A Model for Imitating Human Reaching Movements *

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ABSTRACT

We present a model of human-like reaching movements. This model is then used to give a humanoid robot the ability to imitate human reaching motions. It illustrates that having a robot control similar to human control can greatly ease the human-robot interaction.

Categories and Subject Descriptors: I.2.9 Robotics: Kinematics and dynamics

General Terms: Algorithms

1. INTRODUCTION

The ability of primates to match observed actions to their own lies arguably at the heart of social interactions. Bringing robot movement control closer to human movement control is therefore likely to considerably ease human-robot communication. Indeed, a robot with a human-like control may be given the ability to interpret human actions in terms of its own actions and thus better "understand" them. Conversely, humans are likely to better enjoy interactions with robots that seem "natural" to them.

It has been argued that human movements are controlled by dynamical systems acting on goal-relevant variables [4]. Assuming this hypothesis to be true, bringing robot control closer to human control amounts to designing dynamical systems that are similar to those controlling human movements. Having those similar control systems, "understanding" an observed movement reduces to inferring the input of the dynamical system that produces this movement. This inference process is guided by various clues, among them the movement kinematics, the environment and the context.

In this report, we illustrate this hypothesis in the very simple setting of goal-directed reaching movements. We present a biologically inspired model of reaching movement expressed as a dynamical system. This controller produces human-like motions and can be used to give a humanoid robot the ability to imitate human reaching motions. This imitation behavior is obtained by simply inferring the correct control input from the demonstration.

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2. THE VITE MODEL

The VITE model for reaching movements was originally developed in [2]. It describes the neural signals for muscle control and explains several properties of human reaching movements such as the asymmetric bell-shaped velocity profile and the speed-accuracy trade-off law.

In a slightly modified version, it can be expressed by the following equation:

$$\ddot{\mathbf{r}} = \alpha(-\dot{\mathbf{r}} + \beta(\mathbf{r_T} - \mathbf{r})) \quad (1)$$

where $\mathbf{r}$ is the present position vector, $\mathbf{r_T}$ is the target position vector and α, β are scalars between 0 and 1. It can be easily verified that this dynamical system creates a stable attractor at the target location, and that the present position will reach the target with a straight line and a roughly bell-shaped velocity profile and stay there.

3. A HYBRID CONTROL MODEL

The model of reaching motion is composed of two parallel VITE controllers, one active in the 3D hand location space (or cartesian space) and one active in the joint angle space (or arm configuration space). Of course, those two controllers cannot be completely independent one from another because a particular arm configuration corresponds to a particular hand location. Hence, coherence constraints between the two controllers are necessary.

Let $\theta_\mathbf{t} \in \Re^\mathbf{n}$ and $\mathbf{x_t} \in \Re^\mathbf{m}$ denote respectively the arm configuration and the hand location at time t, where n is the number of degrees-of-freedom (dof) and m the dimension of the external space (3 in general). Then the coherence constraints are enforced in the following way: If the system is in position $(\theta_\mathbf{t}, \mathbf{x_t})$ at time t, the two VITE controllers will bring it to the desired position $(\theta^\mathbf{d}_\mathbf{t+1}, \mathbf{x}^\mathbf{d}_\mathbf{t+1})$ at time $t+1$. This desired arm configuration being in general incompatible with the desired hand location, the system is brought to position $(\theta_\mathbf{t+1}, \mathbf{x_{t+1}})$ which is closest to the desired position, while remaining compatible. This can be expressed by a constrained optimization problem and solved using the classical Lagrange multipliers technique:

$$\begin{array}{ll} \underset{\theta,\mathbf{x}}{\text{Min}} & \frac{1}{2}\left((\theta-\theta^\mathbf{d})^\mathbf{T}\mathbf{W}^\theta(\theta-\theta^\mathbf{d}) + (\mathbf{x}-\mathbf{x}^\mathbf{d})^\mathbf{T}\mathbf{W}^\mathbf{x}(\mathbf{x}-\mathbf{x}^\mathbf{d})\right) \\ \text{u.c.} & \mathbf{x} = \mathbf{K}(\theta), \end{array}$$

where the time index $t+1$ has been dropped. K is the kinematic function and the diagonal matrices $\mathbf{W}^\theta \in \Re^{\mathbf{n}\times\mathbf{n}}$ and $\mathbf{W}^\mathbf{x} \in \Re^{m\times m}$ control the influence of each of the controllers.

