Levitating Across the River Styx

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ABSTRACT

The Styx (9p) protocol has been well documented for use in various distributed systems [1, 2]. Demonstrations have proven that it works for communication with embedded devices [3, 4, 7]. This paper presents an implementation of 9p for the 16-bit dsPIC33 family of digital signal controllers. It is used to collaborate multiple distributed nodes to achieve stable aero-acoustic levitation of a sample by tuning sound pressure levels and managing spin control[b].

1. Introduction

Aero-acoustic levitation (AAL) has been achieved in the past using analog systems with purely manual controls [8, 9]. A newly designed AAL instrument is being built based around a cluster of digital control boards. Each board includes a dsPIC33 embedded controller and an FPGA to handle manual inputs paired with position feedback control sensors used to drive a transducer and produce a stable acoustic field during experiments where significant changes in temperature will be applied to a sample. Temperature changes modify the speed of sound and thus sound pressure levels at the desired focal point. The distributed system of transducer control boards is used to calibrate and adjust acoustic phase and amplitude along three axes to levitate and hold a sample in a fixed position during solid to liquid-phase processing studies.

In addition to a manual control interface, this new system implements a fully digital controlled interface available on an end user's terminal. This newly designed system uses 9p for tuning core parameters on each node as well as communication with external terminals. Exporting all the node sensor data to a single namespace on a user's terminal provides for clean logging and real-time analysis of state changes during an experiment.

1.1. Aero-acoustic Levitation

Research into containerless liquid-phase processing of materials led to the invention of aero-acoustic levitators [8]. The combination of gas jet (aero) and acoustic forces help to stabilize the sample in a levitated (containerless) field such that rapid heating and

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cooling techniques can be applied. In this example it is principally used to conduct experiments on samples that may be super heated to temperatures above 2700°K and rapidly cooled without requiring a crucible or other physical container. Such experiments test the viscosity and surface tension of a sample within a controlled environment able accommodate key state changes important for theoretical and applied material science studies.

1.2. Controller Boards

A distributed feedback control system is used in order to achieve aero-acoustic levitation of samples during significant fluctuations in temperature. A gas jet counteracts gravitational force and is controlled by the user or a program interfacing with an electronically controlled flow valve. Three acoustic axes, a pair of transducers each, are used to provide levitation, stabilization, and spin control of a sample. Position detectors are used perpendicular to each acoustic axis, three in total, to aid in stabilization and to coordinate placement of a sample positioned at the intersection point of the gas flow and the two lasers used in melting the sample. Each component is wired to one of eight controller boards sharing a system bus with software running on the dsPIC33.

By tuning the acoustic phase of each axes to focus a standing wave above the gas jet and near the ideal point for heating a sample, the deadline in which any system event needs to respond becomes quite long. This leaves more than enough time for handling 9p messages at relatively regular intervals. By implementing 9p on the dsPIC33 embedded controller there ends up being enough memory and free cycles to handle feedback loop calculations without requiring further development like the *Styx IP-Core* on an FPGA [7]; however, the option is still there for future research.

2. The River Styx

Each of the eight nodes in the AAL cluster resides in a single chassis with three communication channels: one exposed through a RS-232 interface, and two through the backplane. The first dsPIC33 code used a simple protocol requiring the use of a dumb terminal connected to each board over the RS-232 interface. This configuration allowed for single board initialization and verification, but made debugging inter-node communication over the 485 and SPI busses all the more difficult.

After reviewing file system interfaces for mobile resources [1, 5, 6], the case was made to implement 9p not just for the serial communication from the host terminal to each control node, but as the principal means of communication along the backplane connecting all the nodes in the cluster. This conceptual switch to responding through the same protocol over each serial interface made the design and debugging of the system all the more practical. A master node constructs a representation of the rest of the cluster and exports its namespace using 9p over its RS-232 port. All other nodes are dedicated to reporting the state of their various sensors and calculating responses based on their dedicated feedback loops.

2.1. Embedded Server

Each node with a dsPIC33 serves a single-level namespace with two files: ctl, and status. As with devices on Plan 9 and Inferno (e.g., *uart(3)*) the ctl file is used to write configuration parameters to the board. The status file returns the measured state of all the sensors accessible to the embedded controller: output voltage, output current, phase, mic amplitude, mic phase, temperature, etc.

Future implementations could expand the board to provide register and memory details of the PIC, allowing for even greater debugging options as well as dynamic updates beyond the simple scope of variables required for achieving levitation.

2.2. Embedded Client

A single master board is used as a gateway between all the controller nodes and a user's computer terminal. After board initialization, the master node scans the backplane for all other connected boards, and uses 9p to set up a multilevel namespace representing the system. All the non-master nodes are hot pluggable, so the master node's exported representation of the system will change as a node is disconnected or inserted. In turn, the master board exports a namespace over its RS-232 serial interface, providing a synthesized file system to the user's application with a synopsis:

```
mount /dev/eia0 /n/aal

/n/aal/ctl
/n/aal/status
/n/aal/transtatus
/n/aal/[0-6]/ctl
/n/aal/[0-6]/status
```

The transtatus file contains the last polled state of all the transducer controller nodes, numbered 0-5, eliminating the need to re-poll each node in order to respond to the application's request.

3. Experimental Control Application

The whole exercise of getting 9p on all of these embedded controllers is to provide a consistent API for firmware development and expose a relatively simple interface for end user application programmers to design and support experimental controls over various sample materials in order to have precise position and spin control. There are multiple built-in feedback loops that adjust the system's parameters in real-time when enabled, though there is programmatic control over these events as well. All changes get reported back over timed reads by the master node (host application) of all other status files. Doing so allows for an experimenter/programmer to create events that can be programmed through scripts and run once the sample is levitated. A typical startup example is:

```
# create namespace
bind -a '#t' /dev
mount -bc /dev/eia0 /n/aal
linkflowmeter /dev/eia1
mount -a /net/flowmeter /n/aal
linkheatsource /dev/eia2
mount -a /net/heatsource /n/aal

echo off > /n/aal/heatctl
echo off > /n/aal/flowctl

# acoustic calibration routines
echo findq > /n/aal/ctl
echo pick > /n/aal/ctl
echo phase > /n/aal/ctl
```

```
# prep for sample insertion
echo A .2 > /n/aal/ctl
echo 1000 > /n/aal/flowctl

# change phase on one axis
echo p+1 > /n/aal/[01]/ctl
# increase amplitude from top transducers
echo a+1 > /n/aal/[1,3,5]/ctl

# pseudo code to decrease amplitude over 30s
for(i in ‘{seq −1 0}){
    echo a−1 > /n/aal/ctl
    sleep 1
}
```

4. Conclusion

The use of 9p for inter-process communication in a distributed cluster provided a valuable interface for reading and writing sensor data on a dsPIC33 within certain deadline constraints on each of the eight nodes in the cluster. It also allowed for application development to use a simple file hierarchy to monitor and control a running system. Initial shell script prototypes were used on Plan 9 or Inferno depending on the developer's host system. Subsequent applications were written in Limbo and provided as reference implementations for the use of 9p over the RS-232 interface.

5. References

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