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Acronyme/short title	**Multiple Impacts**
Titre du projet *(en français)*	Modélisation et Simulation des Impacts Multiples dans les Systèmes Mécaniques Multicorps
Titre du projet/Proposal title *(en anglais)*	Modelling and Simulation of Multiple Impacts in Multibody Systems

Les pages seront numérotées et l'acronyme du projet devra figurer sur toutes les pages du document en pied de page. Un sommaire du document est bienvenu

S'il s'agit d'un projet déposé dans le cadre d'un accord de coopération internationale*, préciser avec quelle agence étrangère :
☐ National Natural Science Foundation of China (NSFC)

**** Veuillez vous reporter aux modalités de soumission particulières pour chaque agence sur le site de l'ANR.***

1. Programme scientifique / Description du projet *Technical and scientific description of the proposal*

1.1 Problème posé/Rationale *(1/2 page maximum)*

Présentation générale du problème qu'il est proposé de traiter dans le projet et du cadre de travail dans lequel il sera effectué.

Multibody systems are ubiquitous in many fields of application (aerospace, automotive systems, granular matter, circuit breakers industry, nuclear plants, bipedal locomotion, robotics, biological engineering, computer graphics – e.g. hair simulation--, etc). Their numerical simulation has become a crucial step not only for the virtual prototyping process in industry, but also in academic fields like granular matter, bifurcation analysis, global behavior of complex systems, control and stability, in which it is impossible to push forward the studies without reliable simulation software packages. Numerical simulation must in turn rely on suitable mathematical models. In particular, several points of unilateral contact usually exist in such systems, and impact phenomena and friction are an extremely important feature in most of (if not almost all) multibody systems. As a consequence, *multiple impacts* may occur quite frequently and become a keypoint for the numerical simulation of multibody systems.

A multiple impact occurs when several contact points of the system undergo an impact at the same time. This is for instance the case of a biped that walks on two feet, a docking mechanism of making two aerocrafts combine together, a Newton's cradle with several balls initially in contact, a circuit breaker, granular materials like sand piles, fibrous materials like hair, etc. It happens that such events, even when they occur rarely, may have a crucial influence on the long-term dynamics of a system (because they determine, at a given instant, the right or the wrong new initial conditions after the shock). In mechanical sense, this topic is associated with the problem of multiscale analysis (both in space and time) of a dynamical process, and has been examined since a long time on particular cases (like simple chains of iron balls). At this stage of the analysis these physical phenomena must be modelled from a macroscopic point of view, with suitable so-called restitution mappings (that include or not the frictional effects). Although several multi-impact mappings have been proposed in the literature, all the proposed models still lack either of sufficient generality (hence are not applicable to other systems), or rely on parameters that have no mechanical meaning, or are not easily identifiable, or they do not lend themselves well to numerical simulation (stiff ODEs). The objective of this project is to study models of multiple impacts, without and with friction, that depend on « good » physical parameters, and are numerically tractable. The validation should be done by extensive simulation, and comparisons with experimental results. It is also planned to design and build experimental setups, and to incorporate the discovered restitution mappings in the SICONOS platform of the INRIA. The project will be ended by the organization of a Euromech colloquium on the topic of nonsmooth mechanics, in Grenoble, in July or August 2011.

1.2 Contexte et enjeux du projet/*Background, objective, issues and hypothesis* *(1 à 3 pages maximum)*

*Décrire **le contexte** en dressant un **état de l'art national et international** incluant les références nécessaires et préciser les **enjeux scientifiques** du projet.*

The global context of the project is that of multibody systems, their modeling and their numerical simulation. In particular, we will focus on so-called *multiple impacts*, which are complex phenomena frequently occurring in mechanical systems like granular matter [18] or kinematic chains. The study of multiple impacts is an extension of the field of *impact mechanics*, that is a very old field of solid mechanics. Historically, *simple impacts* have first been considered (i.e. impacts between two bodies with a unique contact point). Many studies have been devoted to restitution coefficients, see e.g. [1,2,3], especially when friction is present. One may consider now that simple impacts have been correctly understood, in the sense that one knows the limitations and the domains of applicability of the numerous models which have been proposed. On the contrary, multiple impacts are still the object of many studies in mechanics and in physics of granular matter as well as in biology of DNA packing, see e.g. [4,5,6,7,8,9,10,11,12, 1, 13,14,18]. The reason for this scientific activity is that multiple impacts are on one hand present in many systems, on the other hand they must be correctly modelled and simulated in order to obtain good numerical predictions. It is noteworthy that the problem of numerical simulation of nonsmooth dynamical systems is a tough issue which still attracts many researchers, see e.g. [16].

Multiple impacts are complex phenomena, which involve two main effects : *local* effects at the contact points (that imply energy dissipation through plastic deformation and friction), and *global* effects that affect the whole system and take the form of waves travelling through the system (the global effects are responsible for the *energy dispersion* among the various bodies in the system). Historically, the mechanical engineering literature has been more focused on the local effects and restitution coefficients. The physics community (in France and elesewhere) of granular matter has rather focused on the study of wave effects in chains of balls, although the need for good restitution coefficients is also felt by physicists [7,15]. Moreover, biologists have realized that collisions with friction between particles should be responsible for large-scale collective behavior emerging in systems of so-called self-propelled particles, such as the swirling and swarming motions [13,14].

Taking into account these two effects in a single rule constitues the main challenge of this project.

