Development of a Scale Test-Bed for Shared Control of Electro-Hydraulic Machinery

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Motivation

Large earth-moving machines are utilized in many crucial industries, including construction and mining. These machines almost universally leverage hydraulic actuation for its power density and actuator stiffness. Interest has grown over the past few decades in deriving controllers to aid in the traditionally manual operation of hydraulic manipulators. The benefits of automation for various classes of industrial manipulation tasks are well known and clearly laid out in literature. However, efforts towards automation of digging tasks have fallen short of advances in other heavy industries like manufacturing and material processing.

Fully automatic control of excavation systems appeared early in control literature with promising results for structured, repetitive earth-moving tasks [1]. However, trends in automation journals and the excavation industry (as well as other vital industries, most notably, automotive) suggest that a **shared control (SC)** architecture offers more situational robustness, by keeping the operator in the control loop continuously.

Shared Control Background

In brief, shared control (SC) consists of methods which directly or indirectly combine a human agent with an electronic agent to control a dynamic system.

Many forms of SC have been assessed in excavation systems, both theoretically and experimentally. **Coordinated control**, which consists of mapping operator inputs in a general three-dimensional workspace to the end-effector position in the manipulator workspace, has been explored by many authors [2].

Virtual constraint SC policies have been most successful in industry adoption, as evidenced by Komatsu's Intelligent Machine Control System, which can fix digging grades (angles) and square the bucket position with the digging surface, to increase digging quality and consistency [2].

Table 1: Examples of Shared Control

Application	Description	SC Classification
Automotive Cruise Control	Speed is fixed, operator steers vehicle	Collaborative Control
DaVinci Surgical Robot	Surgeon moves 3D joystick, controller resolves trajectory for surgical end-effector	Coordinated Control
Drone Pilot Assist	Altitude is fixed, user can move in 2D plane	Virtual Constraint

