M68HC11 GRIPPER CONTROLLER SOFTWARE

NAGW-1333

by

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ACKNOWLEDGEMENT

I would like to thank my mother and father for their support. I would also like to thank Dr. Robert B. Kelley, my thesis adviser, for his guidance during the various stages of development.
This thesis discusses the development of firmware for the 68HC11 gripper controller. A general description of the software and hardware interfaces is given. The C library interface for the gripper is then described followed by a detailed discussion of the software architecture of the firmware. A procedure to assemble and download 68HC11 programs is presented in the form of a tutorial. The tools used to implement this environment are then described. Finally, the implementation of the configuration management scheme used to manage all CIRSE software is presented.
CHAPTER 1
Introduction

The objective of this project was to produce a low-cost gripper controller for CIRSSE and attain the following design goals:

- provide an RS-232 command interface.
- implement position feedback control using potentiometers.
- implement force feedback control using strain gauges.
- allow the gripper to "grab" objects using the infrared sensors.
- minimize sampling period (maximize sampling rate) to allow maximum possible fluctuation in gripper control parameters.

In addition, software tools were created for SunOS and VxWorks to provide an easy to use edit-compile-download-debug environment for the development of programs using the 68HC11 EVB on a Sun workstation.
CHAPTER 2
Overview

2.1 Mechanical Aspects

The gripper is shown in Figure 2.1. The gripper has a crossfire infrared sensor to detect the presence of an object between the fingers. Potentiometers and strain gauges allow position and force feedback control to be implemented.

2.2 Software Interface

The top level interface through the gripper is through the VxWorks gripper library on the MV135 68020 processor boards. The actual servoing is accomplished with the 68HC11 EVB. Communication occurs between the MV135 68020 processor boards and the 68HC11 EVB via an RS232 cable. This configuration is shown in Figure 2.2.

2.3 Hardware Interface

The CIRSSE gripper is a pneumatically controlled system shown in Figure 2.3. The pressure is adjusted by writing an 8-bit value to port B of the 68HC11. This port is connected to a D/A converter outside of the 68HC11 evaluation board. The D/A converter generates a signal that is amplified to control a servo valve. This effectively controls the rate at which air enters the piston from both sides. Table 2.1 shows the port mapping.

Since the air pressure is fixed at all times, the 8-bit value at the 68HC11 port merely acts as an integral gain. A point exists where the servo valve delivers air at the same rate to both sides of the piston. The digital output value at this point is known as $z_{\text{pressure}}$. Although the digital output value may take on the full range of
Gripper

Figure 2.1: CIRSSE Gripper

<table>
<thead>
<tr>
<th>function</th>
<th>68HC11 port</th>
</tr>
</thead>
<tbody>
<tr>
<td>position</td>
<td>E0</td>
</tr>
<tr>
<td>force</td>
<td>E1</td>
</tr>
<tr>
<td>crossfire sensor</td>
<td>C bit 0</td>
</tr>
<tr>
<td>air valve</td>
<td>B bit 7-0</td>
</tr>
</tbody>
</table>

Table 2.1: 68HC11 Hardware Interface
VxWorks Host

Figure 2.2: Configuration
Figure 2.3: Schematic of Pneumatic Piston Assembly
8-bit values, in practice, only very slight perturbations are needed from \( z_{\text{pressure}} \) in order to move the fingers of the gripper to any given position or force setpoint.

The current method used to adjust the pressure is a proportional-integral-derivative (PID) controller. All parameters may be dynamically adjusted while the gripper controller is servoing.
The gripper library is a standardized C library interface to the gripper controller. This allows future changes to be made to the software in the 68HC11 without invalidating the code written at the application level.

The gripper library also isolates the application software from the real-time constraints of the gripper protocol. This is done by providing the proper intercharacter delay and the intercommand delay when sending commands to the gripper.

3.1 grRegWrite, grRegRead

3.1.1 Synopsis

```
#include <grLib.h>

int grRegWrite(int fd, GRREG regNo, double value)
int grRegRead(int fd, GRREG regNo, double *pValue)
```

3.1.2 Description

These functions read and write to software registers in the 68HC11. In all of these functions, the argument \( fd \) is a file descriptor returned by `open (2V)` [Sun 88].

The argument \( regNo \) refers to one of the constants in Table 3.1. The mathematical representations of these registers is given in Table 4.8.

