Dynamic Multibody Simulation of a 6-DOF Robotic Arm

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Dynamic Multibody Simulation of a 6-DOF Robotic Arm

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Abstract. Based on the kinematic model with Cartesian structure, Newton-Euler like algorithm being employed to solve the nonlinear equations of motion and constraints in real-time application, and dynamic multibody simulation, a novel integrated design for a 6-DOF robot is investigated, and the interfaces required for the implementation of different computer aided engineering (CAE) tools used in the design is addressed [1].The presented method in this paper was analyzed and verified by the numerical and physical 6-DOF robot model, the result shows that the topologic projection method [2] is stable. The design experience accumulated will be very useful for the future product design.

Introduction

Prototypes are used for various goals such as communication in marketing, design validation, and industrialization, especially for test style, and technical functions [3]. The virtual prototype model of a 6-DOF(degrees of freedom) robot arm was set up in this paper, and the kinetic and dynamic simulation was analyzed by simulation in ADAMS. Several parts of the prototype were conducted analytically. And the results obtained are consistent with real conditions, so that not only the novel prototype but also the simulation is reasonable and believable, which means the analysis results obtained can be used in further cases.

Simulation Modeling

Algorithm. The topological projection algorithm [2] is used. Let v be a coordinator vector, s be a displacement, then we have $v = s'$, and acceleration $a = v' = s''$. Assuming that the number of the multibodies is n, the vector of coordinates of body i is $u^i = \begin{pmatrix} x^i \\ r^i \end{pmatrix}$, where $x^i = \left(x_1^i, x_2^i, x_3^i\right)^T$ is the vector of position coordinates of body i; r^i the vector of orientation coordinator; and ω^i the angular velocity. We usually assume $u = v$, and let f_b be additional constraints, and f_a be all constraints, then

$$f_a(u) = \begin{pmatrix} k \\ f_b \end{pmatrix} = 0, \tag{1}$$

and f_a's Jacobian matrix:

$$F_a = \frac{\partial f_a}{\partial u} = \begin{pmatrix} F \\ F_b \end{pmatrix} \tag{2}$$

For Euler parameters, $r^i = \left(r_0^i, r_1^i, r_2^i, r_3^i\right)^T$, and $f_b = \left(f_b^1 \ldots f_b^n\right)^T$,where $f_b^i\left(u^i\right) = \sum_{k=0}^{3}\left(r_k^i\right)^2 - 1$, and $i = 1 \ldots n$. Taking into account the perturbation factor of displacement $\Delta = S(u)\cdot\theta$, where θ is the minimal norm solution from : $F(u)\cdot S(u)\cdot\theta = -f(u)$, then we have $u = u_0 + \theta$, $u^i = u_0^{i-1} + \Delta^i$, and the i th iteration step:

$$\Delta^{i+1} = -S\left(u_0^i\right)\cdot F^T\left(u_0^i\right)\cdot\left[F\left(u_0^i\right)\cdot F^T\left(u_0^i\right)\right]^{-1}\cdot f\left(u_0^i\right) \tag{3}$$

And $-f_b(u) = -f_b(u_0 + \Delta) \approx f_b(u_0) + F_b(u_0)\cdot\Delta = F_b(u_0)\cdot S(u_0)\cdot\theta$.
When $f_b(u_0) = 0$, and $F_b(u_0)\cdot S(u_0) = 0$, then $f_b(u) = 0$ .Let $f(u)$ be the vector of scleronomic constraints $f(u)$ and its Jacobian matrix:

$$f(u) = f\left(u_0^i + \Delta^i\right) = 0, \tag{4}$$

$$F\left(u_0^i + \Delta^i\right) = \frac{\partial f\left(u_0^i + \Delta^i\right)}{\partial u} \tag{5}$$

Differentiating Eq.4, we have

$$f_v(u,v) = \frac{d}{dt}f(u) = F(u)\cdot u' = F(u)\cdot S(u)\cdot v \tag{6}$$

Let $\zeta = F\cdot S$, $f_v(u,v) = \zeta\cdot v$, and differentiate Eq.5 twice, we get

$$f_{vv}(u,v,v') = F(u)\cdot S(u)\cdot v' + \frac{\partial\left(F(u)\cdot u'\right)}{\partial u}\cdot S(u)\cdot u' + F(u)\cdot\frac{\partial\left(S(u)\cdot v\right)}{\partial u}\cdot u' = 0 \tag{7}$$

