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REAL-TIME MODEL FOR SIMULATION OF TRACKED VEHICLES

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Abstract. *A massless track-wheel-terrain interaction model for the real-time simulation of tracked vehicles is suggested. The model is oriented for simulation of tracked vehicles on highly non-smooth urban and industrial terrains that include such elements like stairs, vertical obstacles etc. The suggested model provides realistic tracked vehicle dynamics and is used in the computer simulator of mobile tracked robots RobSim. The computer simulator is used in the training centers of Russian State Atomic Energy Corporation for training the operators of mobile robots. The main feature of such mobile robots is the remote control based on pictures from the onboard cameras. Such a remote control needs from the operators special abilities and skills that can be acquired first using the computer simulator. Basic principles of terrain handling for fast simulation and mathematical models of contact forces for the track-wheel-terrain interaction, as well as some features of the suggested model are considered.*

1 INTRODUCTION

Advanced multibody models of tracked vehicles consider tracks to be rigid bodies that are interconnected by rigid or compliant links, [1]. It often results in hundreds of bodies and thousands of degrees of freedom as in the computer model in Fig. (1). Such models based on soil mechanics and terramechanics [2, 3] are proven to be good and accurate enough for computer aimed virtual prototyping, testing and design. At the same time such detailed models of tracked vehicles are not efficient enough for a real-time simulation. Fastest of them are several times slower than real-time using mainstream computers even with multi-core processors and parallel solver [4].

Figure 1: Multibody model of M1A1 Abrams tank in Universal Mechanism software, 371 bodies, 1916 d.o.f.

Complexities of modeling a track vehicle precluded the development of real-time codes that faithfully capture the physics of track and suspension dynamics. The challenge in modeling tracked vehicles for real-time simulation results from difficulties in characterizing the mechanics and surface topology of the terrain, the nonlinear mechanics of the track, the mechanics of track-wheel-terrain interaction, and the coupling to the remainder of the vehicle [5].

Real-time simulation models for tracked vehicles usually use some simplifications. Some codes do not consider track-terrain interaction itself and consider tracked vehicle dynamics simply as wheeled vehicle dynamics. Some codes treat simplified massless mathematical models of track-wheel-terrain interaction and simulate track-related effects as additional forces that act on road wheels [6]. Some advanced fast simulation models for tracked vehicles take into account also inertia properties of tracks.

2 MOTIVATION

Laboratory of Computational Mechanics has been involved in the development of the training simulator for operators of special mobile wheeled and tracked robots that are used by the Russian State Atomic Energy Corporation ROSATOM in emergency cases. The simulator is called RobSim. Remote control of a mobile robot, based on view from on-board cameras, needs many specific practice from the operator. Specific design of chassis, manipulators and tips of different robots also need specific operator’s skills. Such skills for typical operations can be successfully trained with the help of the computer simulator.

The simulator should not provide highly accurate simulation results that are important for detailed dynamical analysis. First of all the dynamical engine of the simulator should be fast enough, credible and provide expected dynamics of a tracked robot. Typical training scenes usually include highly non-smooth elements like stairs and vertical obstacles of many kinds as in Fig. (2, left). Both a virtual computer control model and the real remote control panel can be used during the training, Fig. (2, right).