3.1.3 Return Value

These functions return 0 if the call is successful otherwise 1 is returned.
<table>
<thead>
<tr>
<th>constant</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>grReg_positionSetPoint</td>
<td>fully open = 0, fully closed = 255</td>
</tr>
<tr>
<td>grReg_positionPropGain</td>
<td></td>
</tr>
<tr>
<td>grReg_positionDerivGain</td>
<td></td>
</tr>
<tr>
<td>grReg_positionIntglGain</td>
<td></td>
</tr>
<tr>
<td>grReg_positionIntglMin</td>
<td></td>
</tr>
<tr>
<td>grReg_positionIntglMax</td>
<td></td>
</tr>
<tr>
<td>grReg_forceSetPoint</td>
<td>minimum force = 0, maximum force = 255</td>
</tr>
<tr>
<td>grReg_forcePropGain</td>
<td></td>
</tr>
<tr>
<td>grReg_forceDerivGain</td>
<td></td>
</tr>
<tr>
<td>grReg_forceIntglGain</td>
<td></td>
</tr>
<tr>
<td>grReg_forceIntglMin</td>
<td>lower bound on the integral of the force error</td>
</tr>
<tr>
<td>grReg_forceIntglMax</td>
<td>upper bound on the integral of the force error</td>
</tr>
<tr>
<td>grReg_xfireGrabThreshold</td>
<td>for grab mode, if $x_{\text{sensor}} \leq x_{\text{threshold}}$ then force servo, otherwise position servo</td>
</tr>
<tr>
<td>grReg_xfireLED</td>
<td>turns crossfire LED on or off. off = 0, on = 1</td>
</tr>
<tr>
<td>grReg_zeroPressure</td>
<td>digital output value to air valve to apply zero force</td>
</tr>
<tr>
<td>grReg_position</td>
<td>fully open = 0, fully closed = 255</td>
</tr>
<tr>
<td>grReg_positionError</td>
<td></td>
</tr>
<tr>
<td>grReg_positionErrorPrev</td>
<td></td>
</tr>
<tr>
<td>grReg_positionPropTerm</td>
<td></td>
</tr>
<tr>
<td>grReg_positionDerivTerm</td>
<td></td>
</tr>
<tr>
<td>grReg_positionIntglTerm</td>
<td></td>
</tr>
<tr>
<td>grReg_positionIntgl</td>
<td></td>
</tr>
<tr>
<td>grReg_positionIntglNext</td>
<td></td>
</tr>
<tr>
<td>grReg_positionControl</td>
<td></td>
</tr>
<tr>
<td>grReg_positionControlOutput</td>
<td></td>
</tr>
<tr>
<td>grReg_force</td>
<td>min force = 0, max force = 255</td>
</tr>
<tr>
<td>grReg_forceError</td>
<td></td>
</tr>
<tr>
<td>grReg_forceErrorPrev</td>
<td></td>
</tr>
<tr>
<td>grReg_forcePropTerm</td>
<td></td>
</tr>
<tr>
<td>grReg_forceDerivTerm</td>
<td></td>
</tr>
<tr>
<td>grReg_forceIntglTerm</td>
<td></td>
</tr>
<tr>
<td>grReg_forceIntgl</td>
<td></td>
</tr>
<tr>
<td>grReg_forceIntglNext</td>
<td></td>
</tr>
<tr>
<td>grReg_forceControl</td>
<td></td>
</tr>
<tr>
<td>grReg_forceControlOutput</td>
<td></td>
</tr>
<tr>
<td>grReg_xfireSensor</td>
<td>min intensity = 0 maximum intensity = 255</td>
</tr>
<tr>
<td>grReg_realTime</td>
<td>time in seconds, rolls over back to zero every 65536*(8.19 \text{ milliseconds}) = 536.739 \text{ seconds}</td>
</tr>
</tbody>
</table>

Table 3.1: Register Constants
constant | remarks
--- | ---
S_grLib_VxWorks_INVARG | An invalid argument was given when calling the function.
S_grLib_VxWorks_INVCMD | An invalid command was given. This indicates that garbage was sent over the RS232 serial line, probably a hardware fault.
S_grLib_VxWorks_BAD_RESPONSE | The response from the 68HC11 could not be recognized because the 68HC11 EVB was not initialized properly.
S_grLib_VxWorks_TIMEOUT | There was no response from the 68HC11 EVB.
EBADDF | ioctl(2) failed because the stream was not associated with a valid file descriptor.
ENOTTY | ioctl(2) FIONREAD request does not apply to kind of object associated with the file stream.
EINVAL | The request or arguments to ioctl(2) were invalid.
EFAULT | The Data transfer that occurred within ioctl(2) resulted in a read or write to an address outside of the process' address space.