In order to appreciate the difficulty of multiple impact modelling and the gap between simple and multiple impacts, one may consider that sequences of separated impacts in a simple chain of balls (so-called sequential impacts) usually provide different outcomes when the sequence is changed. Mathematically this is explained by the discontinuity of solutions with respect to the initial conditions in unilaterally constrained mechanical systems (send a tennis ball in an angle that is larger than 90 degrees : depending on whether the ball hits first one side of the angle or the other one, its subsequent motion will be completely different). This means that a multiple impact cannot be understood solely from the local effects at each contact point, but must incorporate the global (wave) effects.

A good multiple impact law should at least satisfy the following conditions :

a) it should depend on a minimal set of parameters which possess a mechanical meaning, and are identifiable with simple experiments of calculations, and do not depend on the initial data.

b) it should be general enough to be transportable from a system to another one (for instance, chains of balls or rods with different kinds of sizes and materials).

c) It should be easily discretized in time (for instance stiff equations have to be avoided), and easily implementable into existing simulation codes for nonsmooth multibody systems.

d) It should provide good predictions, both from the qualitative and the quantitative points of view.

e) It should take into account both the normal and the tangential effects at the contact points ; especially friction cannot be dispensed with, and the stick motion should be well reflected because they may be the origins of some periodic or quasi-periodic motions emerging in systems with unilateral constraints and external vibrations.

f) It should correctly model the local and the global effects.

Our goal in this project is to propose a model of multiple impacts that fulfills requirements a) to f). To the best of our knowledge, no existing multi-impact law satisfies all these conditions. A preliminary work for frictionless impacts can be found in the report [LZB-1]. The so-called Darboux-Keller approach [1] is extended for the first time to multiple shocks, and numerous numerical experiments are shown and compared to experimental results found in the literature. The approach seems very promising as we found that the main physical effects present in simple chains of balls are very well predicted by the proposed method. The scientific challenges which will be the topic of our project concern the extension of [LZB-1] to :

i) 3-dimensional granular matter (spherical grains and elongated particles).
ii) the case with friction (spherical grains and elongated particles).
iii) simple kinematic chains involving contact bodies with complex geometries.

And

iv) validation through comparisons with an experimental setup to be designed and built by the Chinese partner.
v)implementation of the model in the SICONOS software platform of the INRIA (http://siconos.gforge.inria.fr/ [17]).

It is noteworthy that item v) does not concern solely the simulation of the impact process. From the general point of view of the simulation of nonsmooth mechanical systems, v) represents the insertion of a module « multiple impact » inside the SICONOS platform [17]. The treatment of Coulomb friction inside a Darboux-Keller multiple impact law, should benefit a lot from the existing solvers of the SICONOS platform (complementarity problems, quadratic programming solvers).

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[17] V. Acary ,F. Pérignon, An introduction to SICONOS, INRIA Technical report RT-0340, http://hal.inria.fr/docs/00/16/36/84/PDF/RT-0340.pdf .

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[LZB-2] C. Liu, Z. Zhao, B. Brogliato, The multi-impact dynamics in multibody systems, submitted to the ICTAM 2008., XXII International Congress of Theoretical and Applied Mechanics, Adelaide, Australia, 24–30 August 2008.

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1.3 Objectifs et caractère ambitieux/novateur du projet/*Specific aims, highlight of the originality and novelty of the project* (1 à 2 pages maximum)

*Décrire les **objectifs scientifiques/technologiques** du projet.*
*Présenter l'**avancée scientifique** attendue. Préciser l'originalité et les ambitions du projet.*
*Détailler les **verrous scientifiques et technologiques** à lever par la réalisation du projet.*

The scientific objectives of this project are a better understanding of multibody nonsmooth mechanical systems, in particular granular matter and simple kinematic chains, thanks to a better modelling of multiple impacts phenomena. Obtaining a multi-impact law that satisfies the requirements a) to f) above, is a challenge in itself. Once such an impact law is obtained and validated through extensive comparisons with experimental results (found in the literature or performed inside the project, see objective iv) of section 1.2), then it will be used inside the SICONOS platform as a tool for the study of the dynamics of multibody systems with friction, in particular granular matter. Such objectives will tentatively be tackled in this project, but most probably we will restrict ourselves to the achievement of objectives i) to v) .

This scientific goal cannot be achieved without a reliable software package, and without extensive comparisons between the numerical results and the experimental results. The SICONOS platform developed by the team-project BIPOP of the INRIA Grenoble Rhône-Alpes, is a code dedicated to

nonsmooth dynamical systems, written in C++, that will on one hand benefit a lot from the theoretical results in items i), ii) and iii) of section 1.2, and will on the other hand offer an efficient framework for the simulation of many-degrees-of-freedom systems. In parallel the achievement of objective iv) will allow us to improve the preliminary comparisons obtained in [LZB-1]. The results obtained in [LZB] are quite encouraging since they show that the Darboux-Keller approach for multi-impact modelling, provides numerical outcomes that reflect very well the main dynamical effects reported elsewhere in the Mechanical Engineering and the Physics literature. We however feel that using the experimental results of others has now reached its limit and it is mandatory for us to perform our own experiments.

In summary, this project will tackle three main objectives : the theoretical design and analysis of a multi-impact law, the insertion in the SICONOS platform, the design of an experimental setup. These three objectives will have to be led in parallel and not sequentially, for obvious reasons that there will necessarily exist strong interactions between them, and iterations will be needed between the theory, the numerics and the experiments.

1.4 Description des travaux : programme scientifique/*For each specific aim: a proposed work plan should be described (including preliminary data, work packages and deliverables)* *(10 pages maximum)*

Décrire le ***programme de travail décomposé en tâches en cohérence avec les objectifs poursuivis****. Les tâches représentent les grandes phases du projet. Elles sont en nombre restreint.*

Pour chaque tâche, préciser :

- *les objectifs de la tâche*
- *le programme détaillé des travaux correspondants.*

The project will be made of three tasks :

1) **Task 1 : theoretical design of multi-impact laws with friction**.

