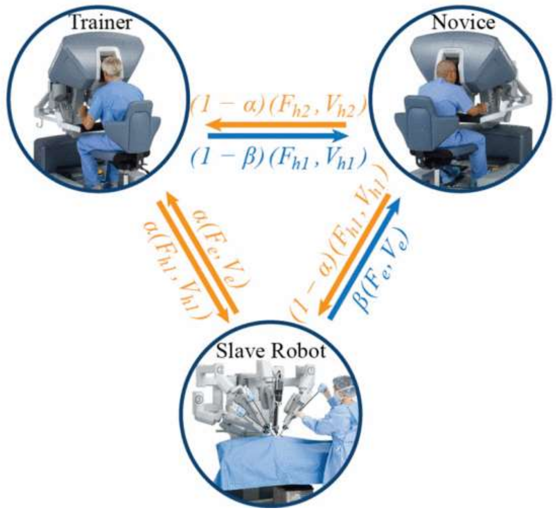
Critical Summary: Design and evaluation of a trilateral shared-control architecture for teleoperated training robots

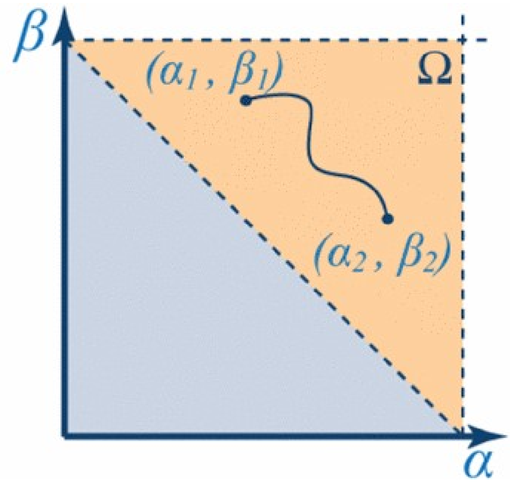
Teleoperated robotic systems have become increasingly more prominent in the field of minimally invasive surgeries. They allow surgeons to perform more complex tasks that may require collaborative interaction between multiple parties. This paper defines and analyzes a trilateral shared control system as a possible control scheme to be used as a possible training method for surgical procedure, namely, minimally invasive surgeries.

One of the key features of this control architecture is the implementation of a dominance factor α in addition to an observability factor β. These factors intend to closely simulate the determinants present in motor learning in humans and are assumed to be modifiable during operation of the master consoles. In this system, the dominance factor determines how shared control of the slave robot is by the two master consoles. Controlled by the trainer surgeon, a dominance factor of 1 corresponds to the trainer having full control of the slave robot as well as receiving full force feedback from the slave robot while a dominance factor of 0 corresponds to relinquishing all control to the trainee. In addition, there is also an observability factor that is controlled by the trainee. This value, which ranges from 1- α to 1, controls whether the trainee is experiencing force feedback from the trainer console, the slave robot, or a combination of the two.

$$F_{h1d} = \alpha F_e + (1-\alpha)F_{h2} \quad \text{(1-a)}$$
$$V_{h1d} = \alpha V_e + (1-\alpha)V_{h2} \quad \text{(1-b)}$$
$$F_{h2d} = \beta F_e + (1-\beta)F_{h1} \quad \text{(1-c)}$$
$$V_{h2d} = \beta V_e + (1-\beta)V_{h1} \quad \text{(1-d)}$$
$$F_{ed} = \alpha F_{h1} + (1-\alpha)F_{h2} \quad \text{(1-e)}$$
$$V_{ed} = \alpha V_{h1} + (1-\alpha)V_{h2} \quad \text{(1-f)}$$

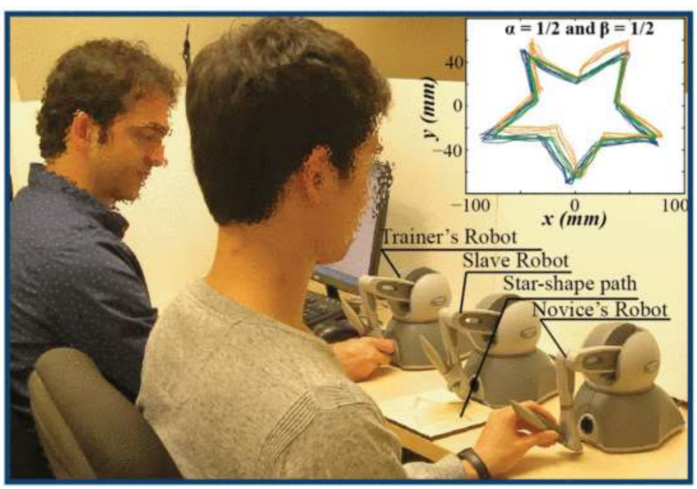
Equations (1-e) and (1-f) define the desired velocity and forces experienced by the slave robot which is a combination of the velocities and forces exerted by the trainer and trainee master consoles controlled by the dominance factor. Equations (1-a) and (1-b) define the desired velocity and forces experienced by the trainer's master console. Note that as the dominance factor decreases, the trainer console switches from observing feedback from the slave robot to observing feedback from the trainee's console. Equations (1-c) and (1-d) define the trainee console's desired velocity and experienced force feedback. These values are controlled by the observability factor as the trainee determines whether to observe the trainer console or the slave robot at any given time. The relation between the three parties is also depicted graphically in the left image below.