Table 3.2: Errors

3.1.4 Errors

The error codes returned are shown in Table 3.2.

3.1.5 See Also

In the UNIX man pages, see open (2V), close (2) [Sun 88].
3.2  grSrvGrab, grSrvForce, grSrvPos

3.2.1  Synopsis

```c
#include <grLib.h>

int grSrvGrab(int fd)
int grSrvPos(int fd)
int grSrvForce(int fd)
```

3.2.2  Description

These functions enable various servo modes. The gripper controller software in the 68HC11 attempts to maintain the position and force set points set by the `grReg(2)` commands.

In all these functions, the argument `fd` is a file descriptor returned by `open(2V)`.

`grSrvGrab()` enables position mode or servo mode depending on whether there is an object detected between the fingers of the gripper.

`grSrvPos()` enables position servo mode and attempts to maintain the position.

`grSrvForce()` enables force servo mode and attempts to maintain the force set point.

3.2.3  Return Value

These functions return 0 if the call is successful otherwise 1 is returned.

3.2.4  Errors

See Table 3.2.
CHAPTER 4
Firmware Software Architecture

The software for the gripper controller is a simple real-time executive which operates in three different modes.

**grab servo mode** servos to the force set point if there is an object detected between the fingers, otherwise servos to the position set point.

**position servo mode** servos the gripper to maintain a position set point.

**force servo mode** servos the gripper to maintain a force set point.

For each section or subsection heading, the relevant subroutine in the gripper controller source code is indicated in parentheses.

4.1 Initialization

4.1.1 Power Up Initialization (powerUpStart)

Upon power up, the 68HC11 EVB \(^1\) starts executing instructions at 0xe000. The power up startup code sets the OPTION register and TMSK2 register immediately since these must be set within 64 bus-cycles after reset [Motorola 89, p. 3-8]. After this period expires, some of the bits in these registers become read-only and may not be set.

4.1.2 ACIA Initialization (ACIAInit, ONACIA)

ACIAInit initializes the ACIA on power up to enable communication via the RS-232 serial port. ONACIA re-initializes the ACIA after an error.

---

\(^1\)The 68HC11 EVB uses the MC68HC11A1 version of the M68HC11 family
Figure 4.1: Software Architecture
Note that there are two RS-232 serial ports on the M68HC11 EVB. The terminal port is connected to the ACIA. The other host port is connected to the SCI on the M68HC11 and is not used [Motorola 86, Figure 6-2].

4.1.3 RAM Initialization (initRAM)

The on-chip RAM space is only 256 bytes. The on-chip EEPROM space is only 512 bytes [Motorola 89, Table 1-1]. Since the gripper controller software exceeds the capacity of both on-chip memories, an external RAM and an external EPROM are needed.

Two methods were considered in allocating program space to the external RAM and EPROM.

1. using the external RAM area for uninitialized data and initialized data; using the EPROM area for constant data, initialized data, and code.

2. using the RAM area for all code and data.

The first method uses EPROM and RAM space optimally. However, it introduces complexity by requiring a separate section of memory for constant data, initialized data, and uninitialized data.

The second method treats all code and data the same and merely copies the whole contents of the EPROM to the RAM area and then executes the code residing in RAM. The primary benefit of this method is that it is trivial to implement at the expense of wasting some space by needlessly duplicating constant data and code.

The second method is used for this application. The firmware copies itself to RAM after performing a few required initializations and jumps to the first routine main in RAM. Note that all jumps and branches prior to the main routine must use relative addressing since the program is assembled with the origin at the start of RAM (0xc000) not EPROM (0xe000). A memory map is shown in Table 4.1.
### 4.1.4 Hardware Initialization (hwInit)

During hardware initialization, the following are accomplished.

- crossfire port initialization
- A/D converter register initialization
- interrupt subroutine vector initialization
- real-time interrupt register initialization
- hardware diagnostics

#### 4.1.4.1 Crossfire Port Initialization (hwInitXfire)

The crossfire LED is turned on by writing to bit 0 of the PORTC register. The port C databus is bi-directional. Each bit in the DDRC register determines whether the corresponding bit of the databus is either an input or output line [Motorola 89, p. 7-20]. Thus, proper configuration of the DDRC register requires that bit 0 be high.