This task is the continuation of the work in [LZB]. The three sub-tasks will be realized sequentially and in close cooperation between the Chinese and the French sides.

Sub-task 1.1 : The frictionless case will be extended to granular media in 3-dimensions, with spherical and then non-spherical (but simple enough) grains. In [LZB] the tests are restricted to one degree-of-freedom chains of balls (that is linear chains of balls) and a very simple nonlinear chain (the Bernoulli's example that is made of three balls in the plane). It is mandatory to extend these to 3-dimensional systems. This will constitute the first step of the task. It is noteworthy that not only systems with few degrees of freedom will be studied but also systems with very large dimensions.

Sub-task 1.2 : The second step will be to incorporate Coulomb friction at the contacts. Coulomb friction will be incorporated at the impulse level, thus rendering the Darboux-Keller shock dynamics nonsmooth. I will then be very interesting to investigate the influence of friction on dispersion and dissipation effects.

Sub-task 1.3 : The third step will consist of departing from granular matter and to consider simple kinematic chains. The global behaviors of granular matters, such as the pattern formation, are expected to be discovered in this sub-task. For the simple kinematic chains with complex interaction (a different manner from the one in [LZB]), we are expecting to bring them into the theoretical framework established in [LZB].

2) Task 2 : insertion in the SICONOS code.

Sub-task 2.1 : insertion of the Darboux-Keller shock dynamics inside the SICONOS tool, computer science and software engineering reflection. The SICONOS platform being written in C++, and thus integrally relies on the object oriented paradigm. This step will necessitate to think of new objects and object classes and how to insert them in the existing tool.

Sub-task 2.2 : development of specific tools (the French word is « modeleurs ») for the targetted applications. It is not possible to develop large-scale and ambitious simulations without an efficient tool to write down the dynamics of the considered system. Depending on the application in view (granular matter with simple smooth dynamics but large number of constraints, or kinematic chains with nonlinear lagrangian dynamics and few constraints), the time-stepping or the event-driven algorithms of SICONOS will be preferred. In particular the two mechanical systems developed by the Chinese partner will be simulated.

3) Task 3 : realisation of the experimental setup.

This task is to design and establish some simple mechanical systems that can include multi-impact events and can well exhibit peculiar behaviors, such that the comparisions between theoretical prediction and experimental results could be carried out. Two simple experimental setups will be realized in this project .

Sub-task 3.1 : The frictionless case will be experimentally verified by a ball-chain system (the Newton's cradle), in which the balls are attached to a horizontal rod with strings and its size and materials are either identical or completely different according to purpose of the experiment sets. Multi-impact events occur when the system is impacted by a striker. In [9] and other papers published in physical journals the experimental reuslts for such a system are recorded by a force sensor inserted in a ball. This is not a direct way of reflecting the wave effects in space scale and the information associated with the attenuation of the so-called « solitary wave » and the local energy loss may be influenced. It is mandatory to develop a new experimental method (like using the laser laser-Doppler vibrometers) to obtain the kinematic quantities of each ball, such that the wave behaviors in the system can be well exhibited experimentally and give reliable information in comparision with the theoretical prediction. In particular this setup should enable us to better understand the issue of energy dissipation and dispersion in the chains.

Sub-task 3.2 : The frictional case will be examined by sending a disc (or a ball with enough radius) with determinate speed colliding against an angle with two rough sides. The disc or ball may be locked into the angle or rebound back from the angle depending on the values of the angle degree and the coefficient of friction, and etc. This simple system may be similar to a brake mechanism when the motion of a rotator stops by suddenly putting friction force on its edge.

Sub-task 3.3 : The experimental verification related to simple kinematic chains will be carried out by the cooperation between Peking University and the aerospace industry in China, including the analysis of the stability of a landing mechanism falling into soils and the impact process of a space robotic system catching an object.

1.5 Résultats escomptés et retombées attendues/*Expected results and potential impact* (1/2 page maximum)

(Plus spécifiquement pour les programmes partenariaux organismes de recherche/entreprises)
*Présenter les **résultats escomptés** en proposant si possible des critères de réussite et d'évaluation adaptés au type de projet, permettant d'évaluer les résultats, tâche par tâche et globalement en fin de projet.*

*Présenter les **retombées attendues** en précisant pour les partenaires concernés :*
- *la valorisation des résultats attendus, connaissances à protéger ou à diffuser, ...*
- *les retombées scientifiques, techniques, industrielles, économiques…*
- *pour les bases de données, les modes de stockage et de maintenance ainsi que les communautés bénéficiaires*

From the theoretical point of view, the expected results are a significant improvement of the understanding of multiple impacts, and the achievement of a multi-impact law which fulfills the items a) to f) of section 1.2. The theoretical results will be validated within the project consortium thanks to the realisation of tasks 2 and 3. A first and direct consequence for the French partner is to enrich the SICONOS platform with the incorporation of a totally new and efficient multiple impact module for the simulation of granular matter and of kinematic chains. The SICONOS platform is an open-source tool, GPL licenced. On the Chinese side, the partner will benefit from improved numerical and analytical tools to carry on more efficiently the design of aerospace systems. From a more general point of view, we hope the results may disseminate both in the Mechanical Engineering and the Granular Matter (Physics and Mechanics) communities. The Robotics community may also find some interest in the use of more efficient contact/impact laws (for instance a workshop dedicated to contact laws is organised at the IEEE Int. Conference on Robotics and Automation ICRA 2008, see http://www.icra2008.org/ and http://robotics.colorado.edu/wiki/index.php/Murphey:ICRA2008_Contact_Mechanics_Workshop).

