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Using task efficient contact configurations to animate creatures in arbitrary environments

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ABSTRACT

A common issue in three-dimensional animation is the creation of contacts between a virtual creature and the environment. Contacts allow force exertion, which produces motion. This paper addresses the problem of computing contact configurations allowing to perform motion tasks such as getting up from a sofa, pushing an object or climbing. We propose a two-step method to generate contact configurations suitable for such tasks. The first step is an offline sampling of the range of motion (ROM) of a virtual creature. The ROM of the human arms and legs is precisely determined experimentally. The second step is a run time request confronting the samples with the current environment. The best contact configurations are then selected according to a heuristic for task efficiency. The heuristic is inspired by the force transmission ratio. Given a contact configuration, it measures the potential force that can be exerted in a given direction. The contact configurations are then used as inputs for an inverse kinematics solver that will compute the final animation. Our method is automatic and does not require examples or motion capture data. It is suitable for real time applications and applies to arbitrary creatures in arbitrary environments. Various scenarios (such as climbing, crawling, getting up, pushing or pulling objects) are used to demonstrate that our method enhances motion autonomy and interactivity in constrained environments.

Research in computer animation is motivated by the need to provide virtual creatures with an increased autonomy of motion in 3D environments. Such improvements allow to propose new forms of gameplay in video games, or to validate ergonomic designs.

In this work we are interested in the contacts created between a creature and the environment: contacts allow to efficiently exert the force necessary to perform motion tasks (such as getting up, climbing or pulling). For instance in Fig. 13, several contacts are created between the end-effectors of a virtual insect and the books composing the environment.

Motion capture methods are inherently limited in such a constrained context: addressing various tasks and environments for different creatures requires the creation of prohibitively large motion databases. Therefore, a common approach is the decomposition of the motion into a sequence of contact configurations between a virtual creature and the environment. The notion of configuration is central in motion planning [1]. Such planners often use randomly generated configurations [2], and select those preserving static stability [3]. However, they lack heuristics to determine if those configurations are suited for the task in terms of force exertion. In the rest of the paper such configurations are called *task efficient*. Dynamic simulations use predefined configurations as inputs to motion controllers, but show little adaptation to the environment [4].

Thus, motion planners and dynamic controllers could benefit from a method to generate appropriate contact configurations. This is our problem statement, formalized in Section 2.

The key idea: The environment as a mean to exert a force: Contacts allow force exertion, which in turn produces the motion. Therefore to select a contact configuration, it is important to make sure it will allow to perform the task. For this reason we need heuristics to measure the compatibility of a contact configuration with a translational motion task. Examples of such tasks are pushing, pulling, standing up, or climbing. This set of motions is commonly needed by interactive simulations (such as video-games). They could benefit from our method to introduce more variety in the environments and interactions they propose. Rotational tasks will be addressed in future works.

To measure the task efficiency, we propose a heuristic inspired by the force transmission ratio [5]. It defines the efficiency of a configuration as the potential force it allows to exert in the direction of a translational task, as detailed in Section 2.4. It is traditionally used to optimize the configuration of a robotic arm, but requires to

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know in advance the future position of the end-effector. To overcome this issue, we combine our heuristic with a random sampling approach, independent from the environment (Section 3).

The sampling of all the possible joint configurations is performed offline to ensure good performance during the online simulation. However simply sampling to joint angles in a random manner may lead to unrealistic poses. To overcome this we propose to limit the sampling to a subspace corresponding to the Range Of Motion for each joint. Classical approaches consider minimum and maximum joint angle values while actual joint limits are more complex to model, as there may be interactions between joint axis – Fig. 7. In this paper we wish to model these interactions between joint axis to limit the sampling to natural configurations (Section 4).

Then, the samples are filtered online to select configurations in contact with the environment, and free of collisions. The chosen configurations are finally used as inputs for an inverse kinematics solver that will compute the final animation.

Therefore the contribution of this paper is a method for the real time, automated computation of task efficient contact configurations for arbitrary creatures. As shown in Section 5, it can be applied to various motions tasks in arbitrary environments. We discuss the limitations of our method, potential applications and future works in Section 6.

