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Special Genetic Identification Algorithm with smoothing in the frequency domain

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ABSTRACT

Due to the increase in speed and lightweight construction, modern robots vibrate significantly during motion. Thus, accurate mechanical modeling and detailed controller behavior is essential for accurate path planning and control design of robots. For the suppression of undesired vibrations detailed models are used to develop robust controllers. Least square identification methods require deep insight in the analytical equations and thus are not very suitable for identification of different highly nonlinear robot models. Recently, we presented our genetic parameter identification in Brussels, Ludwig and Gerstmayr (2011). It minimizes the error of measured and simulated quantities. Highly efficient models in the multibody system tool HOTINT lead to short computational times for various simulations with different parameters. The simulation models can easily be assembled by engineers without a detailed knowledge of the underlying multibody system. As drawback of genetic optimization, many sub-minima were detected. Many simulations were required for the determination of the global minimum. Our current approach was to extend our previous algorithm. Measured and simulated quantities are transformed into the frequency domain. In contrast to previous work, Ludwig and Gerstmayr (2013), amplitude spectra of measured and simulated quantities are smoothed prior to the L2-norm computation. The presented method is tested using small scale test problems as well as real robots. Smoothing in the frequency domain leads to a smaller number of simulations needed for obtaining higher accuracy. It turns out that the presented algorithm is more accurate and precise than a standard algorithm and reduces the computational cost.

1. Introduction

The investigation of undesirable oscillations which occur during the complex motions of industrial robots using only measurement data is a difficult task. Some of the possible reasons for derivations of planned trajectories are the limitations of drive torque, motor current or voltage. Some other reasons are excitations of the Eigenfrequencies during the motion of the robot (as a result of the physical parameters of the mechanical components as well as the electrical parts e.g. the controller circuit). Mathematical models of the coupled electrical and mechanical system are required to get a deep insight into the physics and the source of the oscillations as well as derivations with respect to the planned path. At this point, it must be emphasised that only the use of the original robot controller software and the correct physical parameters lead to accurate models. An overview of a real robot controller system including the path planning Motion Control Unit (MCU) is depicted in Fig. 1. In order to fully understand the physical effects on the robot, we built our own robot simulator. It was programmed within the object oriented multibody code HOTINT, see Gerstmayr and Stangl [5]. The simulated mechanical links of robots with serial kinematics were assembled using the constraint equations, see Ludwig et al. [10]. The generalized force vector of the motor torque was projected into the Newton–Euler equations using the principle of virtual work. The MCU uses four-dimensional matrix transformations to define the position and the orientation of the robot joints – according to Denavit and Hartenberg [3]. In order to define bodies according to the definitions in HOTINT, the transformations are converted into redundant Euler Parameters. To identify the arbitrary uncertain parameters of the robot a novel algorithm was developed. To apply our algorithm to non-linear differential equations (e.g. from the friction models or non-linear drive stiffness), the zero order is selected for the algorithm. Unlike the first and the second order algorithms, the zero order algorithm does not require any gradient information or Hesse matrix from the cost function, see e.g. Bestle [2] or Farkas et al. [4]. The unknown parameters of the simulation are generated by our novel algorithm

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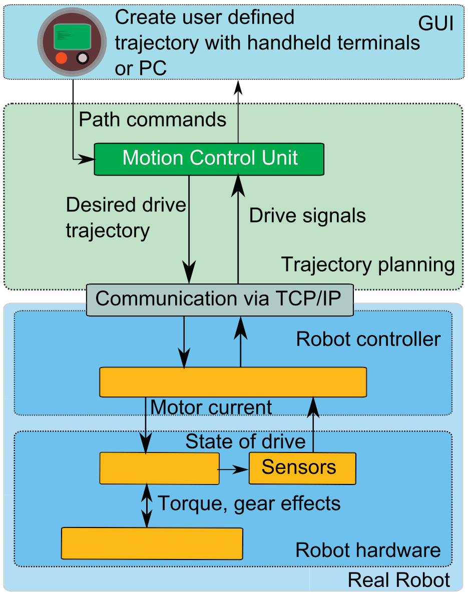

Fig. 1. Motion control process of a real robot. The trajectory planning and the drive controllers communicate via TCP/IP. The virtual version of the Motion Control Unit uses the same interface and is coupled with our robot simulator. Our robot simulator allows the simulation of many different kinematic types of robot as well as the mathematical models of the controller circuits, motors, sensors, robot links and robot joints.

