force. In the test presented here, no particular attention has been paid to redundancy resolution and a simple pseudo-inverse solution is used. The uncertainty on the  $y$  coordinate of the wall is a random number not greater than 2 centimeters, there is a ratio of 5 between the real stiffness of the environment and that estimated for the force control law. 25 % force overshoot is allowed. The

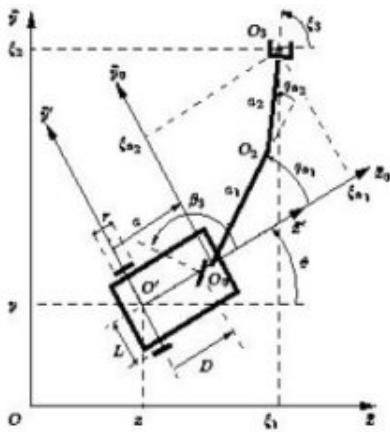


Figure 1: Planar mobile manipulator mounted on a two independent driven rear wheels platform with castor wheel at the front



Figure 2: A writing mission with h<sub>2</sub>bis

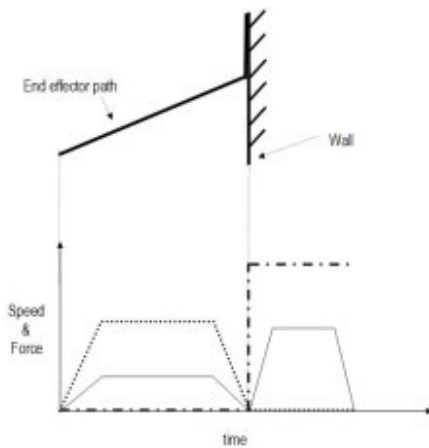


Figure 3: operational task

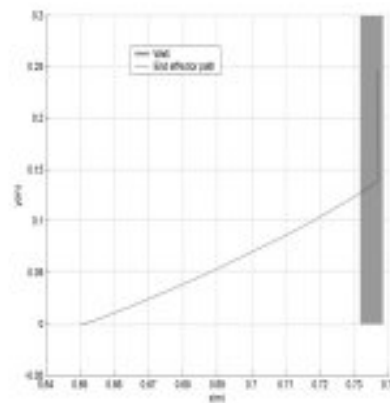


Figure 4: path corresponding to the actual trajectory

results are in accordance with the set-points since the motion is performed and the normal force is applied with a quite good transient.

## 7. CONCLUSIONS, PERSPECTIVES

A framework for dealing with uncertainties in positioning end-effector when contact transition is to be realized in mobile manipulation has been presented. Different results have been obtained with various control laws and different models of the environment for a planar mobile manipulator. Of course, many experiments are to be conducted on the *h<sub>2</sub>bis* mobile manipulator to confirm the simulation results. This strategy is now under development within the *GenoM* controller [5]. In particular, different theoretical assumptions concerning the use of redundancy for minimizing impact forces have to be verified and different control schemes are to be validated for increasing tran-

sient performance.

**Acknowledgement:** This work is partially supported by the French CNRS Robea program within the project *Dynamic sequencing of multi-sensor based tasks for complex motions execution in mobile robotics*.

## REFERENCES

1. B. Bayle, J-Y. Fourquet, and M. Renaud. From manipulation to wheeled mobile manipulation: analogies and differences. In *Proceedings of 7th Symposium on Robot Control (SYROCO'03)*, Wroclaw, Poland, September 2003.
2. B. Bayle, J-Y. Fourquet, and M. Renaud. Kinematic modelling of wheeled mobile manipulators. In *IEEE International Conf. on Robotics and Automation*, Taipei, Taiwan, September 2003.