1.6 Organisation du projet/*Project flow*

Préciser les aspects organisationnels du projet et les modalités de coordination globale, spécifier notamment :

- *le responsable de chaque tâche et les partenaires impliqués (possibilité de l'indiquer sous forme graphique selon le modèle ci-dessous)*
- *les contributions des partenaires (le « qui fait quoi »)*

Exemple de présentation graphique de l'organisation d'un projet, on spécifiera en particulier :

- *les liens entre les différentes tâches identifiées au §1.4*

The three tasks identified in section 1.4 are intimately linked and interlaced. The theoretical findings will feed the simulation tool. In turn the simulation tool will enable us to verify some experimental results. The two experimental setups will not only allow us to check that the models of task 1 represent true mechanical effects, but may also be a source of new theoretical investigations. It is therefore not reasonable at this stage to decide any sequential order in the realisation of the tasks, except that students need some time to get acquainted with the subject. It is therefore likely that the first months of the post-doc and of the PhD students, will be dedicated to bibliorapy. But they should very soon also think about the numerics and the experimental design.

- *l'échéancier des différentes tâches identifiées au § 1.4 (cf. modèle ci-dessous)*

Tâche/Tasks	Partenaires/Partners				Année 1 Year 1		Année 2 Year 2		Année 3 Year 3	
	1	2			6	12	18	24	30	36
1. Task 1 Theoretical developments (C. Liu, B. Brogliato)										
2. Task 2 Numerical implementation (B. Brogliato,V. Acary)										
3. Task 3 Experimental setup (C. Liu)										
Rapports d'avancement semestriel Progress report/expenses					☺	☺	☺	☺	☺	☺
rapport final final report										☆

☺ : Rapport d'avancement semestriel/6 month-progress report
✪ : Accord de consortium (obligatoire dans le cas d'un partenariat public/privé, conseillé dans tous les autres cas)/Consortium agreement
☆ : Rapport de synthèse et récapitulatif des dépenses/Final report and expenses summary

Préciser de façon synthétique les jalons scientifiques et/ou technologiques, les principaux points de rendez-vous, les points bloquants ou aléas qui risquent de remettre en cause l'aboutissement du projet (cf. exemple ci-dessous)

TABLEAU des LIVRABLES et des JALONS (le cas échéant)/*Deliverables and milestones*			
Tâche Task	Intitulé et nature des livrables et des jalons/ *Title and substance of the deliverables and milestones*	Date de fourniture ***nombre de mois à compter de T0 Delivery date, in months starting from T0***	Partenaire responsable du livrable/jalon *Partner in charge of the deliverable/ milestone*
1.			
	Frictionless multiple impacts in granular media	12	1/research reports
	Multiple impacts with Coulomb friction in granular media	24	1-2/research reports
	Multiple impacts in kinematic chains	24	2/research reports
	Rapport final	30	2/final report

2.			
	Definition of new object and classes in SICONOS toolbox	12	1
	Insertion of new models in SICONOS toolbox	12-36	1
3.			
	Design and fabrication of the experimental setup	18	2/physical model
	Experimental implementation	18-24	2/experimental system
	Experimental results analysis	24-36	2/experimental report

1.7 Organisation du partenariat/*Consortium organisation*

1.7.1 Pertinence des partenaires/*Consortium relevance*

Fournir ici les éléments permettant d'apprécier la ***qualité des partenaires et les compétences de chacun*** *dans le projet (le « pourquoi qui fait quoi »). Il peut s'agir de réalisations passées, d'indicateurs (publications, brevets), de l'intérêt du partenaire pour le projet…*

The theoretical aspects will be studied by the two partners who both possess strong experience in nonsmooth mechanics (modelling, analysis, control). The French partner will handle the software/numerics aspects, being the developper of the software package SICONOS [16, 17]. The Chinese partner will deal with the experimental part of the project, who has the successful experience of establishing an experimental setup for verifying the phenomena of the Painlevé paradox in a robotic system, and has a close cooperation with aerospace industry of China who could provide some experimental data to be used as the validation of the algorithm.

1.7.2 Complémentarité et synergie des partenaires/*Added value of the consortium*

Montrer la ***complémentarité et la valeur ajoutée des coopérations entre les différents partenaires****. L'interdisciplinarité et l'ouverture à diverses collaborations seront à justifier en accord avec les orientations du projet.*

Both partners in the consortium also have rich experiences of the cooperations with industry departments. This ensures this project not only will take the potential value in scientific level, but also will find the varieties of application in industry. The fact that the students will spend a significant period of time at INRIA and at Pekin University, will allow the transfer of expertise between the two teams (for instance the Chinese partner will be in position to use the SICONOS platform and contribute to it).

1.7.3 Qualification du coordinateur du projet et des partenaires/*Principal investigator and partners : résumé and CV*

Pour chacune des personnes dont l'implication dans le projet est supérieure à ***3mois/an,*** *une biographie* ***d'une page maximum*** *sera placée en annexe du présent document. Celle-ci comportera :*

- *Nom, prénom, âge, genre, cursus, situation actuelle*
- *Autres expériences professionnelles*
- *Liste des cinq publications (ou brevets) les plus significatives des cinq dernières années, nombre total de publications dans les revues internationales et actes de congrès à comité de lecture*
- *Et pour le coordinateur du projet, son expérience antérieure de coordination*

Le cas échéant, indiquer pour chacun des membres, son implication dans d'autres projets nationaux ou internationaux (contrats publics et privés en cours et les demandes en cours) selon le modèle fourni en annexe. Expliciter l'articulation entre les travaux proposés et les travaux antérieurs ou déjà en cours, en particulier ceux soutenus par l'ANR.