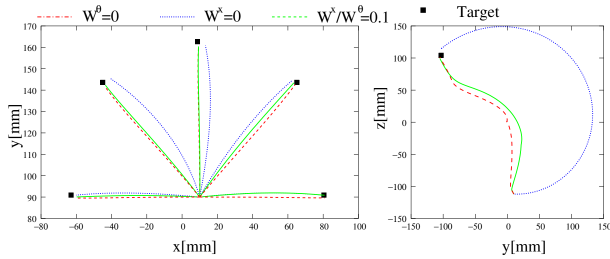

Figure 1: Hand-paths for two reaching tasks, one in the workspace center (left) and one nearby workspace boundaries (right). The three trajectories correspond to a pure joint angle controller (dotted line), a pure cartesian controller (dashed line) and the hybrid controller (solid line).

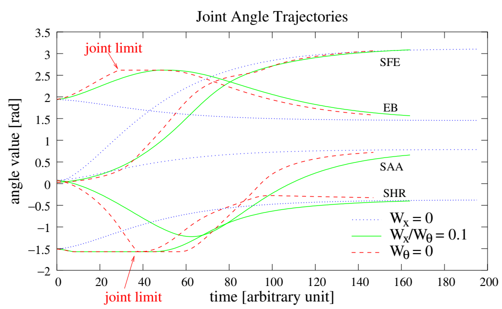

Figure 2: Joint angle trajectories for the movement depicted in figure 1, right. SFE, SAA, SHR, EB correspond to the four dofs of the arm. Not all dashed trajectories (pure cartesian controller) are smooth.

The solution of this optimization problem is given by:

$$\begin{aligned}\theta_{\mathbf{t+1}} \quad &= \quad \theta_{\mathbf{t}} + (\mathbf{W}^{\theta} + \mathbf{J}^{\mathbf{T}}\mathbf{W}^{\mathbf{x}}\mathbf{J})^{-1}\big(\mathbf{J}^{\mathbf{T}}\mathbf{W}^{\mathbf{x}}(\mathbf{x}^{\mathbf{d}}_{\mathbf{t+1}} - \mathbf{x}_{\mathbf{t}}) + \\ &\quad \mathbf{W}^{\theta}(\theta^{\mathbf{d}}_{\mathbf{t+1}} - \theta_{\mathbf{t}})\big),\end{aligned}$$

where $\mathbf{J} \in \Re^{\mathbf{n}\times\mathbf{m}}$ is the Jacobian of the kinematic function K. By modulating the two parameters W^{θ} and W^{x}, one can vary the control strategy from a pure cartesian control ($W^{\theta} = 0$) to a pure joint angle control ($W^{x} = 0$). A more detailed description of the model can be found in [3].

4. RESULTS

The model was implemented on the Hoap2 humanoid robot of Fujitsu. This robot has a four degree-of-freedom (dofs) arm but the model can be adapted to any kind of arm.
The controller is tested for two kinds of reaching tasks: reaching movements in the workspace center and reaching nearby the workspace boundaries (in this case the robot is reaching behind its neck). Each of those movements is executed using either a purely cartesian controller (the classical pseudo-inverse method), a purely joint angle controller or the hybrid controller. Fig. 1 shows the hand-paths and Fig. 2 shows the corresponding joint angle trajectories for the second task. As can be seen on Fig. 1, left, the hybrid controller produces quasi-straight movements that are kinematically similar to those of humans. One can see that the hybrid controller has the smoothness of the joint angle controller (Fig. 2), while keeping the hand path relatively short, like the cartesian controller.

Figure 3: The robot imitates the human pointing to an object. In the background a stereovision system tracks the location of the objects and the demonstrator's hand

5. APPLICATION TO IMITATION

The controller presented here is goal-oriented in the sense that the movement is fully specified by the target location, that is, the input of the dynamical system. Similarly, imitation in humans is known to be goal-directed [1]. This fact can be exploited to give the robot the ability to imitate reaching movements. In our setting (see Fig. 3), a stereovision system tracks the hand of a human reaching to one of two objects. The object to which the human is reaching is extracted using the relative positions and velocity of the hand and objects. This object is then set to be the target for the robot to reach, thus producing a simple imitative behavior.

6. CONCLUSION

The model described above illustrates that the interaction between humans and robots can be considerably simplified if their control systems can be expressed as similar dynamical systems. In the case of goal-directed reaching motions, imitation is achieved by simply giving the proper target as input to the robot controller. Having a controller that produces movements similar to those of humans is likely to yield more natural human-machines interactions and to facilitate the mapping between observed and performed actions. This mapping could then form a basis for human-machine gestural communication.

7. REFERENCES

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