<table>
<thead>
<tr>
<th>address</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0000</td>
<td>direct RAM</td>
</tr>
<tr>
<td>0xc000</td>
<td>user RAM</td>
</tr>
<tr>
<td></td>
<td>gripper controller code gets copied EPROM and is executed here</td>
</tr>
<tr>
<td>0xdf00</td>
<td>top of stack</td>
</tr>
<tr>
<td>0xe000</td>
<td>EPROM initialization copies code and data to RAM</td>
</tr>
</tbody>
</table>

Table 4.1: Memory Map
4.1.4.2 A/D converter initialization (hwInitADC/ADCInit)

The A/D converter subsystem is initialized by the ADPU and CSEL bits in
the OPTION control register. The A/D charge pump is initially disabled upon reset.
The ADPU bit must be set to one to enable the A/D charge pump [Motorola 89, p.
12-12]. The CSEL bit is set to zero for this application since additional A/D error
is caused by internal noise if the alternate clock source for the on-chip EEPROM
charge pump is selected during A/D conversion [Motorola 89, p. 12-13].

4.1.4.3 Interrupt Vector Initialization (RTISetISR)

During each of the grab, position, and force servo modes mentioned in Sec-
tion 4, a separate interrupt subroutine is used. These interrupt subroutines are set
with the RTISetISR subroutine.

4.1.4.4 Real-Time Interrupt Initialization (RTIInit)

The real-time interrupt serves three purposes.

- provides periodic activation of the servo loop to ensure a constant sampling
  rate.

- allows a timer to be maintained so that the delay for grab mode can be im-
  plemented.

- maintains a real-time clock to determine if the servo loop is executing within
  the proper time.

RTIInit first sets the tick counter to zero. The counter is incremented on
every real-time interrupt. This counter is used to calculate the real-time in seconds
and is used to schedule events in grab mode.

Since the interrupt vector table is located from 0xffd6 to 0xffff, the Buffalo
monitor automatically presets the interrupt vectors. However, these vectors merely
Table 4.2: Interrupt Vector Map with Buffalo monitor

<table>
<thead>
<tr>
<th>address</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00c4</td>
<td>Start of Buffalo JMP vector table</td>
</tr>
<tr>
<td>0x00eb</td>
<td>JMP RTIInt</td>
</tr>
<tr>
<td>0x00ff</td>
<td>End of JMP vector table</td>
</tr>
<tr>
<td>0xffd6</td>
<td>Start of Buffalo monitor vector table</td>
</tr>
<tr>
<td>0xfff0</td>
<td>0x00eb</td>
</tr>
<tr>
<td>0xffffff</td>
<td>End of Buffalo monitor vector table</td>
</tr>
</tbody>
</table>

Table 4.3: Interrupt Vector Map with gripper controller

<table>
<thead>
<tr>
<th>address</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00c4</td>
<td>Start of unused JMP vector table</td>
</tr>
<tr>
<td>0x00eb</td>
<td>JMP RTIInt (still initialized but not used)</td>
</tr>
<tr>
<td>0x00ff</td>
<td>End of unused JMP vector table</td>
</tr>
<tr>
<td>0xffd6</td>
<td>Start of gripper controller vector table</td>
</tr>
<tr>
<td>0xfff0</td>
<td>RTIInt</td>
</tr>
<tr>
<td>0xffffff</td>
<td>End of gripper controller vector table</td>
</tr>
</tbody>
</table>

point to JMP instructions in RAM which jump to the appropriate interrupt handler. Thus, a JMP instruction to the real-time interrupt handler must be present at the real-time interrupt address of the Buffalo monitor jump table. This configuration is shown in Table 4.2.

When the Buffalo monitor is removed and replaced with the gripper controller software, the jump table in RAM is no longer necessary since the interrupt vector table located from 0xffd6 to 0xffffff can be set with the appropriate vectors by initializing the corresponding EPROM locations. The JMP instruction is still harmlessly initialized since the gripper controller is never aware of whether it was copied from EPROM or downloaded via the RS-232 port. This configuration is shown in Table 4.3.
The TFLG2 register is used to clear the RTIF status bit which is automatically set at the end of every interrupt [Motorola 89, p. 10-12]. The RTI rate is then set by initializing the lower two bits of the PACTL register.