1.8 Accès aux grands instruments/Access to large facilities

En cas d'utilisation de grand instrument, donnez les références de la demande d'accès à celui-ci (nature du grand instrument, date et demande d'accès, statut de la demande : prévu, demandé, accepté) et le cas échéant, fournir le(s) avis/accord(s) du comité scientifique correspondant.

1.9 Stratégie de valorisation et de protection des résultats/*Data management, data sharing, intellectual property strategy, and exploitation of project results* *(1/2 page maximum)*

Pour les projets partenariaux organismes de recherche/entreprises, les partenaires devront conclure, sous l'égide du coordinateur du projet, un accord de consortium dans un délai d'un an. Indiquer les grandes lignes de la répartition entre partenaires de la propriété intellectuelle, des droits d'exploitation etc.,
Pour les projets académiques, l'accord de consortium n'est pas obligatoire mais fortement conseillé.

Un accord de consortium sera envisagé par les deux partenaires. Etant donné le faible nombre de partenaires et le caractère académique des travaux une telle démarche ne paraît cependant pas absolument nécéssaire.

2. **Justification scientifique des moyens demandés/*Requested budget : detailed financial plan***

*On présentera ici **la justification scientifique et technique** des moyens demandés par chaque partenaire sur le site de soumission et synthétisés à l'échelle du projet dans le tableau récapitulatif ci-dessus.*

Chaque partenaire justifiera les moyens qu'il demande en distinguant les différents postes de dépenses.

2.1 Partenaire 1/*Partner 1 (INRIA Rhône-Alpes)*

2.1.2 Equipement/*Large equipment*

Préciser la nature des équipements et justifier le choix des équipements*
Si nécessaire, préciser la part de financement demandé sur le projet et si les achats envisagés doivent être complétés par d'autres sources de financement. Indiquer alors le montant, l'origine et le statut complémentaires (« acquis », « demandé », « à demander ») de ces financements.

** Un devis pour tout équipement d'un montant > 4 000euros, sera demandé si le projet est retenu pour financement.*

Two personnal computers (one laptop and one fixed PC) ; total amount less than 4000 euros.

2.1.3 Personnel/*Manpower*

Le personnel non permanent (doctorants, post-doctorants,..) financé sur le projet devra être justifié.
Fournir les profils des postes à pourvoir pour les personnels à recruter (1/2 page maximum par type de poste à renseigner directement sur le site de soumission). Ne sont pas éligibles au financement les personnels administratifs.
Pour les doctorants, préciser si des demandes d'allocations de thèse sont prévues ou en cours, indiquer la nature et la part de financement imputable au projet.

One post-doc student (2 years). The post-doc will be hired during the first two years of the project (January 2009-December 2011). The post-doc student should spend the first year at INRIA and the second year at Pekin university. On the other hand the PhD student will spend one year at INRIA during the completion of his thesis.

Post-doc subject : The topic of this post-doc concerns the modelling and analysis of multiple impacts in multibody systems, more particulalrly granular matter. Frictionless bodies will first be considered. The first task will be to extend previously obtained results on linear chains of balls, to the case of 3-dimensional chains. Then Coulomb friction will be added at the contacts. A basic knowledge of the statistical mechanics in order to study the complex behavior in granular matter will be an advantage. Numerical simulations will be performed with the SICONOS platform developed by the INRIA Rhône-Alpes. The student will spend one year at the INRIA Grenoble (France) and one year at the Peking university.

2.1.4 Prestation de service externe/*Services, outward facilities*

Pour ces prestations de service dont le montant ne pas être supérieur à 50% de l'aide demandée, préciser :

- *la nature des prestations*
- *le type de prestataire*

2.1.5 Missions/*Travels*

***Si le montant excède 5% de l'aide demandée**, préciser :*

- *les missions liées aux travaux d'acquisition sur le terrain (campagnes de mesures…)*
- *les missions relevant de colloques, congrès, réunions entre partenaires…*

Travels : Grenoble to Peking (project meeting, post-doc mission): 3
One international conference

2.1.6 Dépenses justifiées sur une procédure de facturation interne/*Expenses for inward billing*

Préciser la nature des prestations (ex : accès à des plates-formes technologiques, moyens de calcul, bases documentaires,…)

2.1.7 Autres dépenses de fonctionnement/*Other expenses*

*Toute dépense **significative** relevant de ce poste devra être justifiée.*

Organisation of a EUROMECH colloquium (July or August 2011) in Grenoble. Partner 1 has already organised such a colloquium in July 1999. The INRIA Rhône-Alpes offers facilities for such events. The number of participants will be about 50. An initial budget of about 5 kEuros is needed for the invitation of about three plenary speakers from Europe. This will allow us to keep the registration fees for PhD and post-doc students low (less than 100 euros), as it is usual for Euromech colloquia.

2.2 Partenaire 2/*Partner 2 (Peking University)*

2.2.1 Equipement/*Large equipment*

Préciser la nature des équipements et justifier le choix des équipements*

Si nécessaire, préciser la part de financement demandé sur le projet et si les achats envisagés doivent être complétés par d'autres sources de financement. Indiquer alors le montant, l'origine et le statut complémentaires (« acquis », « demandé », « à demander ») de ces financements.