Ludwig and Gerstmayr [11] for the automatic parameter identification (shortly an identification) using the time domain. The algorithm is based on the theory of genetic optimization – a theory which is well suited for searching optimal solutions for the real world problems, see Begambre and Laier [1] and Hemmatian et al. [6]. The cost function – minimized by the identification – is the sum of the L2-norms of the difference between the measured and the simulated outputs in the time domain. Many multiple minima appeared in the distribution of the cost function and lead to a number of optimization steps. Parseval's Theorem guarantees that the L2-norm of the cost function in the time domain and the frequency domain is equal. In order to benefit from this fact, the Discrete Fourier Transform (DFT) was implemented into our identification. Compared to the time domain, the weight functions in the frequency domain lead to lower values of local minima of the cost function. This technique was successfully applied to identify several parameters of a test example with well-known nominal parameters as well as to a real robot, see Ludwig and Gerstmayr [12]. The disadvantage of this technique is that the weight functions in the frequency domain must be selected very carefully.

The main point of this paper is the following: instead of employing the user defined weight factors for the identification, compare Ludwig and Gerstmayr [12], a smoothing operation is applied before the evaluation of the L2-norm. First, we test the effect on the distribution of the cost function on a simple example of a PT2-system with well-known parameters. Afterwards we identify several parameters of a robot using the smoothing technique in the frequency domain. One limitation of our method is that the zero order identification does not use derivatives of the cost function with respect to the parameters. This fact might lead to higher computational efforts in the case of simple problems with no discontinuities and non-linearities (compared to the methods using gradients or the Hesse matrix). On the other hand, our zero order identification is well suited for the real problems where these effects should not be neglected. Another complication of the higher order algorithms is a strong dependency of the derivative on a small differentiation parameter which is used for the computation of the differential quotient. If the magnitude of the selected differentiation parameter is not sufficiently small, the gradient information might be incorrect. In some special cases, the numerically computed gradient has an opposite direction to the real gradient, see Zielkinsky and Neumann [13]. The higher computational effort in our zero order identification is therefore compensated by a more robust behavior. Due to the fact that the identification is based on the theory of genetic optimization, the user has to choose a sufficient number of initial parameter values, surviving parameters, children and realistic limits for the parameter space – in which the optimal parameters are searched Ludwig and Gerstmayr [11]. The distribution of the DFT depends on the length of the time window which is defined by the duration of the simulation or a time window and the sample frequency. If the time values of the simulation have no equidistant time interval, the values are interpolated in order to get a constant sample frequency. The ratio of the sample frequency and the number of samples within the time window define the frequency step of DFT.

The new approach discussed in our paper should lead to a simplification of the identification and to a higher accuracy of the identified parameters in comparison to the methods using only the L2-norm of the cost function in the time domain. The presented paper extends the existing literature in the field of robotics which employs genetic algorithms to the best of the author's knowledge. In contrast to Lei et al. [8], Kaoru et al. [9] and Hong et al. [7], where optimal paths of robots are investigated, we identify unknown physical parameters of robots to obtain a realistic behavior of the robot simulation. It is well-known, that the kinematic equations for Tripod – robots lead to very ill-conditioned problems. After applying our Special Genetic Algorithm we were able to successfully identify simulation parameters of a Tripod. In comparison to the Particle Swarm Optimization algorithm, our Special Genetic Algorithm lead to higher accuracy and precision of the cost function residual and as well a lower computation effort and a lower number of cost function evaluations, see Section 4.

2. Calculation and theory

2.1. Simulation with interface to original controller software

The trajectory planning is called Motion Control Unit (MCU). It is suitable for various applications – e.g. high speed pick-and-place motions, painting and sealing operations. Furthermore, experience with complicated tasks such as accurate compliance of limits concerning torque or acceleration, tracing of moving objects and use of model-based torque by means of feed-forward control, reduce path deviations. The MCU is available in a virtual version as well. Our robot simulator and the virtual MCU were coupled in a co-simulation via TCP/IP. An oscilloscope service is also a part of the real and virtual controller software. It is used for the visualization of the drive and the controller signals, compare Fig. 1.

The interface of the coupled simulation fulfills three main tasks: the initialization of the simulation, the transfer of the reference signals and the synchronization of the MCU as well as our robot simulator. After the start of our robot simulator and the MCU, the initial reference values are transferred to the robot simulator and the dynamic model is initialized with these values. The numerical simulation is then started and the reference signals are transferred to our simulator – they represent the input of our control circuits in the robot simulator. The reference values are updated at a certain point in the time – dedicated to the update time step – and interpolated in the intervals between the points in time. An extended DLL of the oscilloscope service was included in our robot simulator – it is necessary for retaining a consistent connection to the data server of the MCU.