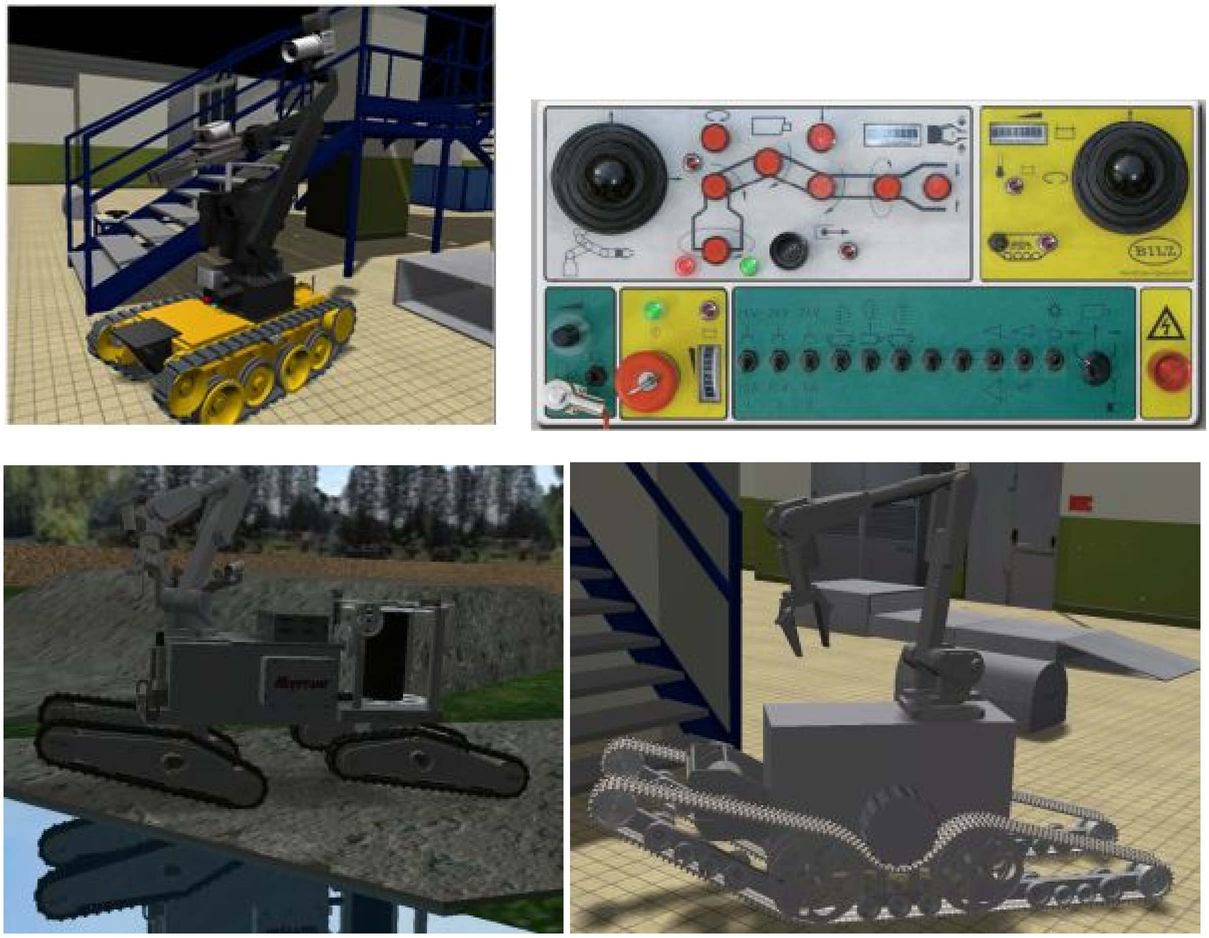
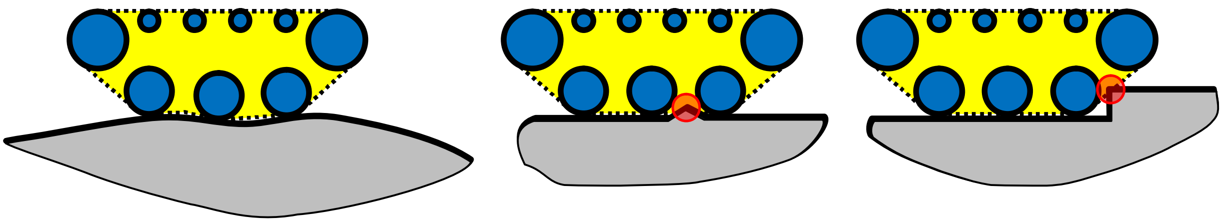


Figure 2: RobSim virtual proving scene and a virtual control panel.

3 SIMULATION MODEL

3.1 Overview

The simplest solution to calculate dynamics of mobile robots in real-time is just to ignore track influence on robot dynamics and consider tracked robots as wheeled ones. It works well enough for smooth terrain in Fig. (3a), but does not work correctly anymore for rough terrains in Fig. (3b) and (3c). If sizes of obstacles are comparable with diameters of road wheels, the influence of the track on the vehicle dynamics is significant and cannot be ignored.



a) b) c)

Figure 3: Tracked robot on a smooth (a) and rough (b, c) terrains.

