REAL-TIME SIMULATION OF TRACKED VEHICLES ON ROUGH TERRAIN

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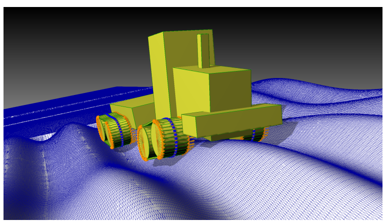
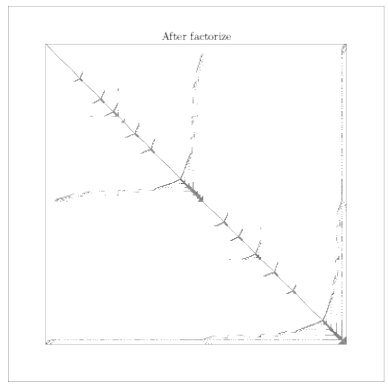


(a) Simulation frame



(b) Matrix Sparsity

A simulation frame from one of the simulations, and the sparsity pattern of the factored matrix, showing that good scalability can be achieved using direct methods.

A model of a tracked vehicle is described which reprents shoes, rollers, idler, sprocket and chassis, refered to as the *wheels* henceforth, as rigid bodies. The connections between shoes are represented as *relaxed*, but arbitrarily stiff hinge constraints, and they are attached to the chassis using planar constraints to prevent sideway slip. The shoes are modelled as thin boxes and are in dry frictional contact with the wheels and the terrain. The latter is modeled as a height field, and obstacles can be introduced with convex shapes or arbitrary triangle meshes. We use standard methods for collision detection and contact generation.

The normal foces of the terrain are relaxed constraint with a normal response law of the form $f = \epsilon^{-1} z^{\gamma}$, for $\gamma = 7$ and very small $\epsilon < 10^{-6}$. This is treated implicitly as all other constraints. The contact forces are computed by solving a Linear Complementarity Problem (LCP) formulation of Coulomb friction laws with a simple box approximation. We solve a sequence of Quadratic Programming problems to approximate the Coulomb conditions between normal and tangential forces. For this we use a non-smooth, undamped Gauss-Newton method which is in turn based on a special purpose symmetric indefinite direct factorization code Lacoursière et al. (to appear). The overall model of relaxed, stabilized constraints as well as single stage time stepping and constraint stabilization methods were presented previously Lacoursière (2007). Suffice to say here the stepper is stable against constraint drift.

There are other strategies available but none of these can work in real-time on arbitrary terrain Heyn (2009); Madsen et al. (2010).

A time step of 1/60 was used to produce 60Hz updates in real-time simulations for training systems. This was stable in all cases we considered, including extensive runs lasting hours with user interaction. The same models are used in optimization design of prototype bogeys and control systems for ride stabilization and the fidelity of was found sufficient. Such simplified models are not usable to design track shoes, or evaluate vibrarions or real vehicle as required in production. Other models are then necessary Heyn (2009); Madsen et al. (2010).

Our examples include, among others, a vehicle with 90 bodies, 80 of which are shoes. This introduces 90 hinge constraints, 80 planar constraints, and usually up to 50 contact constraints, i.e., a total of 1310 linear equations with same amount of unknowns on average, as well as more than 100 complementarity conditions for contact forces. These problems can be solved within 7ms an ordinary desktop computer with a 3GHz 64bit x86 family processor with four cores and sufficent RAM. Our solver is not yet parallelized. We also require 1ms to compute contacts between the shoes and the terrain and wheels.

Variants of the Projected Gauss-Seidel (PGS) relaxation are and are at the core of nearly all publically available multibody simulation libraries used for real-time interactive simulations. Experimentation with said libraries and our own PGS codes showed that such techniques can only handle vehicles with artificially low mass ratios, e.g., $2, 9$ and 350Kg for shoes, wheels and chassis, respectively. The simulations are only usable if one performs at least one hundred iterations per step and this takes between 5–10ms depending on the library. Our direct solver can handle the exact masses used in the real vehicle, namely, $10, 400$ and $10, 000$Kg for shoes, wheels and chassis, respectively, and the computational time mentioned above compares favorably. The benefit however is a very robust simulation, as the tracked vehicles can be driven over rough terrains for arbitrarily long times. PGS based simulations led to collapse of the vehicle, and the tracks often came off the wheels.

These results clearly that low order time-steppers with constraint stabilization techniques are viable for large multibody systems in real-time, and so are direct solvers applied to LCP formulations of dry frictional contacts.

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