** Un devis pour tout équipement d'un montant > 4 000euros, sera demandé si le projet est retenu pour financement.*

1) The design and fabrication of the Ball-Chain system and the Disc System.
2) The laser-Doppler vibrometer

2.2.2 Personnel/*Manpower*

Le personnel non permanent (doctorants, post-doctorants,..) financé sur le projet devra être justifié.
Fournir les profils des postes à pourvoir pour les personnels à recruter (1/2 page maximum par type de poste à renseigner directement sur le site de soumission). Ne sont pas éligibles au financement les personnels administratifs.
Pour les doctorants, préciser si des demandes d'allocations de thèse sont prévues ou en cours, indiquer la nature et la part de financement imputable au projet.

A PhD student will be hired during the 3 years of the project. He will be supervised jointly by C. Liu and B. Brogliato (a « co-tutelle » between Pekin university and the National Polytechnique Institute of Grenobe is envisaged). He will be in charge, among other things, of the development of the experimental setup which will make a major part of his PhD work. The student will spend the second year at the INRIA Rhône-Alpes in the BIPOP project. His work will focus on the kinematic chains. Indeed the Chinese partner leads a project from CAST (China Aerospace Agency), in which a landing mechanism with multi-impact events and a space robotic system with 3 fingers touching an object will be investigated by using our theory. The PhD student should establish the experimental setup for the ball-chain and the disc-Angle systems to be designed in this project (see sections 1.4 (task 3) and 2.2.1).

2.2.3 Prestation de service externe/*Services, outward facilities*

Pour ces prestations de service dont le montant ne pas être supérieur à 50% de l'aide demandée, préciser :

- *la nature des prestations*
- *le type de prestataire*

The leasehold of the vibration platform
The experimental data from aerospace industry of China.

2.2.4 Missions/*Travels*

***Si le montant excède 5% de l'aide demandée**, préciser :*

- *les missions liées aux travaux d'acquisition sur le terrain (campagnes de mesures…)*
- *les missions relevant de colloques, congrès, réunions entre partenaires…*

Travels :

Peking to Grenoble (project meeting, PhD student mission): 3

2.2.5 Dépenses justifiées sur une procédure de facturation interne/*Expenses for inward billing*

Préciser la nature des prestations (ex : accès à des plates-formes technologiques, moyens de calcul, bases documentaires,…)

2.2.6 Autres dépenses de fonctionnement/*Other expenses*

*Toute dépense **significative** relevant de ce poste devra être justifiée.*

Annexes

Description des partenaires/*Partners informations* (cf. § 1.7.1) *(1 page maximum par partenaire)*

INRIA Rhône-Alpes (BIPOP Team-Project)

The BIPOP team http://www.inrialpes.fr/bipop/ is concerned with non-smooth dynamical systems, also known as complementarity dynamical systems. More precisely, modelling, control and numerical simulation are the main scientific topics. The basic tools therefore come from nonsmooth mechanics, systems and control theory, nonsmooth optimisation, and convex and nonsmooth analysis. The main applications can be found in mechanical systems (multibody systems with unilateral constraints, friction, nonsmooth contact laws), and in electrical systems (circuits with diodes, MOS transistors). Some more abstract problems (like optimal control with state constraints, generalized predictive control) also fit within this framework. The main areas of application are: automotive systems, aerospace applications, electro-mechanical systems (mechatronics), robotics, etc. There are still many open fields of theoretical research (in systems theory: controllability, observability, stabilisation, trajectory tracking; in mechanical modelling: multiple impacts modelling, nonmonotone contact laws, Painlevé paradoxes), as well as on a more applied level (numerical simulation and software development). The biped robot of the INRIA is a privileged application for control. An important biomedical application concerns paraplegic rehabilitation by electro-stimulation.

The activities around nonsmooth optimization are driven by application problems (in operation research, numerical mechanics, decision making, robotics, identification...), which require the development of algorithms, the latter motivating in turn fundamental research. These three aspects are interspersed in our research work. Within the BIPOP team, the main applications we consider are robots control and contact mechanics. Generally speaking, we are working on the fruitful connection between nonsmooth optimization and nonsmooth dynamic systems. Besides, the project has an «expertise» aspect, consisting mainly in consulting or software release.

The BIPOP team develops two toolboxes (SICONOS http://siconos.gforge.inria.fr/ and HUMANs http://www.inrialpes.fr/bipop/software/humans/index.html). It has several contacts with industry (Schneider Electric, France Telecom R&D, Staubli Robotics, Electricité de France, Raise Partners).

At the present time the BIPOP team-project is constitued of 7 permanent researchers (6 INRIA and 1 CNRS) all working around nonsmooth dynamical systems or nonsmooth optimisation.

Peking university (College of engineering, State Key laboratory for Turbulence and Complex Systems)

Peking University is a comprehensive and top-level National key university in China. The State Key laboratory for Turbulence and Complex Systems is one of 12 national key laboratries in the univeristy. The group of the Aeronautics and Astronautics Dynamics and Control at the college of engineering focuses on the Modelling of Impact dynamics, Contact with friction, Flexible Multibody

Dynamics, Multiple Scale Simulation and Continuum Approximation in granular matter. The main applications in aerospace are: Dynamics and control of tensegrity structures; Space Robotic Maupulator; Docking Mechanism; Landing Dynamics of Spacecraft. We also concern the fundamental problems in non-smooth dynamical systems, such as the singularities of rigid body dynamics and the Painleve paradox due to friction. We are the first one to establish an experimental setup demonstrating the phenomena of the Painleve paradox in a robotic system, and present a method that can well reproduce the Painleve's phenomena with the comparision of the experimental results.