When real-time interrupt initialization is complete, the interrupts are in a disabled state. They may be turned on and off with the RTIStart and RTIStop routines.

A real-time clock is maintained and is displayed as seconds. This parameter, \( t \), is one of the gripper controller software registers shown in Table 4.8. If the interrupt handler routine does not execute in time for the next interrupt then the real-time clock here will be off from the actual elapsed time by some integer factor.

For example, if the interrupt routine takes 10ms to execute and an interrupt occurs every 8.19ms, the next interrupt will be missed. Therefore the real-time clock will be slowed by a factor of two. Thus, by merely observing the real-time clock and using a wristwatch, it is possible to verify that real-time interrupts are not being missed. An example of this type of error is given in Figure 4.2.

4.1.4.5 Hardware Diagnostics (hwInit, hwInitADC)

Hardware diagnostics are performed to ensure that the following features of the M68HC11 EVB are functional:

- A/D conversion
- real-time interrupts

To test the A/D subsystem, a conversion command is output to the ADCTL register and the CCF flag is then polled to ensure that a conversion complete is returned at approximately the correct time.

To test the real-time interrupt, a subroutine to set a byte in memory is installed as an interrupt handler. Proper generation of interrupts is verified by checking the
4.1.5 Software Initialization (swInit)

Software initialization consists of all the run-time initialization of various constants used in the controller algorithms. The two goals are to minimize the amount of information that needs to be updated if parameters are changed and to optimize performance by computing common subexpressions beforehand.

4.2 Command Processing (processCmd)

Command processing is performed at the non-interrupt driven level. This level of execution performs all the command line processing through the RS-232 serial interface.

First, the software reads a command line from the RS-232 serial port. Each
The command consists of a single letter. When a command is received, the command is parsed by searching the table of letters shown in Table 4.4.

Using the index into this table, a corresponding entry is found in the table of subroutine addresses shown in Table 4.5. The subroutine is then invoked to execute the command. The X register points to the current character being parsed. Upon entry into each of the subroutines invoked, the X register points to the arguments in the command buffer.

The commands for the gripper controller are shown in Table 4.6. The argument register in the write register and read register commands refers to one of the registers in Table 4.8. The registerValue parameter is a floating point number.

After processing each command, a line is returned to the host through the

<table>
<thead>
<tr>
<th>offset</th>
<th>command letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>g</td>
</tr>
<tr>
<td>1</td>
<td>p</td>
</tr>
<tr>
<td>2</td>
<td>f</td>
</tr>
<tr>
<td>3</td>
<td>w</td>
</tr>
<tr>
<td>4</td>
<td>r</td>
</tr>
<tr>
<td>5</td>
<td>s</td>
</tr>
</tbody>
</table>

Table 4.4: Command Character Table

<table>
<thead>
<tr>
<th>offset</th>
<th>process command subroutine</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>grSrvGrab</td>
</tr>
<tr>
<td>2</td>
<td>grSrvPos</td>
</tr>
<tr>
<td>4</td>
<td>grSrvForce</td>
</tr>
<tr>
<td>6</td>
<td>grRegRead</td>
</tr>
<tr>
<td>8</td>
<td>grRegWrite</td>
</tr>
<tr>
<td>10</td>
<td>dispGripStat</td>
</tr>
</tbody>
</table>

Table 4.5: Subroutine Table
<table>
<thead>
<tr>
<th>function</th>
<th>command to 68HC11</th>
<th>response from 68HC11</th>
</tr>
</thead>
<tbody>
<tr>
<td>grab servo mode</td>
<td>g</td>
<td>errorCode</td>
</tr>
<tr>
<td>position servo mode</td>
<td>p</td>
<td>errorCode</td>
</tr>
<tr>
<td>force servo mode</td>
<td>f</td>
<td>errorCode</td>
</tr>
<tr>
<td>read register</td>
<td>r register</td>
<td>errorCode registerValue</td>
</tr>
<tr>
<td>write register</td>
<td>w register</td>
<td>registerValue</td>
</tr>
</tbody>
</table>

Table 4.6: RS-232 Serial Port Commands

<table>
<thead>
<tr>
<th>errorCode</th>
<th>error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no error</td>
</tr>
<tr>
<td>1</td>
<td>invalid argument</td>
</tr>
<tr>
<td>2</td>
<td>invalid command</td>
</tr>
</tbody>
</table>

Table 4.7: Error Codes

RS-232 serial port. The errorCode field contains the error status code. The meaning of the errorCode field is shown in Table 4.7. There is another registerValue field returned in response to the read register command. This is a floating point number.

