A model predictive control framework to control hand movements relying on tactile illusions

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***Abstract*—Recent studies showed that the sense of touch is able to guide hand movements. When a blindfolded subject slides his/her finger-pad on a ridged plate to reach a target, the contribution of tactile feedback induces the illusory percept of bending towards the direction estimates by tactile cues (i.e., the one perpendicular to the ridges), and this induces a systematic error on hand trajectories in the opposite direction with respect to the one estimated by touch. The goal of this paper is to control the previously explained illusion to guide the user's finger moving on the ridged plate towards an arbitrary desired point A, while he/she is instructed to move towards an another point B. To this end, we designed a Model Predictive Control strategy, relied on the results of a Kalman filter model, in a simulated environment to estimate at each time instant the optimal ridge orientation. Here, we simulated fifty trials for a particular position of the point A and B. The results show that the final points of the simulated hand trajectories are for the 90% of the cases in a range of $\pm 1.5°$ with respect to the angular position of the desired final goal A. These results open promising applications in the framework of haptic retargeting where only one real object is used and the other items of the scene are virtual.**

***Index Terms*—Tactile illusion, Model predictive Control**

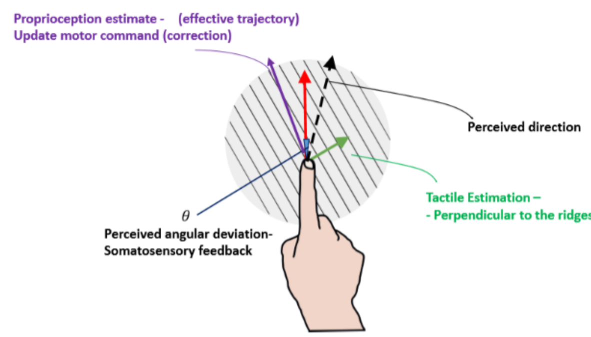

Fig. 1. When a participant moved the index finger on a plate with oblique ridges, along the direction indicated by the solid red arrow the tactile cues produced an illusory sensation of bending towards a direction perpendicular to the ridges (dashed black line). This eventually led to an adjustment of the motion trajectory towards a direction opposite to the one arisen from tactile motion estimate (solid violet arrow).

I. Introduction

Recent studies showed that tactile sensation contributes to our sense of hand position and displacement in perceptual tasks. In our previous works [1], [2], we showed that touch provides auxiliary cues to guide hand movements. Indeed, when a user slides, without any visual feedback, his/her finger-pad straight ahead on a plate with oblique parallel ridges, the contribution of tactile cues on motion direction estimate induces the illusory sensation of moving perpendicularly to the ridge orientation. For this reason, the subject corrects the movement going in the opposite direction with respect to (w.r.t.) the one estimated by tactile cues. (see Fig. 1).

This illusion is still present when participants are instructed to move towards a target, positioned with a certain orientation w.r.t the mid-line of the plate, and visualized through a head mounted display [1]. Therefore, if touch is an auxiliary cue for proprioception, then it would be reasonable to hypothesize that cutaneous and extra-cutaneous information (from classical muscular-skeletal proprioception) on hand motion are integrated for hand motion estimation, in the reaching tasks previously explained. To formalize this hypothesis, in [1], we simulated trajectories at different ridge orientation using a Kalman filter model, which predicts the integration from the two different sensory cues. The results reported in [1] show that the filter is able to reproduce the empirical findings. Building upon these findings, here we design a control problem, which is able to direct the movement of the user's finger to an arbitrary point A, while eliciting the illusory percept of reaching another point B. This was done by dynamically re-orienting the ridged plate by means of a Model Predictive Control strategy. In this manner, the participant should ideally perceive to move towards the instructed direction, but the controller guides him/her towards another desired direction. First results presented in this paper have been tested in simulation, while additional work is required to apply this strategy with human beings. The results reported in this paper open promising applications for human-machine interaction in the framework of haptic retargeting [3]. Indeed, our control strategy could be used in augmented reality scenarios where only one real object is used and the other items of the scene are virtual. The here proposed framework could be used to

