Dual Arm Manipulation using Constraint Based Programming

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I. INTRODUCTION

For robotics to move from the factory floors to unstructured domestic environments, progress is needed in several areas of robotics technology. One such area is dual arm manipulation, where the human-like structure of a robot, such as the one in Figure 1, is exploited to perform tasks in environments originally intended for humans, as explained by [1]. In this paper, we present a technique for online generation of dual arm trajectories using constraint based programming based on bound margins. Using this formulation, we take both equality and inequality constraints into account, in a way that incorporates both feedback and feedforward terms, enabling e.g. tracking of timed trajectories in a new way.

The potential benefits of endowing robots with dual arms fall into four main categories. First, using tools and workflows designed for humans is easier if the kinematic structure of the robot is similar to a human. Second, teleoperation is easier if the robot is similar to the operator. Third, the use of the two arms can either provide additional strength and precision by cooperating as a parallel manipulator, or provide flexibility and speed by doing two separate tasks simultaneously. Fourth, the two arms are able to perform task that are inherently bi-manual, i.e., tasks that require motion of both arms to be carried out efficiently.

The strength of constraint based programming is that it facilitates the formulation and solution of a wide range of robot control problems, where a number of different, possibly contradicting constraints, or objectives, needs to be taken into account. In this paper, we will present a new variation on constraint based programming, and apply it to do online dual arm manipulation.

The main contribution of the present work is the theoretical extension of margin based constraint based programming using inequality constraints, to also include time dependent equality constraints in a compact and uniform way. In order to demonstrate the applicability of the proposed approach to a dual arm problem, we take a bi-manual dish washing task as a proof of concept example. We model the dish washing task with specified contact force with a set of time dependent equality constraints as well as one more inequality constraint and a set of secondary constraints with another set of inequality constraints. We treat these constraints with the proposed method and the result is verified both in simulation and on a physical robot platform. The task function values from the experiment are later plotted in Figure 5.

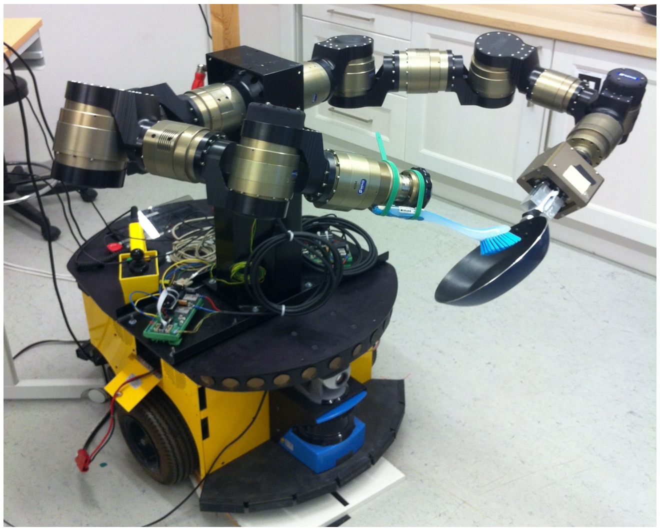

Fig. 1: The robot setup performing a dual arm task

II. A NEW VARIATION ON CONSTRAINT BASED PROGRAMMING

In this section we will describe the proposed version of constraint based programming using bound margins. The inequalities part of the proposed approach was described in detail [2]. Here we will adopt the basic ideas and add equality constraints to the formulation. We aim to find a feasible *good enough* solution for the primary and secondary constraints with the following online (local) controller to generate a new control at each time step:

Problem 1:

$$\begin{aligned} \min_{u} \quad & \dot{f}_j(q(t),u,t) + u^T Q u, \; j \in I && (1)\\ \text{(s.t.)} \quad & \dot{f}_i(q,u,t) \le -k_i(f_i(q,t)-b_i), \; \forall i \in I_{ie}, && (2)\\ & \dot{f}_i(q,u,t) = -k_i(f_i(q,t)-b_i), \; \forall i \in I_{e}, && (3)\end{aligned}$$

where k_i are positive scalars and Q is a positive definite matrix. In the spirit of [3], we note that the above problem is in fact a Quadratic Programming (QP) problem as is stated in the following Lemma.

Lemma 1: Problem 1 is equivalent to the following QP

$$\begin{aligned} \min_u \quad & c^T u + u^T Q u && (4)\\ \text{s.t.} \quad & A_{ie} u \le k_{ie}(b_{ie} - f_{ie}) - h_{ie} && (5)\\ & A_e u = k_e(b_e - f_e) - h_e && (6)\end{aligned}$$

where $c = \frac{df_j}{dq}$, and each row of $A_{ie}, A_e, \; b_{ie}, b_e, f_{ie}, f_e, h_{ie}, h_e$ contains the corresponding parts of $\frac{df_i}{dq}, b_i, f_i, \frac{\partial f_i}{\partial t}$ respectively.

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III. EXPERIMENTS AND SIMULATIONS

In this section we present the results of both Matlab simulations and real experiments conducted on the dual arm robot in Figure 1. We first compare the theoretical noise free (simulation) performance and the real hardware performance through a contact force free bi-manual pan cleaning task. Then we extend the hardware experiment by adding force feedback, compensating for the geometric model imperfections. The simulations aim to validate both the feasibility of the proposed solution and its ability to generate solutions with different convergence speed k.