4.2.1 Register Model

The register model is used to set all of the parameters for the gripper controller primarily because the control algorithm is expected to change often. Therefore, it is important that control parameters can be easily added or deleted from the system without requiring any major changes to the gripper protocol.

In addition to the PID gains, there are additional registers representing terms which must be computed at the end of every sample period. These terms are included in order to assist the user in determining the correct gains to be used with a gripper. The mathematical representations for all these registers are shown in Table 4.8.
<table>
<thead>
<tr>
<th>register</th>
<th>control parameter</th>
<th>writable</th>
<th>representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>position set point</td>
<td>yes</td>
<td>$P_{setpnt}$</td>
</tr>
<tr>
<td>1</td>
<td>position proportional gain</td>
<td>yes</td>
<td>$P_{pgain}$</td>
</tr>
<tr>
<td>2</td>
<td>position derivative gain</td>
<td>yes</td>
<td>$P_{dgain}$</td>
</tr>
<tr>
<td>3</td>
<td>position integral gain</td>
<td>yes</td>
<td>$P_{igain}$</td>
</tr>
<tr>
<td>4</td>
<td>position integral minimum</td>
<td>yes</td>
<td>$P_{imin}$</td>
</tr>
<tr>
<td>5</td>
<td>position integral maximum</td>
<td>yes</td>
<td>$P_{imax}$</td>
</tr>
<tr>
<td>6</td>
<td>force set point</td>
<td>yes</td>
<td>$F_{setpnt}$</td>
</tr>
<tr>
<td>7</td>
<td>force proportional gain</td>
<td>yes</td>
<td>$F_{pgain}$</td>
</tr>
<tr>
<td>8</td>
<td>force derivative gain</td>
<td>yes</td>
<td>$F_{dgain}$</td>
</tr>
<tr>
<td>9</td>
<td>force integral gain</td>
<td>yes</td>
<td>$F_{igain}$</td>
</tr>
<tr>
<td>10</td>
<td>force integral minimum</td>
<td>yes</td>
<td>$F_{imin}$</td>
</tr>
<tr>
<td>11</td>
<td>force integral maximum</td>
<td>yes</td>
<td>$F_{imax}$</td>
</tr>
<tr>
<td>12</td>
<td>crossfire grab threshold</td>
<td>yes</td>
<td>$X_{threshold}$</td>
</tr>
<tr>
<td>13</td>
<td>crossfire grab delay</td>
<td>yes</td>
<td>$X_{delay}$</td>
</tr>
<tr>
<td>14</td>
<td>crossfire LED</td>
<td>yes</td>
<td>$X_{led}$</td>
</tr>
<tr>
<td>15</td>
<td>zero pressure point</td>
<td>yes</td>
<td>$Z_{pressure}$</td>
</tr>
<tr>
<td>16</td>
<td>position</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>position error</td>
<td>no</td>
<td>$P_{err} = P - P_{setpnt}$</td>
</tr>
<tr>
<td>18</td>
<td>previous position error</td>
<td>no</td>
<td>$P_{prev}$</td>
</tr>
<tr>
<td>19</td>
<td>position proportional term</td>
<td>no</td>
<td>$P_{term} = P_{pgain}P_{err}$</td>
</tr>
<tr>
<td>20</td>
<td>position derivative term</td>
<td>no</td>
<td>$P_{dterm} = P_{dgain}(P_{term} - P_{prev})$</td>
</tr>
<tr>
<td>21</td>
<td>position integral term</td>
<td>no</td>
<td>$P_{iterm} = P_{igain}P_{i}$</td>
</tr>
<tr>
<td>22</td>
<td>position integral</td>
<td>no</td>
<td>$P_i$</td>
</tr>
<tr>
<td>23</td>
<td>next position integral</td>
<td>no</td>
<td>$P_{next} = P_i + \frac{1}{T}(P_{prev} + P_{err})$</td>
</tr>
<tr>
<td>24</td>
<td>position control</td>
<td>no</td>
<td>$P_{ctl} = P_{term} + P_{dterm} + P_{iterm}$</td>
</tr>
<tr>
<td>25</td>
<td>position control output</td>
<td>no</td>
<td>$P_{out} = \min(\max(P_{ctl} + Z_{pressure}, 0), 255)$</td>
</tr>
<tr>
<td>26</td>
<td>force</td>
<td>no</td>
<td>$f$</td>
</tr>
<tr>
<td>27</td>
<td>force error</td>
<td>no</td>
<td>$f_{err} = f - F_{setpnt}$</td>
</tr>
<tr>
<td>28</td>
<td>previous force error</td>
<td>no</td>
<td>$f_{prev}$</td>
</tr>
<tr>
<td>29</td>
<td>force proportional term</td>
<td>no</td>
<td>$f_{term} = f_{pgain}f_{err}$</td>
</tr>
<tr>
<td>30</td>
<td>force derivative term</td>
<td>no</td>
<td>$f_{dterm} = f_{dgain}(f_{term} - f_{prev})$</td>
</tr>
<tr>
<td>31</td>
<td>force integral term</td>
<td>no</td>
<td>$f_{iterm} = f_{igain}f_{i}$</td>
</tr>
<tr>
<td>32</td>
<td>force integral</td>
<td>no</td>
<td>$f_i$</td>
</tr>
<tr>
<td>33</td>
<td>next force integral</td>
<td>no</td>
<td>$f_{next} = f_i + \frac{1}{T}(f_{prev} + f_{err})$</td>
</tr>
<tr>
<td>34</td>
<td>force control</td>
<td>no</td>
<td>$f_{ctl} = f_{term} + f_{dterm} + f_{iterm}$</td>
</tr>
<tr>
<td>35</td>
<td>force control output</td>
<td>no</td>
<td>$f_{out} = \min(\max(f_{ctl}, 0), 255)$</td>
</tr>
<tr>
<td>36</td>
<td>crossfire sensor</td>
<td>no</td>
<td>$X_{sensor}$</td>
</tr>
<tr>
<td>37</td>
<td>expiration time</td>
<td>no</td>
<td>$t_{expire}$</td>
</tr>
<tr>
<td>38</td>
<td>real time</td>
<td>no</td>
<td>$t$</td>
</tr>
<tr>
<td>39</td>
<td>grab state</td>
<td>no</td>
<td>$s_{grab}$</td>
</tr>
<tr>
<td>40</td>
<td>grab mask</td>
<td>no</td>
<td>$s_{mask}$</td>
</tr>
</tbody>
</table>

