A Simple Method for Generating Smooth Robot Arm Motion

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Abstract. A computer algorithm is described for generating smooth robot arm motion in task space trajectories. The algorithm is based on observations and analysis of task space trajectory profiles produced by human operators manually, using a six degree-of-freedom position hand controller. The algorithm is formulated in the velocity-position phase space and employs a harmonic (sinusoid) base function in the phase space. Hence the name: Harmonic Motion Generator (HMG). Performance capabilities of HMG are illustrated, including its combination with force-moment sensor based active compliance control and with task space (Cartesian space) position servo control.

1 Introduction

Robot arm motion can be generated in two ways: manually by an operator using a suitable manual control input device, and algorithmically by a computer program. A novel algorithmic motion generator technique which circumvents the usual time-based robot arm motion generators, normally acting in the robot arm’s joint space, is briefly described in this paper. The described novel technique offers a motion generator capability which closely resembles the kinematical profiles of trajectories generated by operators manually in position control mode acting in the Cartesian task space. Indeed, the novel algorithmic technique is based on observations and analysis of manually generated robot arm trajectories in position command mode in the task space.

First a brief analysis of manually generated trajectories is presented in position control mode. Then an algorithmic scheme is formulated matching the profile of manually generated trajectories in position control mode in the task space. Performance results are then presented illustrating capabilities of the algorithmic control scheme.
2 Manually Generated Trajectories

Manually generated trajectories in position control mode express much more than just position commands or position profiles versus time, they implicitly also express both velocity and acceleration and deceleration profiles. Using a six-degree of freedom Force Reflecting Hand Controller (FRHC) of the Jet Propulsion Laboratory (JPL) Advanced Teleoperator Laboratory, many series of position versus time motion profiles were generated and recorded for moving the robot hand from point A to point B in a distance of about 50 cm in position control mode. A close inspection and analysis of manually generated robot arm trajectories in position mode of control revealed important features as seen in the phase space.

1. The trajectories have three kinematical segments: acceleration after start of motion, constant velocity, and deceleration to stop. The significant element is the constant velocity segment.
2. In the quoted motion range, the acceleration/deceleration segments cover about 5 cm distance in about 0.5 sec. time.
3. The operator’s hand motion is not controlled by a clock (or time): there are some time variations for a fixed distance. The operators rather observe the distance to be traveled and start the deceleration accordingly.
4. The start and stop of motion are gradual but definite.
5. The transition from acceleration to constant velocity and from constant velocity to deceleration is very smooth, without jerks.
6. The maximum comfortable velocity for operator’s hand motion is about 20 to 25 cm/sec.
7. The velocity-position phase diagrams of manually generated trajectories in position control mode resemble an “augmented” harmonic (sine) function. The notion “augmented” refers to the second (constant velocity) segment of the trajectory. The notion “harmonic function” refers to the first quadrant of a sine function for the acceleration segment and to the second quadrant of a sine function for the deceleration segment of the trajectory.

3 Algorithmically Generated Trajectories

Based on observations and analysis of manually generated trajectories in position control mode outlined above – and specifically defined under point (7) there – an “augmented” Harmonic Motion Generator (HMG) algorithm with sinusoidal velocity-position phase space function profile was formulated and implemented at JPL. For a straight line motion, for instance, the HMG only needs three parameter values to be specified by the operator or, in case of an automated system, by a higher level program: i) The total distance to be traveled. ii) The maximum constant velocity to be attained. iii) The distance to be used for acceleration and deceleration.