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Optimizing Parameters Using Firefly Algorithm in Hydraulically Actuated Multibody Systems

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EXTENDED ABSTRACT

1 Introduction

In the field of multibody system dynamics, Kalman filter based approaches have recently [1], [2] been used to estimate the parameters of a mechanical system. Parameter estimation, through Kalman filters, can be challenging, because the unknown parameters may be function of other system variables and can be expressed only via complicated non-linear variations [1]. However, in general, the parameters are treated as constants in the simulation world. The functions and first derivatives defining the unknown parameters are not always available in practise. Furthermore, Kalman filters require the variances of unknown parameters [1], which makes the parameter estimation process even more complex. An alternative solution could be the use of Swarm intelligence technique [4] in determining the parameters. As a proof of concept, in this study, a swarm intelligence algorithm named as Firefly Algorithm is applied to optimize the parameters of a hydraulically actuated fourbar mechanism. The application of optimization algorithm is explained using the simulation models of mechanism which are named as real model and optimization model. The modelling errors are introduced in the force model of the optimization model. The hydraulic parameters and mass are optimized, since the information of such parameters is difficult to obtain in the real-world applications.

2 Hydraulically actuated multibody model

The dynamics of closed loop systems can be described in terms of independent acceleration vector $\ddot{\mathbf{z}}^{\mathrm{i}}$ using the double-step semi-recursive formulation as [3]

$$\mathbf{R}_{\mathrm{z}}^{T}\mathbf{R}_{d}^{T}\mathbf{T}^{T}\overline{\mathbf{M}}\mathbf{T}\mathbf{R}_{\mathbf{d}}\mathbf{R}_{\mathrm{z}}\ddot{\mathbf{z}}^{\mathrm{i}} = \mathbf{R}_{\mathrm{z}}^{T}\mathbf{R}_{d}^{T}\left(\mathbf{T}^{T}\overline{\mathbf{Q}} - \mathbf{T}^{T}\overline{\mathbf{M}}\mathbf{D}\right), \tag{1}$$

where $\mathbf{R}_{\mathrm{z}}$, $\mathbf{R}_{d}$, $\mathbf{T}$, $\overline{\mathbf{M}}$ and $\overline{\mathbf{Q}}$ are the velocity transformation, block-diagonal, constant path, composite mass matrices and vector of the composite forces, respectively, and $\mathbf{D} = \mathbf{T}\mathbf{R}_{\mathbf{d}}\begin{bmatrix} -\left(\mathbf{\Phi}_{\mathbf{z}}^{\mathrm{d}}\right)^{-1}\left(\dot{\mathbf{\Phi}}_{\mathbf{z}}\dot{\mathbf{z}}\right) \\ \mathbf{0} \end{bmatrix} + \mathbf{T}\dot{\mathbf{R}}_{\mathbf{d}}\dot{\mathbf{z}}$. Here, $\mathbf{\Phi}_{\mathbf{z}}^{\mathrm{d}}$ and $\dot{\mathbf{\Phi}}_{\mathbf{z}}$ are the jacobian matrix of constraint equations with respect to the vector of dependent joint positions and the first time derivative of the jacobian matrix of constraint equations with respect to the vector of joint position. The lumped fluid theory can be used to model the vector of pressure $\mathbf{p}$ in the hydraulic actuators. The states of a hydraulically actuated multibody system can be expressed as $\mathbf{x} = \begin{bmatrix}\mathbf{z}^{\mathrm{i}} & \dot{\mathbf{z}}^{\mathrm{i}} & \mathbf{p}\end{bmatrix}^{T}$.

3 Firefly Algorithm

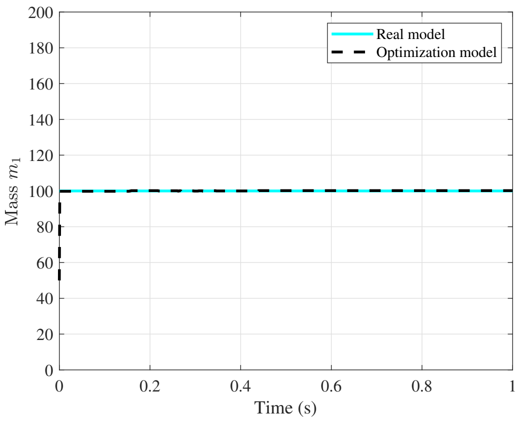
The states of a mechanical system can be updated as [4],

$$\mathbf{x}_{k+1} = \mathbf{x}_{k} + \beta_{0}e^{-\gamma r_{kh}^{2}}(\mathbf{y}_{k} - \mathbf{x}_{\mathbf{k}}) + \alpha\boldsymbol{\epsilon}_{k}. \tag{2}$$