Table 4.8: Registers
4.2.2 Servo Modes (grSrvGrab, grSrvPos, grSrvForce)

The grab, position, and force servo commands initiate calls to grSrvGrab, grSrvPos, and grSrvForce respectively. All these routines initialize an interrupt subroutine vector using RTISetISR. This creates three top level states that are initiated by each command. The top level states for the gripper controller are shown in Figure 4.3. The gripper controller begins in grab servo mode upon initialization.

Both positionServo and forceServo are similar in that they contain no additional states. However, the grabServo mode contains substates.

When the gripper controller is in the grab servo state, the gripper will close whenever an object blocks the crossfire beam between the fingers. This closing can be delayed a certain period of time. Figure 4.4 shows the different states for grab servo mode. In both Position Wait and Position Delay states, position servoing is performed and in the Force state, force servoing is performed.

Figure 4.3: Top Level State Transition Diagram
Figure 4.4: Grab Servo Mode State Transition Diagram
### Table 4.9: State Transition Table

<table>
<thead>
<tr>
<th>timer expired</th>
<th>crossfire blocked</th>
<th>state 3\textsubscript{grab}</th>
<th>action</th>
<th>next state 3\textsubscript{grab}</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>no</td>
<td>position wait</td>
<td>position servo</td>
<td>position wait</td>
</tr>
<tr>
<td>no</td>
<td>no</td>
<td>position delay</td>
<td>position servo</td>
<td>position wait</td>
</tr>
<tr>
<td>no</td>
<td>no</td>
<td>force</td>
<td>position servo</td>
<td>position wait</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>position wait</td>
<td>start timer</td>
<td>position delay</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>position delay</td>
<td>position servo</td>
<td>position delay</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>force</td>
<td>force</td>
<td>force</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>position wait</td>
<td>position servo</td>
<td>position wait</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>position delay</td>
<td>position servo</td>
<td>position wait</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>force</td>
<td>position servo</td>
<td>position wait</td>
</tr>
<tr>
<td>yes</td>
<td>yes</td>
<td>position wait</td>
<td>start timer</td>
<td>position delay</td>
</tr>
<tr>
<td>yes</td>
<td>yes</td>
<td>position delay</td>
<td>force servo</td>
<td>force</td>
</tr>
<tr>
<td>yes</td>
<td>yes</td>
<td>force</td>
<td>force</td>
<td>force</td>
</tr>
</tbody>
</table>

