Project Overview

When soldering electronics, a technician often must hold a PCB, a wire or component, a soldering iron, and a strand of solder. For a two-handed individual, this requires creativity. Small passive fixtures called "helping-hands" feature swiveling alligator clips mounted to a weighted base. The user will clip the PCB in a convenient configuration and attempt to solder. This is frustrating due to the limited orientations of the clips and the tendency of the clips to drift as force is applied during soldering. We propose a robotic "helping-hands," which could intuitively grasp, adjust, and steady PCBs while a human interacts with it. This platform must allow the user to adjust compliantly adjust the workpiece into position, yet resist motion during the actual soldering process. Project development will be based on the KUKA youBot, a 5-DOF arm unit attached to a omnidirectional wheeled base.

Individual Component

I will be working on low-level controls. This module will take information from motion planning and high-level robot state to return current commands for the individual arm motors. High-level robot state (e.g. modes for adjustment, motion resistance, and trajectory tracking) will determine how compliant the arm should be. For instance, during soldering, the arm should keep the PCB steady despite the external force. During adjustment, the arm should allow the user to adjust the position/orientation of the board with little resistance Ideally, this should feel like manipulating an object in a viscous fluid. For large movements to reach for objects, the low-level controls will track a trajectory provided by the motion planning module.

Theory and Novel Component

The robot arm must be able to act with varying levels of compliance depending on user interaction and current high-level state. This is an ideal candidate for Impedance Control. Described by Hogan in his seminal work [1], systems come in two varieties: admittances and impedances. Admittances accept force and yield motion. Impedances accept motion and yield force. For compliant adjustment, the user is the admittance, and the robot is the impedance.

Impedance control imposes a certain stiffness and damping on the end effector in world coordinates. The basic feedback law takes the form:

$$T = J^T[K(x_r - x) + B(\dot{x}_r - J\dot{\theta})], \qquad (1)$$

where x_r is a reference point or trajectory, x is current end effector position, and J is the instantaneous jacobian s.t. $\dot{x} = J\dot{\theta}$. K and B are adjustable stiffness and damping gains, respectively. Essentially, this is a gain-scheduled PD controller in which non-linear transformations adjust the P and D gains to produce constant end-effector behavior [2]. Impedance control has two major advantages: it requires no inverse kinematics/dynamics, and it requires no force sensing (the youBot has none). Impedance control has become a standard tool in all sorts of robotics applications.

In my personal field of legged locomotion, impedance controls have made several appearances. For example, MIT's Cheetah quadruped uses impedance controllers to track a leg trajectory when a leg is in the air and also impose a certain ground reaction force profile when the leg in stance phase [3]. To achieve the ground reaction force, they set a virtual leg trajectory which lies below the ground. This approach is informed by the *equilibrium point hypothesis* [4], which states that animals may change the equilibrium points (rather than just stiffnesses) of their compliant limbs, even into penetration, in order to exert appropriate forces on the environment. Using this controller, Cheetah has become one of the best legged robots produced by the academic world.

Following this same bio-inspired approach, I propose to apply this methodology of modulating the penetration depth of the reference point to our current project. This novel component would be applied during the soldering phase, in which the robot should resist motion. At first glance, this seems similar to Cheetah's control during the stance phase. However, due to the periodic nature of running, they can modulate the tracked penetration depth using a sinusoidal function. In our manipulation problem, we have no expectation of predictable, periodic interaction with the user. Thus a major theoretical contribution of this work, should it prove wildly successful, would be on the generation of this virtual trajectory.

Proposed Steps

I am splitting my efforts into two paths that I will pursue simultaneously: implementation on hardware and theory on a simplified model. This is "insurance" in case one portion gets bogged down or becomes infeasible. Implementation will take priority since other parts of the total project are highly dependent.

Implementation on hardware:

1) Gain proficiency in ROS (**in progress**)
2) Send motor commands to a simulated youBot using ROS
3) Send motor commands to a real youBot using ROS
4) Perform the analysis to implement a basic (equation 1) impedance controller on the hardware
5) Write necessary code
6) Test and tune on hardware

Theory on a simplified model:

1) Write a basic 2D, 2-Link manipulator simulation (**complete**)
2) Implement an impedance controller in code (**complete**)
3) Literature review and idea generation (**in progress**)
4) Testing and iteration in simulation
5) Extension to 3D
6) Addition to actual hardware controller

References

[1] Hogan, N., "Impedance Control: An Approach to Manipulation," *American Control Conference, 1984* , vol., no., pp.304,313, 6-8 June 1984

[2] Hogan N, Buerger SP (2004) Chapter 19: Impedance and interaction control. In Kurfess T, ed.: Robotics and Automation Handbook. CRC Press 149–164

[3] Dong Jin Hyun, Sangok Seok, Jongwoo Lee, and Sangbae Kim. 2014. High speed trot-running: Implementation of a hierarchical controller using proprioceptive impedance control on the MIT Cheetah. Int. J. Rob. Res. 33, 11 (September 2014), 1417-1445.

[4] Bizzi E, Hogan N, Mussa-Ivaldi FA, et al. (1992) Does the nervous system use equilibrium-point control to guide single and multiple joint movements? Behavioral and Brain Sciences 15(04): 603–613.