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Separating Concerns in Robot Arm Motion Path Planning

Evgeniy Krastev*

Faculty of Mathematics and Informatics, St Kl Ohridski University of Sofia, Bulgaria

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***Corresponding author:** Evgeniy Krastev, Faculty of Mathematics and Informatics, St Kl Ohridski University of Sofia, Bulgaria

Abstract

The current state of robotic operating systems and application software does not offer enough ease of programming, reusability and adaptability to changes. Most of the algorithms for motion control are implemented in terms of older programming languages and concepts. This paper illustrates the advantages of employing object-oriented principles in designing computational algorithms in robotics. The novelty in the proposed approach is the application of the Separation of concerns principle in solving the inverse kinematic problem for motion control of redundant robot arms along a prescribed path in task space. The obtained model is ready for software implementation that adapts to changes in geometry and motion control subject to different quality criteria.

Keywords: Robot motion, separation of concerns principle, inverse kinematics, kinematic control

Introduction

Statistical reports denote an impressive sales growth of industrial and service robots at the end of 2018. The greatest demand for industrial robots is established in the metal, electrical/electronics and automotive industries, while medical robots are the most valuable service robots [1,2]. Robot arms are usually employed in these subject areas for executing repetitive tasks with high accuracy. Most recent innovative technical improvements of such tasks, for example in welding and painting, require a natural kind of movement of the robot arm along a preplanned path in task space or in joint space. This requirement for more flexibility, precision and optimization of the motion is satisfied by introducing redundant degrees of freedom in the design of the robot arm kinematic structure [3]. It allows to obtain quality in the execution of the work operation barely achievable manually.

Kinematic redundancy provides a solution to a variety of problems like obstacle avoidance, minimization of execution time or energy consumption or satisfying the hard constraints on the displacements in the joints in motion control [4-7]. On the other side, the precision of repetitive task executions depends on how the motion control algorithm deals with the so called “unmodelled dynamics”. For example, the Iterative learning Control algorithm appears to be one of the fastest convergent with respect to a given accuracy algorithms that consider the “unmodelled dynamics” in motion control along a preplanned path in joint space [8,9].

The inherent computational complexity of such motion planning algorithms and the respective models of multibody systems require efficient software implementations making use of multithreading and event- driven data sources. Unlike the object-oriented principles and the best practices adopted in modern software industry, most of such software implementations still rely on structured programming languages and concepts [10]. Besides, existing software solutions in robotics are tightly coupled in the geometrical structure and the hardware of the robotic system. It is also not so easy to hide the high complexity of an algorithm for motion planning in terms of object-oriented concepts [11]. Therefore, the ease of programming, software reusability, portability and maintenance remain among the greatest challenges in robotic software development.

Separating Concerns in Motion Path Planning

The objective of this paper is to illustrate the advantages of using object- oriented principles and in particular, the Separation of concerns principle, in resolving the current challenges in robotic software design. In robotics we can outline several major concerns at a higher level, for example, mechanical engineering, electrical engineering and computer science [12]. At a lower level we can identify several other concerns, like motion and geometry in mechanical engineering. The application of the Separation of concerns principle allows to create a well-ordered model of independent components addressing a separate concern so that the model as a whole is easy to adapt to change. In the following we will employ this principle in formulating a mathematical model for kinematic control of the end- effector of a redundant robot arm along a prescribed path in task space.

For clarity, consider a redundant robot arm with n degrees of freedom and a smooth geometrical curve γ, defined in a m–dimensional task space ($m \le 6$), where γ is parametrically defined in the interval [$\lambda 1$, $\lambda 2$] and $m<n$. Denote by *Int QM* the interior of the set $Q_M = \{q = (q_{1,...,}q_n): q_i \in [a_i, b_i] \text{ for } i = 1,2,3,..,n\}$ of configurations of the joint variables. Without loss of generality we assume that the points of γ belong to the workspace W of the robot arm or in other words, $\Upsilon: \lambda_1, \lambda_2 \to F(Int\ Q_M)$, where $F(Int\ Q_M)$ represents the forward kinematics of the robot arm. Unlike existing solutions to the inverse kinematics, we note the existing clear distinction between geometrical and motion parameters in task space. The motion parameters of the work task are given with respect to the points of γ, while γ and $F(Int\ Q_M)$ represent the geometrical aspects of the problem. Obviously, the motion parameters can change without the need of changing γ. Once γ is given, the end- effector can execute a variety of different motions along this path. These two groups of parameters reflect two different concerns in executing the work task. It is natural to retain this kind of separation of concerns in the space of configurations *Int QM* of the robot arm. Then it would be possible to control the motion in joint space in an analogous way to controlling the motion over a geometric curve in task space. For this reason, we extend by one the dimension of the joint space, where the parameter $qn+1$ represents parametrically $\Upsilon = \Upsilon(q_{n+1}), q_{n+1} \in [\lambda_1, \lambda_2]$. Further on we refer to $Q = IntQ_M \times R$ as extended space of configurations, where we discover the smooth manifold

$$B = \{q^* = (q, q_{n+1}): F(q) - \Upsilon(q_{n+1}) = 0, q^* \in Q\} \quad (1)$$

This manifold represents the geometrical concerns of the inverse kinematics in the extended space of configurations the same way as γ represents these concerns in task space. Indeed, all the motions $q^*(t) = (q(t), q_{n+1}(t)), t \in [t_1, t_2]$ of the robot arm that satisfy the assigned geometrical parameters of the work task, belong to $\mathcal{B}$. Among these motions are also motions that satisfy the motion parameters of the assigned work task. In our previous research [3] we obtain $q^*(t)$ as a solution to the following differential equation:

$$\dot{q}^* = K\hat{U}_t, t \in [t_0, t_1] \quad (2)$$

where $\hat{U}_t = (u^T, u_{n+1})^T : \mathcal{B} \to R^{n+1}$ is the assigned motion control, K is a $(n+1)x(n+1)$ block matrix representing only the geometrical aspects of the robot arm and the assigned work task.

Conclusion

The current state of robotic operating systems and application software does not offer enough ease of programming, reusability and adaptability to changes. Most of the algorithms for motion control are implemented in terms of older programming languages and concepts. This paper illustrates the advantages of employing object-oriented principles in designing computational algorithms in robotics.

The novelty in the proposed approach is the application of the Separation of concerns principle in solving the inverse kinematic problem for motion control of redundant robot arms along a prescribed path in task space. The obtained model is ready for software implementation that adapts to changes in geometry and motion control subject to different quality criteria.

Discussion

The introduction of the extended space of configurations allows to separate motion and geometry concerns in analogous way these concerns are separated in task space. It is easy to adapt the software implementation of (2) to independent changes in motion and geometry. Both the curve γ and the manifold $\mathcal{B}$ (1) are fixed geometrical structures. They are determined by the kinematical structure of the robot arm and the assigned geometrical path in task space. On the other hand, this representation allows to control the robot motion over $\mathcal{B}$ in a similar way we control the motion over γ in task space. For example, in related research we introduce motion control in sliding mode taking in consideration the constraints in the joints [6]. Ongoing research efforts focus on extending these results in an Iterative Learning Control model for motion control [9,8].

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