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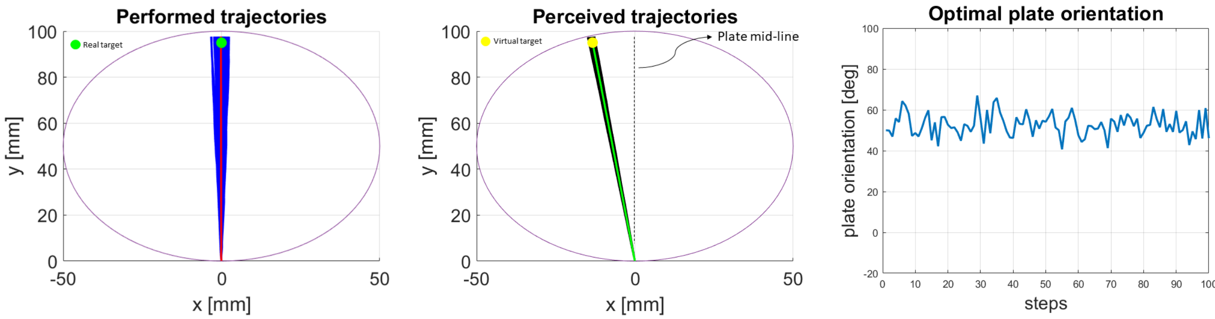

(a) (b) (c)

Fig. 2. **a**: In blue, simulated hand trajectories, in red the median trajectory. The real target is positioned at $0°$ w.r.t the mid-line of the plate. **b**: In black, simulated perceived hand trajectories perceived and in green the median trajectory. The virtual target is positioned at $8°$ w.r.t the mid-line. **c**: The optimal plate orientation for a simulated trial. The starting position of the plate orientation is $50°$.

guide the user's finger sliding on a ridged plate to reach the only real target in the scene, while the experimental instruction is to reach a virtual target placed at a different location.

II. Control Problem

In this section we report the Model Predictive Control strategy that we implemented to compute at each time instant the optimal plate orientation that has to guide the user towards a desired point A, while he/she is instructed to move towards another point B. The optimal ridge orientation is computed considering at each time instant the output of the Kalman filter reported in [1], which simulates the direction of hand motion perceived by subjects at each time instant.

III. Optimization problem

The problem to be solved requires finding an optimal ridge plate orientation at each time instant k, which is used to guide the user towards a desired point (defined as *real target* P_R), while he/she is perceiving to move towards another target (defined *virtual target* θ_V). To this end, we implement a cost function $J(k)$ that minimizes both the error between $\hat{\theta}_k$ (estimation of the perceived hand direction from the Kalman filter) and θ_V, and the error between P_k (simulation of hand actual motion) and P_R. All the quantities are angles computed w.r.t the mid-line of the plate. The cost function is formally defined as follows:

$$J(k) = (\hat{\theta}_k - \theta_V)^2 + (P_k - P_R)^2, \quad (1)$$

where $\hat{\theta}_k$ is function of the ridge orientation (as presented in [1]). The choice of such a cost function is based on the idea that the hand position has to be guided towards P_R, while the user is perceiving to move towards θ_V. The optimal plate orientation is then extracted through a Model Predictive Control strategy, by evaluating the cost function (1) over a time window of 3 steps (i.e., $[k, k+1, k+2]$). The time window length was determined considering the minimum step number for which the performance of our algorithm did not improve if we increased the time window length.

Here, we simulated the condition with $\theta_V = 8°$ w.r.t the mid-line of the plate and $P_R = 0°$ w.r.t the mid-line of the plate.

1) Results:

We simulated 50 trials for the condition previously reported. The results show that the 90% of the final points of the 50 simulated hand trajectories were in a range of $\pm 1.5°$ w.r.t the orientation of the real target (this means that if the real target was placed at $0°$ w.r.t the mid-line of the plate, the 90% of the final points of the simulated trajectories were placed in a range of $\pm 1.5°$ w.r.t the mid-line of plate)(see Fig. 2 for the results).

IV. Discussion and Conclusions

In this paper we presented the simulation of an optimization control problem that could be applied in haptic retargeting applications in a situation where only one object is used and the other items are virtual. Relying on the illusion presented in [1], [4], here we implemented a Model Predictive Control strategy that computes at each time instant the optimal ridge orientation that would guide, in a virtual environment, the user's hand trajectories towards a real target, while the participant is instructed to move towards a virtual one. The results obtained simulating the participant's trajectories, using the prediction of a Kalman filter model, are promising and show that the final points of the simulated hand trajectories for a particular task are for the 90% of the cases in a range of $\pm$ $1.5°$ w.r.t the target orientation. In future work, we will test different conditions (i.e. different real and virtual target positions), and we will try to apply the strategy in a real haptic retargeting experiment.

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