Let $\xi(u,v) = \frac{\partial\left(F(u)\cdot u'\right)}{\partial u}\cdot S(u)\cdot u' + F(u)\cdot\frac{\partial\left(S(u)\cdot v\right)}{\partial u}\cdot u'$, we get

$$\zeta\cdot v' = -\xi(u,v) \tag{8}$$

From Eq.8and Newton-Euler equations, let η be the outside forces, Γ be the mass matrix, and δ be the Lagrange multipliers, finally we can get the equations for motion:

$$\begin{pmatrix}\Gamma(u) & \zeta^T(u)\\ \zeta(u) & 0\end{pmatrix}\cdot\begin{pmatrix}v'\\ \delta\end{pmatrix} = \begin{pmatrix}\eta(u,v)\\ -\xi(u,v)\end{pmatrix} \tag{9}$$

where $\Gamma = S^T\cdot\Gamma_0\cdot S$, $\eta = S^T\cdot\left(\eta_0 - \Gamma_0 S v\right)$, and $F_A = \frac{\partial\left(F_A(u)\cdot v\right)}{\partial u}\cdot v$.

Robotic Arm's Structure. A 6-DOF robotic arm is composed of a base, rotational parts, snatch part, joints, and driving parts. A typical hierarchical 6-DOF robotic arm model is shown in Fig. 1.

Virtual Prototype Modeling and Kinematical Simulation Using ADAMS [4]. It is first important to create the parametric simulation model in a CAD system, for example Pro/E, which must contain the mass, material properties, etc. Then using Mechanism/Pro plug-in under Pro/E environment to define the rigid bodies, and build constrains. There are 44 rigid body groups, 44 constraints, 6 DOF, and 6 motivations for the arm. Assuming the hierarchy and geometry information of the actual model can be exported successfully, then the simulation model can be translated into ADAMS. The integrated virtual and physical prototype is shown in Fig. 2.

The model is formed by gluing six subsystem models: a hand model, a wrist model, a fore-arm model (joined with wrist), a lower-arm model, a waist model and a base model. ADAMS is a kind of software for kinematical simulation of mechanical structure, where the model is unnecessary to be modeled very detailed in the scenario. The results would be convincing and promising when the model is applied accor-dingly physical parameters [5] using the algorithm above.

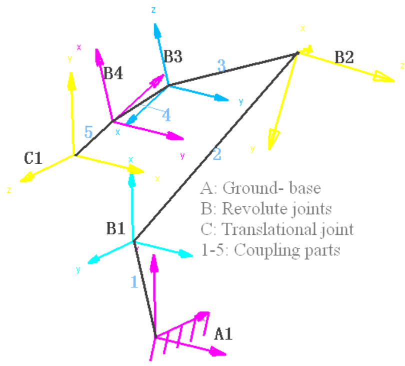


Fig.1 Geometry model

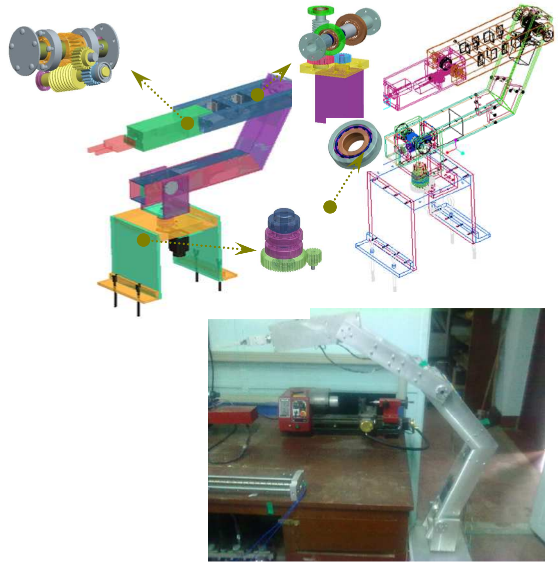
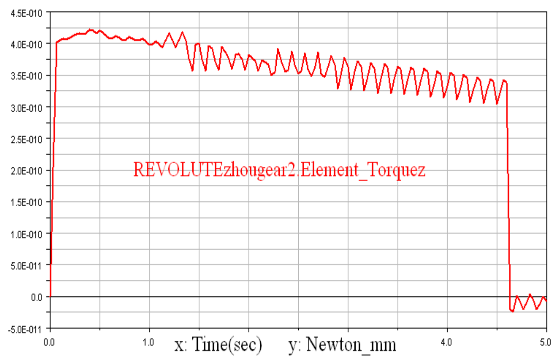