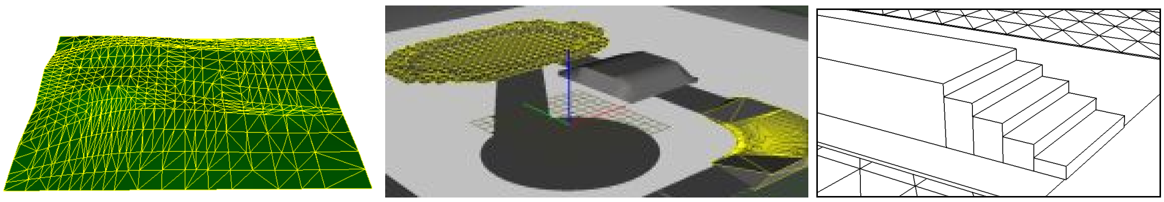
The suggested mathematical model simulates the track-terrain interaction with the help of force elements between terrain and road wheels and does not introduce tracks as rigid bodies that keeps small degrees of freedom in computer models of tracked vehicles. The model introduces both road wheel-terrain forces and special extra forces that simulate track-terrain interaction between road wheels. Track-terrain interaction forces depend on current road wheel configuration and penetration of terrain irregularities into the nominal track projection that is given within dotted line in Fig. (3b) and (3c). It finally gives a possibility to simulate credible vehicle dynamics in real-time even if there is a contact between track and terrain in the middle of road wheels, Fig. (3b) and (3c).

Computation of normal contact forces between the road wheels and terrain is based on the following assumption: the force is proportional to the area of penetration of a ‘rigid road wheel’ into the plane by vertical displacement of the wheel center.

Using implicit numerical methods along with analytic expressions for Jacobian matrices of stiff forces [7] helps to keep a relatively big integration step size and low computational efforts for each step size that finally provides real-time simulation of tracked vehicles.

3.2 Terrain handling

The suggested model supports description of training scenes and terrains as triangulated surfaces or a set of such surfaces, Fig. (1a, 1b). The model also supports highly nonlinear (rough) terrains, Fig. (1c). As it was mentioned above, tracked vehicles on smooth terrains can be successfully simulated simply as road vehicles without regard to tracks. Such an approach for simulation of tracked vehicles on smooth terrains is widely used for approximate simulations in all kinds of simulators including video games and even for many kinds of dynamical analysis. However such an approach to consider a tracked vehicle as a road one does not work accurate enough for rough terrains even for approximate simulator needs. RobSim computer simulator is developed for training of operators of mobile robots. It is expected that such robots should work mainly in industrial scenes like nuclear power plants, industrial and civil buildings, subway stations, urban streets. Such scenes usually have a lot of non-smooth elements like stairs, curbs, obstacles, etc.



a) b) c)

Figure 4: RobSim virtual scenes as triangulated surfaces.

Regarding to real-time simulation it is important to provide efficient handling of triangulated surfaces. The hierarchical approach is used that is typically for such problems. The basic idea behind this refers to the oriented boundary boxes approach, [8]. It supposes to organize a scene in a tree-like structure where the root comprises the whole scene and each leaf contains a smaller subpart. The whole terrain is divided into $N \times N$ oriented rectangular boxes. The oriented boxes approach means that rectangle boxes are oriented so as its sides are parallel to the global axes. It finally gives us simpler shapes that have simpler ways to test for overlap. Initial boxes are divided into sub boxes while the count of face of triangulated surface in one box is greater than a certain constant. Finally terminal boxes have just a few faces and it is not CPU-time consuming operation to enumerate them all.

3.3 Algorithm workflow

The algorithm treats the so-called plane models of track that has zero width. The track plane is described in the body-fixed frame of reference of a hull of a robot. The track model also includes a number of road wheels and track rollers, an idle wheel and a sprocket that form the track itself.