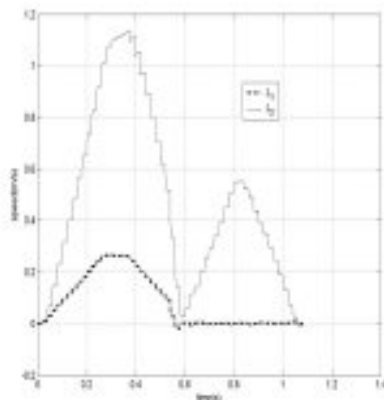


Figure 5: Velocity responses with nonzero velocity at the impact

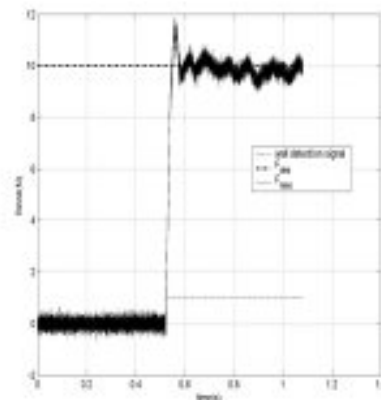


Figure 6: Normal force: set-point and response

3. B. Bayle, J-Y. Fourquet, and M. Renaud. Manipulability of wheeled mobile manipulation: application to motion generation. *The International Journal of Robotics Research*, vol. 22(7-8):565–581, July 2003.
4. N. Doh, W.K. Chung, and Y. Youm. On hard contact force control. In *IEEE/RSJ International Conf. on Intelligent Robotic Systems*, pages 1528–1533, Takamatsu, Japan, November 2000.
5. S. Fleury and M. Herrb. *GenoM : Manuel d'Utilisation*. LAAS/CNRS, 1999.
6. N. Hogan. Stable execution of contact tasks using impedance control. In *IEEE International Conf. on Robotics and Automation*, pages 1047–1054, Raleigh, North Carolina, March 1987.
7. J. M. Hyde and M. R. Cutkosky. Contact transition control. In *IEEE International Conf. on Robotics and Automation*, pages 363–368, Atlanta, Georgia, May 1993.
8. W. Khalil and E. Dombre. *Modeling, Identification and Control of Robots*. Hermes Penton Science, 2002.
9. J.K. Mills and D.M. Lokhorst. Control of robotic manipulators during general tasks execution: A discontinuous control approach. *The International Journal of Robotics Research*, vol. 12(2):146–163, April 1993.
10. K. Nagatani and S. Yuta. Door-opening behaviour of an autonomous mobile manipulator by sequence of action primitives. *Journal of Robotic Systems*, 13(11):709–721, 1996.
11. R.P. Paul. Problems and research issues associated with the hybrid control of force and displacement. In *IEEE International Conf. on Robotics and Automation*, pages 1966–1971, Raleigh, North Carolina, March 1987.
12. M. H. Raibert and J. J. Craig. Hybrid position/force control of manipulators. *ASME Journal of Dynamic Systems, Measurement, and Control*, 103:126–133, 1981.
13. L. Sciavicco and B. Siciliano. *Modelling and control of robot manipulators*. Springer, 1999.
14. M. W. Spong and M. Vidyasagar. *Robot Dynamics and Control*. J. Wiley and Sons, 1989.
15. K. Tchoń and R. Muszyński. Instantaneous kinematics and dexterity of mobile manipulators. In *ICRA'2000*, pages 2493–2498, San Francisco, California, April 2000.
16. I. D. Walker. The use of kinematic redundancy in reducing impact and contact effects in manipulation. In *IEEE International Conf. on Robotics and Automation*, pages 434–439, Cincinnati, Ohio, May 1990.
17. I.D. Walker. Impact configurations and measures for kinematically redundant and multiple armed robot systems. *IEEE Transactions on Robotics and Automation*, vol. 12(5):670–683, 1994.
18. Y. Yamamoto and X. Yun. Unified analysis on mobility and manipulability of mobile manipulators. In *ICRA'99*, pages 1200–1206, Detroit, May 1999.
19. B. Yu and P. R. Pagilla. A Switching Control Scheme for Constrained Robot Tasks. In *IEEE Conf. on Control Applications*, Mexico City, Mexico, September 2001.