The activities around the granular matter are driven in hand by the scientific problems of the connection between the micro- and macro- scales in complex systems and in other hand by the application problems like the landing mechanism falling into soils. Some preliminary results with the comparison of the experimental results provided by CAST (China Academy of Space Techonolgy) for a landing modular have been developed, and seem to be very sound.

At the present time our group is constitued of 3 permanent researchers (2 Peking Univeristy and 1 CAST) all working around nonsmooth dynamical systems in spacecrafts. I supervise one post-doc and 3 PhD students, 3 master students in the group.

Biographies/*Résumés and CV* (cf. § 1.7.3) *(1 page maximum par personne)*

***Bernard Brogliato** :* was born in 1963. Graduated from the Ecole Normale Supèrieure de Cachan. PhD from the National Polytechnique Institute of Grenoble (January 1991), and Habilitation à Diriger des Recherches (November 1995). CNRS researcher from September 1991 to September 2001. Directeur de recherche at INRIA since October 2001. Head of the team-project BIPOP http://www.inrialpes.fr/bipop/ . Main scientific themes : nonsmooth dynamical systems (analysis, control, modelling), dissipative systems. He was the coordinator of the FP5 european project IST 2001 37-172 SICONOS (September 2002 to December 2006), see http://siconos.inrialpes.fr/ . He has published more than 40 papers in journals and authored or co-authored 3 monographs, see http://www.inrialpes.fr/bipop/people/brogliato/ for all details. According to Google Scholar and Scopus, his papers and books have been cited (excluding self-citations) about 1100 times in the literature. Main publications of the past 5 years :

B. Brogliato « Some perspectives on the analysis and control of complementarity systems », IEEE Transactions on Automatic Control, vol.48 , no 6, pp. 918-935, June 2003.

D. Goeleven, B. Brogliato « Stability and instability matrices for linear evolution variational inequalities », IEEE Transactions on Automatic Control, vol.49 , no 4, pp. 521-534, 2004.

B. Brogliato, D. Goeleven « The Krakovskii-LaSalle invariance principle for a class of nonsmooth dynamical systems », Mathematics of Control, Signals and Systems, vol. 17, no 1, pp. 57-76, 2005.

B. Brogliato, R. Lozano, B. Maschke, O. Egeland , *Dissipative Systems Analysis and Control*, 2nd Edition, Springer London, 2007.

B. Brogliato, A. Daniilidis, C. Lemaréchal, V. Acary « On the equivalence between complementarity systems, projected systems and differential inclusions », Systems and Control Letters, vol.55, pp.45-51, 2006.

Vincent Acary was born in 1973. Graduated from theEcole Supérieure de Mecanique de Marseille (Ecole Centrale Marseille). PhD Thesis from Université d'Aix-Marseille II, Ecole supérieure de Mécanique de Marseille (January 2001). Best thesis awards of the Université de la Méditerranée - Aix-Marseille II. Post-doctoral fellow CNRS/Schneider Electric from February 2001 to September 2003 on the modeling and the simulation of multiple impacts in Circuits breakers. Since September 2003, INRIA research fellow in the Bipop project. He was the coordinator of the work package 2 « Numerical method and software » in the the FP5 european project IST 2001 37-172. He is the main designer of the siconos platform see see http://siconos.gforge.inria.fr/. More details can be found at http://www.inrialpes.fr/bipop/people/acary/

V. Acary, B. Brogliato, D. Goeleven « Higher order Moreau's sweeping process. Mathematical analysis and numerical simulation », Mathematical Programming A, vol. 113, no 1, pp. 133-217, 2008.

V. Acary, B. Brogliato, *Numerical Methods for Nonsmooth Dynamical Systems. Applications in Mechanics and Electronics.* Lecture Notes in Applied and Computational Mechanics, vol.35, Springer Verlag Heidelberg, 2008.

V. Acary, B. Brogliato « Concurrent multiple impact modelling : case study of a 3-ball chain », Proceedings of the MIT Conference on Computational Fluid and Solid Mechanics (K.J. Bathe, Ed.), Elsevier Science, pp. 1836-1841, 2003.

V. Acary and F. Pérignon. « Siconos A software platform for modeling, simulation, analysis and control of Non Smooth Dynamical systems. » In: /Proceedings of MATHMOD 2006, 5th Vienna Symposium on Mathematical Modelling/. Vienna. Published by ARGSIM Verlag, Vienna, 2006 ISBN 3901608303.

M. Renouf and V. Acary and G. Dumont « 3D frictional contact and impact multibody dynamics. A comparison of algorithms suitable for real-time applications. » In: ECCOMAS Thematic Conference Multibody Dynamics 2005.. Madrid.

M. Renouf and V. Acary . « Comparison and Coupling of Algorithms for Collisions, contact and friction in rigid multi-body simulations. » In: ECCM 2006, III European Conference on Computational Mechanics. Lisbon.

Florence Bertails : was born in 1978. A graduate from the Telecommunication Engineering School of INP Grenoble, she received in 2002 a MSc in Image,Vision and Robotics, and completed in 2006 a PhD on hair simulation at INP Grenoble (2006 SPECIF Award). She worked at the University of British Columbia as a postdoctoral researcher, before joining INRIA in September 2007 as a Chargée de Recherche. Her research interests deal with the modeling and the simulation of complex mechanical objects (nonlinear thin structures, solids interacting with fluids, heterogeneous materials such as hair), mainly for graphics applications. She presented her work at international conferences such as the ACM-EG Symposium of Computer Animation, Eurographics, and SIGGRAPH (see http://www.inrialpes.fr/bipop/people/bertails/ for further details).