Fig.2 The virtual prototype, linestyle mode and physical prototype

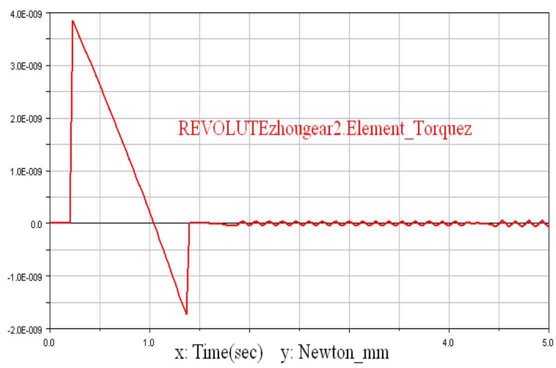
Simulation Result

Simulate the model by steps with starting up different number of motors [6]. Simulation output can be picked up in ADAMS. We set simulation time to be 5s, and record the simulation result.

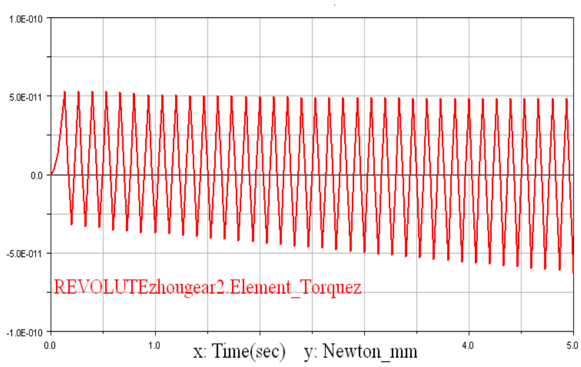
From Fig 3(a), under the first working condition driven by only one electric motor, the result shows that the driven gear encountered strongly fluctuations on the basis of torque at both the beginning and end of the motion.



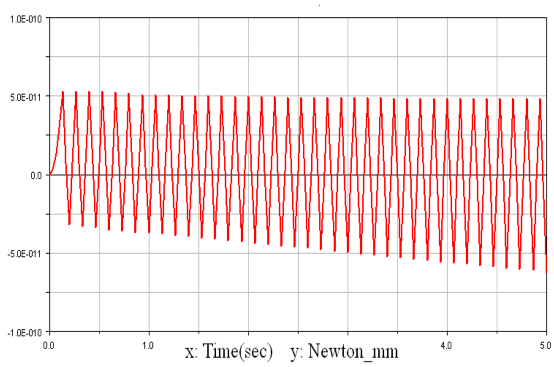
(a) driven by 1 electric motor



(b) driven by 2 electric motors



(c) driven by 3 electric motors



(d) driven by 4 electric motors

Fig.3 Time evolution in torque for a driven gear

In Fig 3(b), under the second working condition driven by two electric motors, the result shows that it just fluctuated drastically at the beginning, but ran flatly afterward, which was normally caused by gear clearance and impact at the beginning, coupling function after.

From Fig 3(c) and Fig 3(d), driven by 3 or more electric motors, the results show that they fluctuated periodically steady, only the peak values amplified very slightly, which was caused by the inertial of the mechanism.

The driving electric motors for this robotic arm are in parallel arrangement with strong coupling, so accumulated errors can be avoided for the location and orientation, both of which are very important indexes for the robotic arm snatching work pieces, as far as precision being concerned.

The simulation results show that the corresponding outputs comply with the prospective results. So the design meets requirements.

Conclusion and Future Work

This paper presents the concept of designing a novel 6-DOF robotic arm. A virtual simulation model for the robotic arm is developed. The real and virtual systems are implemented in parallel with the multibody dynamics model in Cartesian based on topologic projection like algorithm [7]. It has been shown that the kinematic and static properties are very good. Therefore, drawbacks of the concept are found in the displacement of the cubic workspace and in the possible vibration of the arms [8] under some special working conditions, and it is not also completely matched with the actual working situations. Because some parts of the arm can not be always taken as rigid-body, we need to take into account of softbody under special working conditions to simulate. In the future work, emphasis will be on the reliability analysis.

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