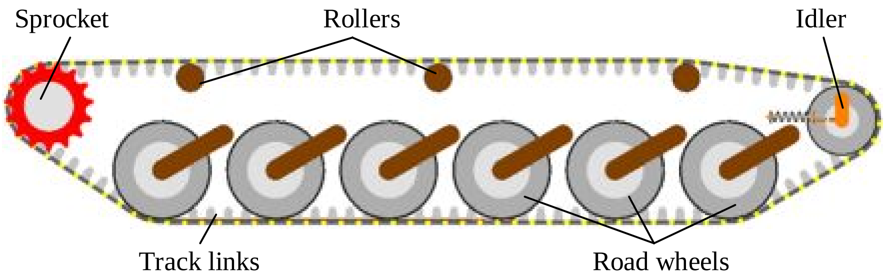


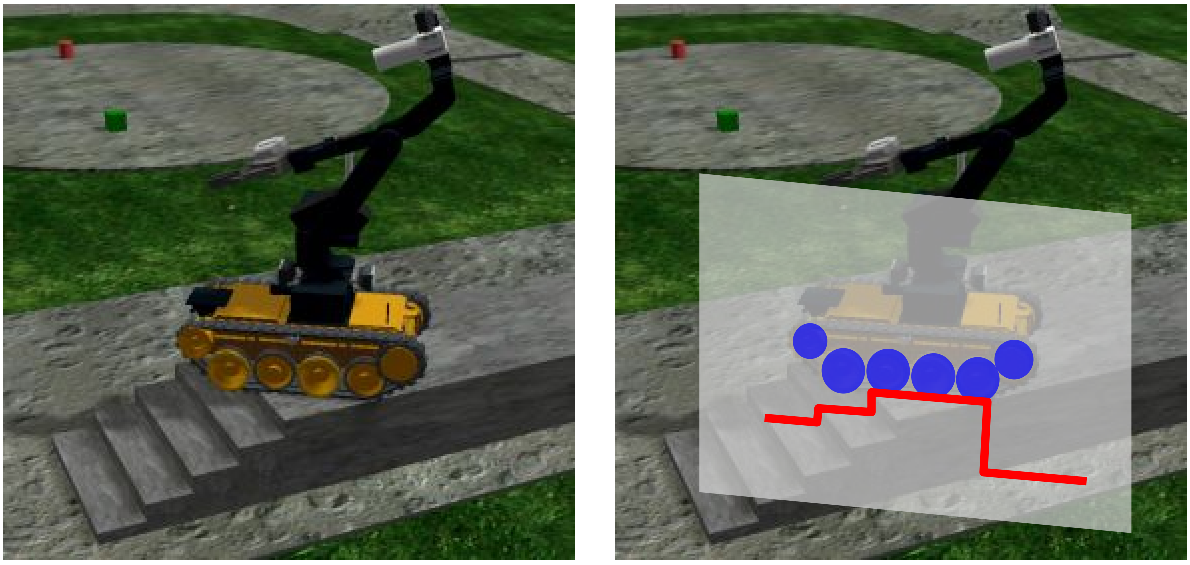
Figure 5: Components of a track.

The suggested algorithm supposes the following steps to be done on each step of a numerical simulation.

Step 1. Defininition the current position and orientation of the track plane, Fig. (6b). Getting current position and orientation of the hull of the robot. Since the track plane is described in the body-fixed frame of reference, the hull position and orientation are all what is need to define the current position and orientation of the track plane.

Step 2. Determination of the polyline of the terrain-plane intersection, Fig. (6b).

Step 3. Calculation of contact forces between road wheels and sections of the track between them and the terrain-plane intersection obtained on step 2.



a) b)

Figure 6: Track plane, terrain-plane intersection as polyline.

