Chapter 7
Yes, We K-an: Modulated Collaborative Control

Yeah well, if she doesn’t give us some extra flow from the engine room to offset the burn through, this landing is gonna get pretty interesting.

Define interesting.
Oh god oh god we’re all gonna die?
- Wash and Mal, Serenity

In previous episodes of our hospital series, we saw how collaborative control equalized the performance of persons with different cognitive and physical disabilities. In almost every case, they were able to finish mildly complex trajectories. However, it was only a matter of time until we found a person with disabilities so severe that assistance provided by our control scheme was not enough for her to finish a trajectory. We also observed that control glitches in complex areas where both robot and human efficiency changed very quickly led to remarkably lower average efficiencies. This was also the case when CBR was used, specially after short trainings where only a reduced number of cases had been learnt and robot control switched a lot from PFA to CBR. Naturally, these problems could be solved, at least partially, if the amount of assistance provided could be stabilized during a certain time period, condition or situation. However, we did not want to lose the reactive nature of our algorithm, that had worked so fine for us thus far. In fact, there is a pretty classic approach to solve this problem in a strictly analytical way: modulation of the control function.

7.1 Surfin’ the Wave

This effect of modulation is very easy to observe in Fig.7.1. Let us take, for example, a simple gaussian envelope (Fig.7.1a), and two periodic functions: a fancy one, all full of nifty ripples (Fig.7.1b), and a boring triangular one (Fig.7.1c). If we simply combine them into a third one, we get something in the middle (Fig.7.1d). However, if we previously modulate the sum with our envelope, voila!: a modulated control function all ripply where the envelope is high and triangly when it is close to zero (Fig.7.1e).

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Our collaborative control equation (Eq. 3.5) is very easy to modulate. We only need to multiply human contribution by an amplification factor $e(x)$ and robot contribution by its complementary $(1-e(x))$ to modulate their combination, as in (Fig. 7.1e). Thus, assistance is still controlled by human efficiency, but emergent commands are more or less affected by punctual efficiency driftings depending on $e(x)$.

A short discussion with the medical staff at FSL seemed to point out that, in fact, it might not be advisable to make $e(x)$ a continuous function. As commented over and over, disability is not easy to define -much less to quantify- and it would make no sense to fine-tune control in terms of something we can not really grasp. Instead, their advise was to use just a discrete function $K_H$ that adopts only a few values, depending on how much assistance the person seems to need:

- In human standalone mode, $K_H=1$. Yet, it needs to be noted that the safeguard layer is always on in our system, so collisions can not happen.
- $K_H=0.75$ if the person does not need much assistance. In any case, if the user performs poorly, his/her contribution to control will be low, yet, in general, they will be dominant.
- $K_H=0.5$ corresponds to non modulated collaborative control as seen in previous chapters, where human and robot contributions to control are merely a function of their respective efficiency.
- $K_H=0.25$ corresponds to robot dominance in control if the person can not or is not performing adequately.
- $K_H=0.01$ corresponds to robot standalone performance. We never use $K_H=0$ because the robot is not supposed to move unless the person is operating the joystick. Yet, his/her contribution to control is neglectable in this case.

$$v_S = (1 - K_H) \cdot \eta_R \cdot v_R + K_H \cdot \eta_H \cdot v_H \quad (7.1)$$

where $\eta_R$ and $v_R$ are the robot command and its efficiency, $\eta_H$ and $v_H$ are the human command and its efficiency and $K_H$ works as our wave envelope.

The problem at this point is, obviously, to decide how and when to change $K_H$. Mainly, $K_H$ may change depending on the person’s condition -as stated by doctors-, state -as determined by biometric sensors, when available-, or the person’s general performance -in absence of any other information-. In case of severe disabilities or