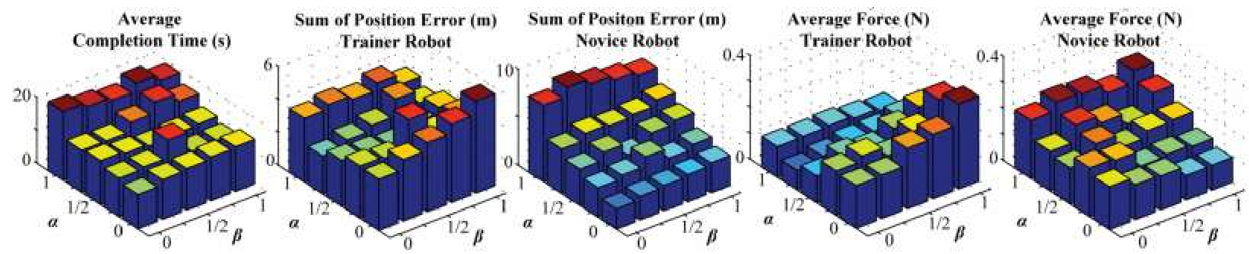




1. Valid Space for α and β shown in orange

In order to test their system, the authors designed an experiment that involved implementing the trilateral control architecture on three Phantom Omni haptic devices. One of the robots was denoted the slave robot and had its degrees of freedom restricted to purely translational movement. A similar movement limitation was put on the trainer's master robot to better simulate a degree of expertise. In addition to the physical limitations on the robots, the participant playing the part of the trainer used their dominant hand and supported their arm on the table. The participant playing the part of the trainee, on the other hand, used their non-dominant hand and could not support their arm on the table. The task for this experiment was to collaboratively control the slave robot to draw a star on a piece of paper. The task was completed 25 times by the participants with each trial using a random combination of α and β ({0,0.25,0.5,0.75,1} were the chosen values for both α and β).





These plots show the results taken from the experiment and some notable trials were highlighted in the paper. Namely, average task completion time and total positional error were at their lowest during the trails where $\alpha = \beta = 0.5$, signifying best results when the trainer and trainee had completely shared control over the slave robot. In addition, it was mentioned that whenever either participant had less control over the slave robot's position, their average force input was higher which may have simply been a reaction to seeing that their movements were not being fully acknowledged by the slave robot.

The paper has multiple shortcomings especially in the context of the experiment performed. Firstly, the 25 trails each had α and β set to values within the set $\{0,0.25,0.5,0.75,1\}$, however it was specified in the definition of the system that the lower bound of β was $1-\alpha$. The selection of α and β in the experiment results in combinations that violate this rule, making those trials essentially invalid. In addition to this, it was assumed that, in actual operation of this system, the trainer and trainee would have full control over α and β, respectively. Randomly selecting values of α and β without at the very least informing the participants of what values were chosen for α and β detracts from the purpose of these two constants being controllable. It also does not facilitate the type of motor learning that the paper intends to bring about with this system. With future experiments, it would benefit either to allow the trainer and trainee to control α and β on their own or to randomly select α and β while constantly informing the participants of their current values.

Regarding the task that the participants were asked to complete, the actual task does not effectively simulate any kind of procedure or movements that an actual surgeon would be performing in an operating room. While the task of drawing a star on paper might have been sufficient for the robots used in the paper, it would be beneficial to perform similar test on a robot actually used in minimally invasive surgery such as a DaVinci or Galen robot in addition to having the participants complete a task that more effectively simulates the motions of a surgeon in an operating room, such as suturing a simulated incision or moving through a tight space with a certain level of accuracy, for example. If this modification were made, there would also be a need for an experienced surgeon to be operating on the trainer console since simply feigning a lack of dexterity probably would not be an effective way to simulate a difference in amount of expertise.

All images used were taken from the paper cited in the References page.

References

K. Shamaei, L. H. Kim and A. M. Okamura, "Design and evaluation of a trilateral shared-control architecture for teleoperated training robots," *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Milan, 2015, pp. 4887-4893.