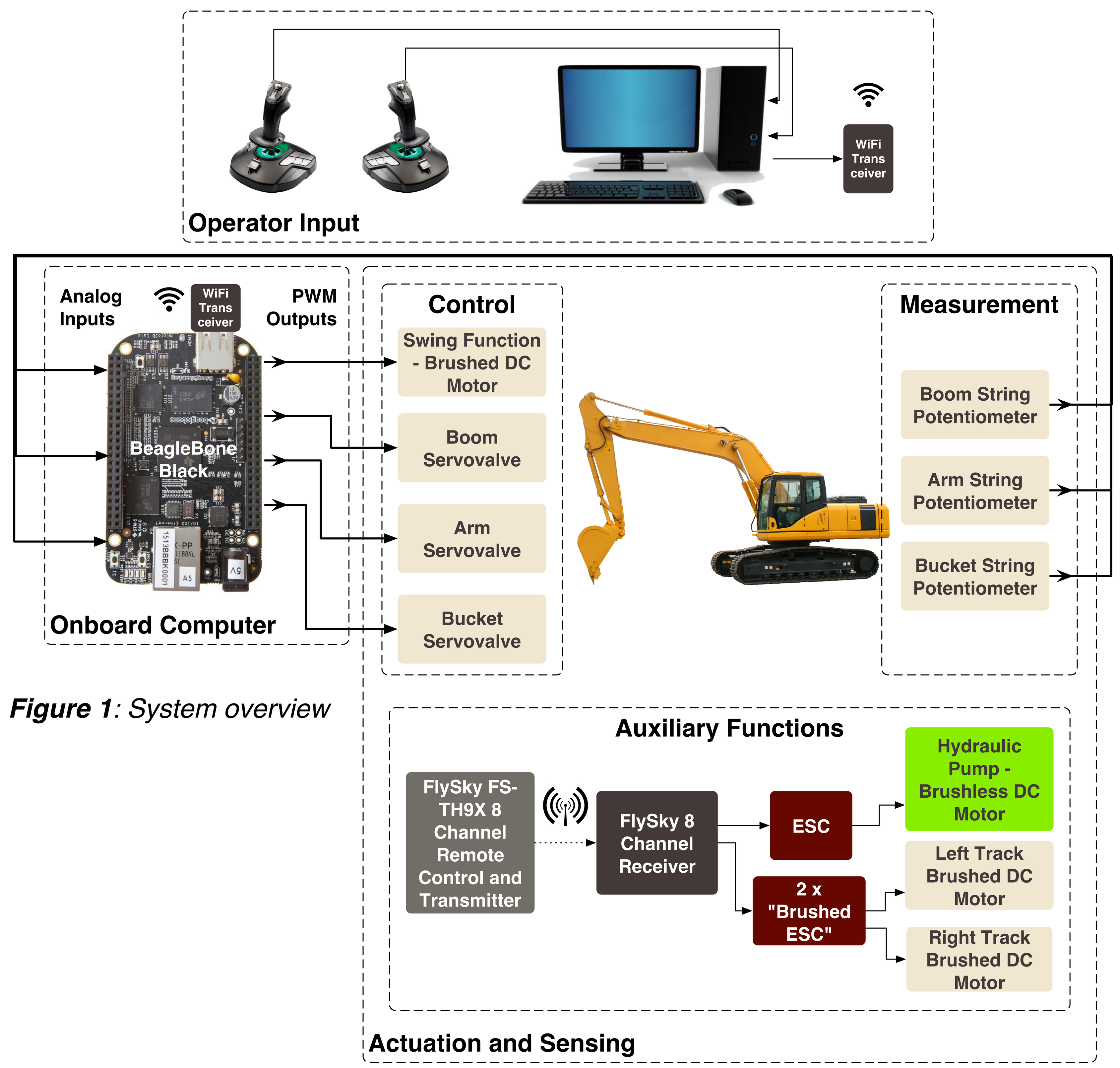

***Figure 1**: System overview*

Recently, in robotics and and automation, promising developments have been made in **continuously shared control**, whereby operator input is continuously combined with automated assistance. Dragan, et al, presented a holistic policy-blending formalism for shared control, decomposing the electronic agent's task into **prediction**, or determining user intention, and **arbitration**, which refers to combining the autonomous control with the operator command to assist in the completion of the user's task [3].

In the earth-moving domain, Enes presented **blended shared control (BSC)**, which continuously combined the operator command with a time-optimal control perturbation. The prediction step is aided by use of motion primitives, which classify the operator's inputs by specific actuator and direction commanded. Then, filtering algorithms use previous operation data and the current measurements to predict future actuator displacement. In the arbitration step, an additive perturbation was generated by the controller, and was weighted by a blending parameter, denoted alpha, as is typical in continuous SC applications [4].

Test-Bed Architecture

Our test-bed consists of a 1/12th scale fully hydraulic excavator, which has been modified to be capable of fully autonomous control, with feedback of each hydraulic function. The onboard computer is an embedded SoC running Linux (BeagleBone Black), which will read the pose of the excavator manipulator and the commands broadcasted from the operator, then execute the prediction and arbitration steps. Finally, the onboard computer will execute the blended input by way of PWM signal commands to the scale excavator.

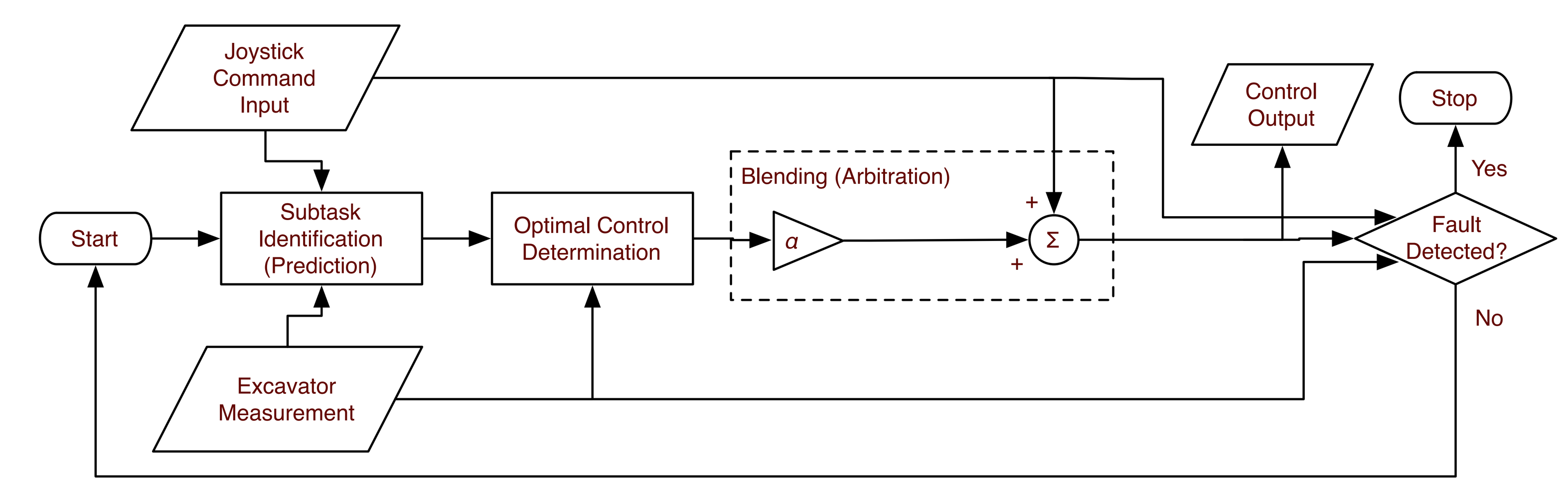

***Figure 2**: Flowchart for onboard controller*

Future Work

The test-bed will be used for a series of experiments in shared control operation for simulated digging tasks. Several different mathematical formulations for blending policies have been developed but not evaluated. Specifically, a novel dynamic blending policy, that offers more control to the operator when the prediction confidence decreases, will be tested and reported.

References

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