Main publications during the 5 past years:

F. Bertails, B. Audoly, M.-P. Cani, B. Querleux, F. Leroy, J.-L. Lévêque « Super-Helices for predicting the dynamics of natural hair », ACM Transactions on Graphics (Proceedings of the ACM SIGGRAPH conference), vol 25, issue 3, August 2006.

C. Batty, F. Bertails, R. Bridson « A fast variational framework for accurate solid-fluid coupling », ACM Transactions on Graphics (Proceedings of the ACM SIGGRAPH conference), vol 26, issue 3, August 2007.

K. Ward, F. Bertails, T.-Y. Kim, S. Marschner, M.-P. Cani, M. Lin « A survey on hair modeling: styling, simulation, and rendering », IEEE Transactions on Visualization and Computer Graphics, vol 13, issue 2, March 2007.

F. Bertails, T.-Y. Kim, M.-P. Cani, U. Neumann « Adaptive Wisp Tree: a multiresolution control structure for simulating dynamic clustering in hair motion », Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation, June 2003.

F. Bertails, C. Ménier, M.-P. Cani « A practical self-shadowing algorithm for interactive hair animation », Proceedings of Graphics Interface, May 2005.

Caishan Liu **:** was born in 1965. Master degree from South-East University in 1989. PhD from Tianjin Univerisity in (September) 1997. Lecturer in the Shandong University from July 1989 to September 1994. Post-doc in Peking University from January 1998 to January 2000. Joining in the department of mechanics of Peking Univerisy since 2000. Main research interests : Multibody Dynamics and Granular Matter. He was the fellow of the General Mechanics Division of the Academic Society of Theoretical and Applied Mechanics of China, and the Fellow of Space Aircraft Dynamics and Control Division of the Academic Society of Space and Aviation of China.

Main publications in the past 5 years :

Wei Ma, Caishan Liu, Theoretical model for the pulse dynamics in a long granular chain, Physical Review E, Review E, 74，046602, 2006

Zhao Zhen, Liu caishan, Bin Chen, Experimental Investigation of the Painlev´e Paradox in a Robotic System, J of Applied Mechanics, Transaction of ASME (in press,2008)

Caishan Liu, Ke Zhang, Lei Yang, The FEM analysis and approximate model for cylindrical joint with clearances, Mechanism an Machine Theory, 42 (2): 183-197, 2007

Liu CS, Zhao Z, Chen B, The bouncing motion appearing in a robotic system with unilateral constraint, Nonlinear Dynamics 49 (1-2): 217-232, 2007

Zhao Zhen, Caishan Liu, Bin Chen, The Analysis and Simulation for 3D impact with friction, Multibody System Dynamics, 18 (4): 511-530, 2007

Wenli yao, Bin Chen, Caishan liu; Coefficient of restitution of planar two-body oblique collision with friction, International Journal of Impact Engineering. Vol. 31 255–265, 2005

Zhen Zhao : Post-doc in Peking university

Zhen Zhao, Bin Chen, Caishan Liu, Impact Model Resolution on Painleve's, Parodox, ACTA, Mechanica Sinica, Vo.20,No.6 649-659,2004

Zhao Zhen, Caishan Liu, Bin Chen, The Numerical Method for Three Dimensional Impact with Friction of Multi-Rigid-Body System, Science in China (series G)，Vol.49(1),102-118, 2006

Zhao Zhen; Liu caishan, Bin Chen, The Painlevé paradox studied at a 3D slender rod, Multibody Syst Dyn (in press)

Lei Yang: Senior Researcher in CAST.

Caishan Liu, Ke Zhang, Lei Yang; The Compliance contact model of cylindrical joints with clearance, Acta Mech. Sinica,Vol.21,No.5, 451-458,2005

Caishan Liu, Ke Zhang, Lei Yang, The Normal Force-Displacement Relationship of Spherical Joints with Clearances, ASME, Journal of Computational and Nonlinear Dynamics, 2006，No.2 160-167

Implication des personnes dans d'autres contrats/*Partner's involvement in other projects* (cf. § 1.7.3) *(un tableau par partenaire)*

Partenaire Partner	Nom de la personne participant au projet Name of the person involved in the project	Personne. Mois Man.month	Intitulé de l'appel à projets Source de financement Montant attribué Name call for proposals Other fundings from different organisms Allocated budgets	Titre du projet Proposal title	Nom* du coordinateur Name Principal Inverstigator	Date début -Date fin Start- End of the project
N° 1	Bernard Brogliato	0.6 ETP	BLANC	GUIDAGE	Dominikus Noll	January 2006-December 2008
N° 1	Vincent Acary	20% (4.8 months)	SETIN	VAL-AMS	Thao Dang	January 2007-December 2008
N° 1	Bernard Brogliato	5% (1.2 months)	SETIN	VAL-AMS	Thao Dang	January 2007-December 2008
N° 1	Florence Bertails	25%	RIAM	CHEVEUX	Damien Anicelle	January 2008-December 2010

Demandes de contrats en cours d'évaluation[1]/Other proposals under evaluation

Partenaire Partner	Nom de la personne participant au projet Name of the person involved in the project	Personne. Mois Man.month	Intitulé de l'appel à projets Source de financement Montant demandé Name call for proposals Other fundings from different organisms Expected grants	Titre du projet Proposal title	Nom* du coordinateur Name Principal Inverstigator
N°					
N°					

[1] *Mentionner ici les projets en cours d'évaluation soit au sein de programmes de l'ANR, soit auprès d'organismes, de fondations, à l'Union Européenne, etc. que ce soit comme coordinateur ou comme partenaire. Pour chacun, donner le nom de l'appel à projets, le titre du projet et le nom du coordinateur.*