3.4 Force model

Let us consider the algorithms of calculation of contact forces for road wheels more detailed. The main idea is as follows. The normal contact force is proportional to the area S of penetration of a road wheel into the segment of the terrain-plane intersection by the vertical displacement of the wheel center δ, Fig. (7),

$$F = \kappa S, \tag{1}$$

where *k* is the constant of proportionality characterizing the wheel and terrain flexibility. The area *S* can be expressed in terms of penetration δ or angle φ

$$S = \frac{2}{3} R^2 \varphi^3, \ \varphi = \sqrt{\frac{2\delta}{R}}. \tag{2}$$

Substitution of Eq. (2) into Eq. (1) gives the following dependence of the force on the penetration

$$F = \frac{2}{3} \kappa R^2 \varphi^3 = \frac{4}{3} \kappa \sqrt{2R}\, \delta^{3/2}. \tag{3}$$

Note that the exponent factors in this formula and in the Hertz formula for contact of two semispaces are the same that confirms the correctness of the above assumption.

The normal contact force is perpendicular to a separate section of the polyline and proportional to the penetration area under the section. If a road wheel penetrates into several sections of the polyline the correspondent contact forces are summarized.

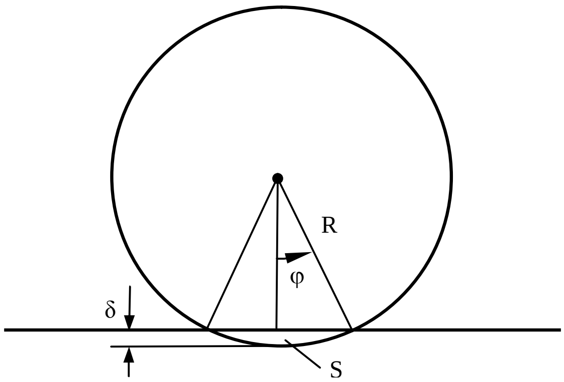


Figure 7: Penetration of a road wheel into a segment of the terrain-plane intersection.

Let us consider the basic idea of simulation of contact interaction of section of track between road wheels and the terrain. The following approach is used. The algorithm checks if the terrain polyline penetrates the imaginary track line between each pair of adjacent road wheels. If yes, the factitious irregularity for the pair of road wheels is created, Fig. (8). The contact forces between road wheels and factitious irregularities are calculated using the general approach as it was described above. If the terrain polyline penetrates track line in several points the mean depth of the factitious irregularity is used. Using mean depth provides the smooth force model for complex terrains.

The algorithm supposes that the contact stiffness of the factitious irregularity is variable. The basic idea behind this is as follows. Deformation of the track under the single terrain irregularity between road wheels is the biggest in the middle of the road wheels and the closer to any road wheel the deformation is smaller, Fig. (9). So the far the road wheel from the terrain irregularity the smaller contact stiffness between the road wheel and the factitious irregularity is used. It provides more realistic bigger deformation of the track between road wheels and smaller one directly on the road wheel. Maximum contact stiffness in Fig. (8b) is equal to the constant contact stiffness between road wheels and terrain. It keeps smooth contact forces when the road wheel drives up the terrain irregularity that just was between road wheels.

Interaction of the road wheels and such a factitious irregularity provides a quite realistic dynamics of chassis of tracked vehicles without introducing track links as separate rigid bodies and keeping relatively small number of degrees of freedom for a multibody model of a tracked vehicle.

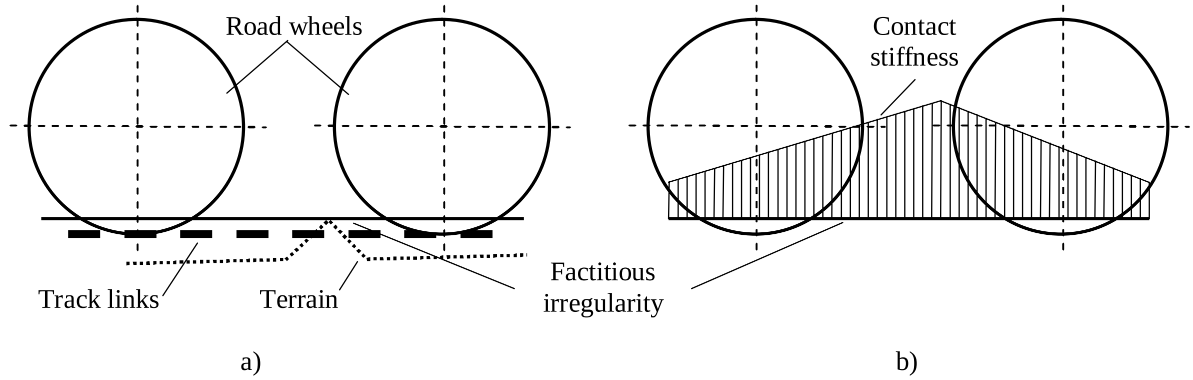


Figure 8: On track-terrain interaction: generation factitious irregularity for road wheels.