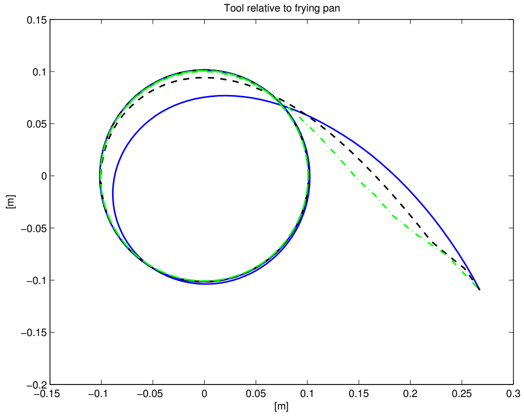

Fig. 2: The simulated motion of the cleaning utensil in the frying pan, projected onto the frying pan plane. (blue: $k = 0.2$, black: $k = 0.5$ and green: $k = 1$.)

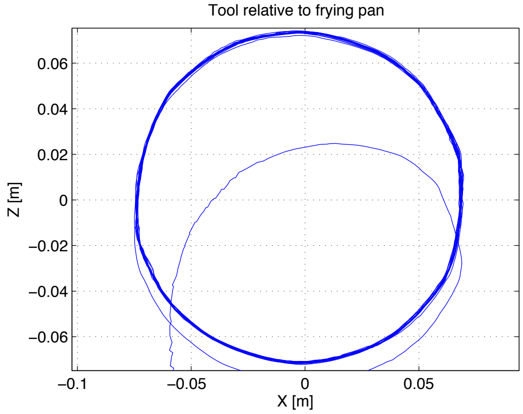

Fig. 3: The trajectory of the hardware experiment, as defined in the frying pan coordinate frame.

In the first simulation (green dash-dotted) we have used $k_i = 1, \forall i$ in the second (black dashed) $k_i = 0.5, \forall i$ and in the third (blue solid) $k_i = 0.2, \forall i$. The resulting motion, in all three examples, of the cleaning utensil tip relative to the frying pan is shown in Figure 2. As can be seen, due to the use of different parameters the cleaning utensil approaches the pan at different speed but traces out the same circular pattern. Running the algorithm on the dual arm manipulator of Figure 1, we got the trajectory shown in Figure 3. All parameters were the same, except that we only used one value of the parameter $k_i = 0.6$, and moved along the circular path at a higher velocity. Then we add a contact force control to the same algorithm and change the parameters to achieve even faster constraint convergence.

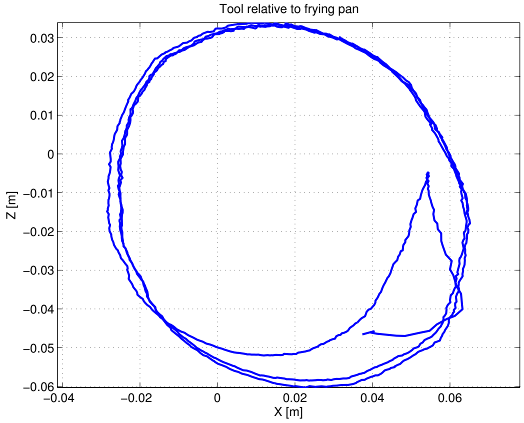

Fig. 4: The trajectory of the hardware experiment with contact force, as defined in the frying pan coordinate frame. It deviates from the perfect circle shown in Figure 3. However it gives us guaranteed contact as indicated by the force curve shown in the fifth plot of Figure 5.

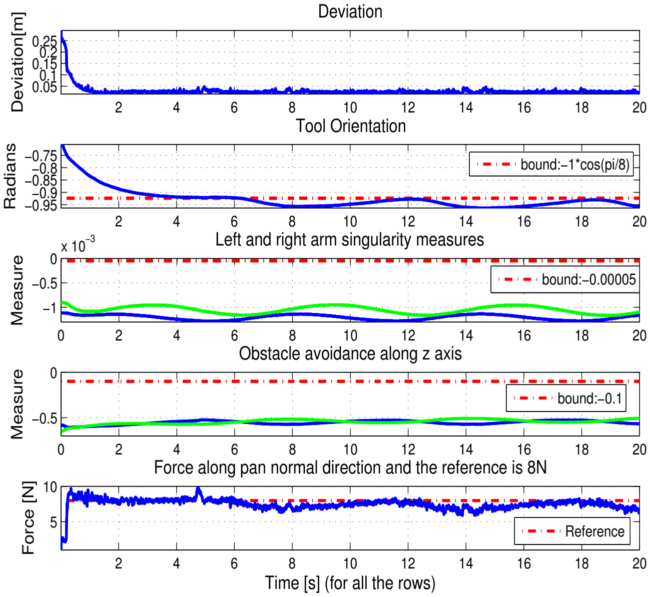

Fig. 5: Time evolution of the functions $f_i(q)$ of the hardware experiment with force control.

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