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Safe Motion Generation and Online Reshaping using Dynamical Systems

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Abstract - In the future, robotic platforms will be integrated in social environment to actively cooperate with humans during their daily-life. A feasible human-robot co-working requires close and safe interaction, in which the partners can understand and quickly adapt their mutual behaviors. In this work, we present a real-time approach to generate safe (velocity scaling) and feasible (collision avoidance, goal adaptation) motions in a human-robot interaction scenario.

The basic assumption is that robot's motion is generated using a first-order, asymptotically stable Dynamical System (DS):

$$\dot{\boldsymbol{x}} = \boldsymbol{f}(\boldsymbol{x}) \,, \tag{1}$$

where $\boldsymbol{x}$ and $\dot{\boldsymbol{x}}$ represent the robot end-effector position and velocity respectively. Driving robots with DS has several advantages in terms of robustness to external perturbations, such as unexpected contacts or changes in the goal/initial position.

The DS structure allows us to easily implement a human-based velocity scaling algorithm, by modifying Eq. (1) as:

$$\dot{\boldsymbol{x}} = \alpha_h \boldsymbol{f}(\boldsymbol{x}) \,, \tag{2}$$

where $0 < \alpha_{min} \leq \alpha_h \leq 1$ is a scalar function inversely proportional to the human-robot distance. When the human, tracked using an RGB-D camera, enters in the robot's workspace $\alpha_h = \alpha_{min}$, while the human goes away, α_h linearly goes to 1. Being α_h strictly positive, this scaling will not affect the equilibrium of the DS, in other words, the task will always be correctly executed.

During tasks execution, unforeseen obstacle can appear in the robot workspace. To avoid possible collisions, saving the convergence properties of the DS, authors propose to *modulate* a generic first-order DS as [1]:

$$\dot{\boldsymbol{x}} = \boldsymbol{M}(\boldsymbol{x})(\boldsymbol{f}(\boldsymbol{x}) - \dot{\boldsymbol{o}}) + \dot{\boldsymbol{o}} \,, \tag{3}$$

where $\dot{\boldsymbol{o}}$ is the obstacle velocity and $\boldsymbol{M}(\boldsymbol{x})$ is the so-called *modulation matrix*, used to reduce the end-effector velocity in the obstacle normal direction [2]. To avoid collisions with the robot's links, we calculate the closest point on the robot to the obstacle and use the approach in Eq. (3) to drive away that point. This task is projected in the manipulator Jacobian null-space to not affect the end-effector motion.

The described approaches for velocity scaling and obstacle avoidance are integrated, together with an online reshaping method used to modify the robot's goal position, in a two levels hierarchical architecture (see Fig. 1). The higher level of the architecture is used to recognize human activities and to select/reshape the robot motion according with the current activity. The *Human Activities Interpreter* determines the user status (far/interaction) and the goals status (free/occluded). Rough depth data from a RGB-D sensor are first filtered to remove the points belonging to the robot surface and then used to track human and obstacles. Using this information, the *Robot Behaviour Selection/Reshaping* module to select the right behavior from a database of *Motion Primitives*, scaling down the velocity and changing the goal position when needed. The selected motion primitive is passed to the *Collision Avoidance* level, that implements the real-time, reactive collision avoidance algorithm in Eq. (3).

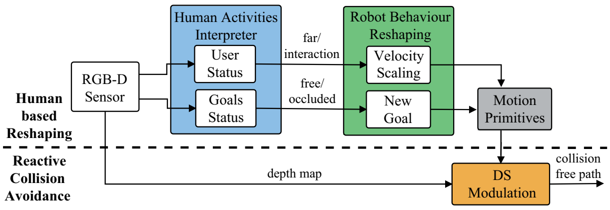

Fig. 1 System overview: data from an RGB-D sensor are used for understanding human activities and, in case, to reshape robot's motion. The same data are used to avoid possible collisions.

The related video shows an application of the proposed approach in a human-robot interaction scenario. The robot moves counterclockwise towards four goal positions, while it avoids possible collisions. When the user enters in the workspace, the velocity of the robot is scaled down. If the user hides with his hands the goal, the next free goal position becomes the equilibrium point of the DS.

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References

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