1. Related work

The issue of creating contact configurations has been addressed in different ways: Example-based methods use motion clips as references for motion (Section 1.1); Biomechanical and robotical approaches define relevant contact configurations by quantifying them in terms of force exertion (Section 1.2); Motion planning and optimization methods focus on contact configurations that preserve balance (Section 1.3).

1.1. Example-based methods for constrained environments

To improve the natural aspect of an animation, a common method consists in using motion clips, either created by an artist or obtained through motion capture. Effective methods exist to adapt those clips to the constraints of the environment such as external force pressure [6] or locomotion on uneven terrain [7,8]. Similarly foot-step planning techniques proposed hybrid approaches to address this issue [9,10].

Motion graphs [11,12] or precomputed search trees [13] can be used for acyclic motions, and be adapted for contact interaction in constrained environments.

Other methods address acyclic motions such as reaching and manipulating tasks [14,15], or close contact interaction motions [16].

However, methods based on motion capture do not easily apply to arbitrary virtual creatures.

Another drawback is that although motion adaptation is possible (for instance through inverse kinematics), the adaptation of a motion clip is limited to a motion including the same end-effectors in contact. This is problematic when the environment differs too much from the one used in the reference motion. To provide such methods with rich contact interactions for complex environments would require to be able to produce the animations corresponding to each possible interaction and appropriately choose between them at run time.

Conversely the generality of our method covers a large set of tasks, applies to any kind of virtual creature and adapts to the environment.

1.2. Inverse kinematics and manipulability for virtual creatures

The issue of optimizing a contact configuration for a task has been widely studied. Inverse kinematics methods exploit the redundancy of kinematic trees to optimize secondary objectives [17]. Yoshikawa presented the manipulability measure for quantifying the ability of robotic mechanisms in positioning and orienting end-effectors [18]. Based on this work, Chiu proposed the force transmission ratio, another index for optimizing a manipulator pose relatively to a specific task [5]. Several manipulability-based methods have since been proposed to either optimize a configuration [19] or a trajectory [20,21]. Recent works in biomechanics tend to show the relevance of the manipulability measure for human beings [22].

Those methods require *a priori* knowledge of the target that an end-effector must reach. They only solve half of our problem because we need to know where a contact must be created to find a suitable configuration.

Conversely, our method extends the force transmission ratio and uses it along with a random sampling approach. This allows us to address simultaneously the issues of finding a contact position and a task efficient configuration.

1.3. Motion planning and optimization for constrained environments

The advantage of procedural methods over example-based ones is that they are not limited by a motion database. Recently Wampler et al. proposed a method to automatically synthesize gaited motion for arbitrary creatures [23].

In [24], Kallman and Mataric generate a roadmap of configurations independent from the environment. The roadmap is updated at runtime as the environment is modified: colliding nodes are removed and paths consequently updated. Our method is also based on environment independent sampling, but the objective is different: Kallman and Mataric build a roadmap to address the issue of computing a collision-free motion; we do not build a roadmap and use sampled configurations as candidates for task efficient contact configurations.

Contact interactions have been considered for grasping tasks [25,26], or for motion planning problems. Hauser et al. introduced the *Contact before motion* approach [27], used in several other contributions [28,3,29]. A common drawback of this approach is that it requires prior discretization of possible contact positions in the environment. Also, task efficiency is not always considered in the process of finding contact configurations.

In the continuity of those works, Mordatch et al. proposed the Contact-Invariant Optimization (CIO) term [30]: contact positions and trajectory are planned simultaneously in the same optimization loop. Along the process, an end-effector is guided towards the nearest surface satisfying dynamic constraints. Al Borno et al. proposed a full-body trajectory optimization method that does not require explicit contact definition, but still requires to specify with which obstacle an effector should be in contact [31].

However, to get up from a chair in the environment shown in Fig. 8, a human would more likely put his hand on the table than on the chair, even if the table is farther away. Those methods cannot achieve this without requiring the user to explicitly define the table as an input of the problem (Fig. 8). Another drawback of those approaches is that, as for other planning methods, the computation time is too long for interactive simulations.

Other contributions in robotics have considered the quality of the contact configurations in their approach [32]. In particular Bretl et al. proposed a heuristic similar to the manipulability measure as a criteria for contact creation [33].

Our method lies in the continuity of these procedural approaches. It does not address the planning issue, rather the