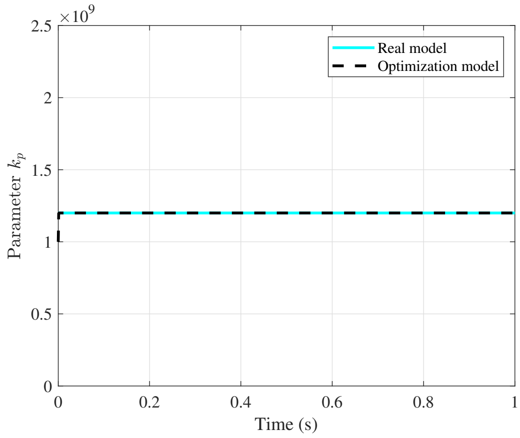
where the second term $\beta = \beta_{0}e^{-\gamma r^{2}}$ defines the attraction. The third term is randomization with α being the randomization parameter, and $\boldsymbol{\epsilon}_{k}$ is a vector of random numbers drawn from a Gaussian distribution or uniform distribution. Here, β_{0} is the attractiveness at $\mathbf{r}$ = 0 and $\mathbf{r}$ is calculated according to [4].

4 Results and Conclusion

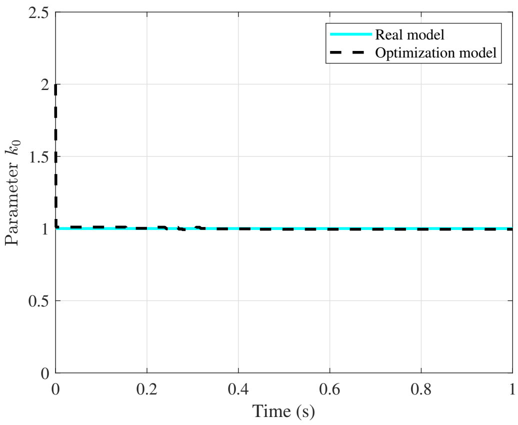
The detailed modeling of the hydraulically driven four-bar mechanism can be found in [1]. Augmented state vector $\mathbf{x} = \begin{bmatrix} s & \dot{s} & p_1 & p_2 & m & k_p & k_0 & C_d \end{bmatrix}^T$ defines the state and parameters of mechanism. Here, s and $\dot{s}$ are the actuator position and velocity, p_1 and p_2 are the system pressures, m_1 is the mass of first body in mechanism, k_p, k_0 and C_d are the hydraulic parameters. Figure 1 demonstrates that m_1, k_p, k_0 and C_d are accurately optimized. This study will enable the synchronization of simulation with the real world.



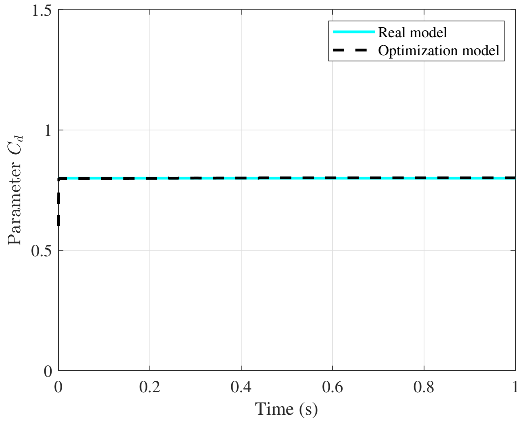
(a) Optimization of bar 1 mass m_1 (kg).



(b) Optimization of hydraulic parameter k_p (Pa).



(c) Optimization of hydraulic parameter k_0.



(d) Optimization of hydraulic parameter C_d ($\frac{m^3}{s\sqrt{\text{Pa}}}$).

Figure 1: Optimized parameters m_1, k_p, k_0 and C_d of mechanism with the application of Firefly Algorithm.

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