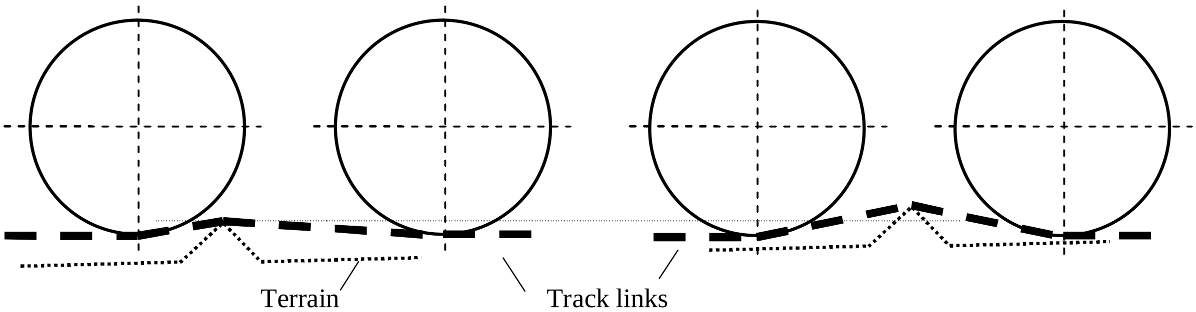


Figure 9: On track-terrain interaction: irregularity between road wheels.

3.5 Model features

Many designs of tracked robots use stiff railings with many number of small road wheels on it, Fig. (10a). Since the suggested algorithm treats the interaction of the track and the terrain it allows to simplify the models of tracked vehicles as it showed in Fig. (10). Removing rigid bodies from the computer model reduces the number of d.o.f. of the final model, as well as it reduces CPU efforts regarding the track model calculation since the number of road wheels to calculate is fewer.

a) real design of the tracked vehicle b) simplified model

Figure 10: Simplification of models of tracked vehicles.

Since the suggested model treats the plane model it might be not enough to use one track model per robot (vehicle) track and is necessary to use several plane track models, for example, outer and inner edges of the track, Fig. (11). It surely makes the simulation process a bit slower but increases reliability of the dynamics of the simulated tracked vehicle.

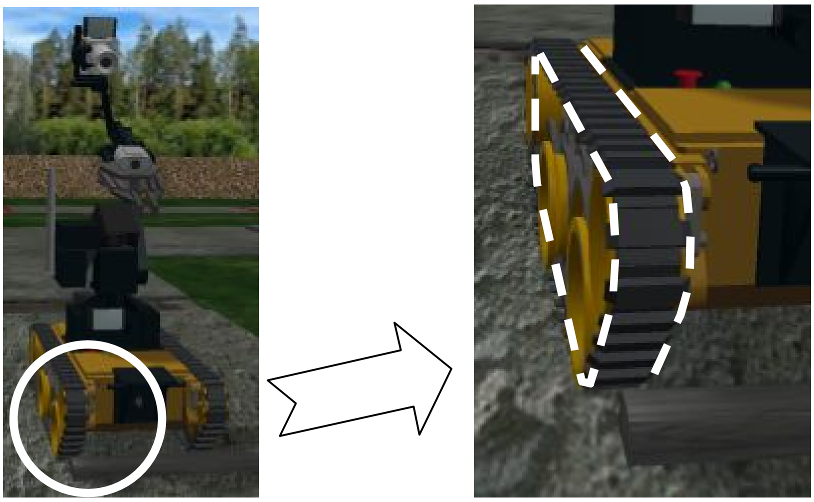


Figure 11: Real track and plane track model.

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