### 4.3 Interrupt Level (\text{positionServo}, \text{forceServo}, \text{grabServo})

The interrupt level refers to the interrupt driven software in the controller, the interrupt handler code. This level of execution performs the servoing of the fingers. A periodic interrupt occurs every sampling period $T$. $T$ is 8.19 milliseconds.

The ADCTL register is configured so that the position, force, and crossfire sensors are read simultaneously from ports E0, E1, and E3 respectively as shown in Figure 2.1. Conversions are performed on all three channels simultaneously by setting the SCAN bit to zero and setting the MULT bit to one [Motorola 89, p. 12-14].

#### 4.3.1 Grab Servo (\text{grabServo})

Table 4.9 shows the the grab servo state table. There are two inputs which cause all state changes. Table 4.11 is derived after substituting the bit representations in Table 4.10.

The actual implementation of the state transition table uses the first three
### Table 4.10: Bit Representation

<table>
<thead>
<tr>
<th>symbol</th>
<th>bit representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td>yes</td>
<td>1</td>
</tr>
<tr>
<td>position wait</td>
<td>00</td>
</tr>
<tr>
<td>position delay</td>
<td>01</td>
</tr>
<tr>
<td>force</td>
<td>10</td>
</tr>
<tr>
<td>position servo</td>
<td>00</td>
</tr>
<tr>
<td>force servo</td>
<td>01</td>
</tr>
<tr>
<td>start timer</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 4.11: State Transition Table in Bit Representation

<table>
<thead>
<tr>
<th>timer expired</th>
<th>crossfire blocked</th>
<th>state $s_{grab}$</th>
<th>action $s_{grab}$</th>
<th>next state $s_{grab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>00</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>01</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>10</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>00</td>
<td>10</td>
<td>01</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>01</td>
<td>00</td>
<td>01</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>10</td>
<td>01</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>00</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>01</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>10</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>00</td>
<td>10</td>
<td>01</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>01</td>
<td>01</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>10</td>
<td>01</td>
<td>10</td>
</tr>
</tbody>
</table>
columns of Table 4.11 as an offset into a table which contains the action routine to be performed and the next state.

4.4 Critical Data

There are two sets of critical data.

- the floating point control parameters written and read by the user via the write register and read register commands
- the working memory used by the floating point routines

4.4.1 Floating Point Control Parameters

Critical data is inevitably introduced because of the use of floating point control parameters. There is no atomic instruction which can read or write 3 bytes, the length of a floating point number. When a critical control parameter is set, the interrupts are masked while the floating point number is being transferred to the register area used by the interrupt handlers. This prevents the interrupt handler from using a partially updated floating point parameter. Fortunately, the amount of critical code is limited to two places in the software. Thus, masking can be performed without losing any interrupts and without causing any discontinuities in the servoing.

4.4.2 Working Memory of Floating Point Routines

Critical data also exists in the working memory of the floating point routines, labeled floatContext in the source code. Since one set of floating point routines are used for both non-interrupt and interrupt driven software, potential problems arise if both levels of execution are using the same data.

Since the working memory only involves 6 bytes of memory which can be copied quickly, the real-time interrupt handler saves the non-interrupt level contents
of this memory area before calling the interrupt handler. After the interrupt handler completes, the non-interrupt level contents is restored and execution resumes.

4.5 EPROM

The gripper controller firmware is designed to replace the Buffalo monitor firmware at 0x6000. Testing has been simplified by avoiding the use of any programming methods which would require the configuring of jumpers.

4.6 Control Loop

The control algorithm is essentially the same for position and force servoing. Thus, it would have been possible to have one generic control loop subroutine. However, this would require one of the following time consuming activities:

- indexing to each of the two control structures for each position and force parameter.

- copying of the control structure to and from the memory area used by the shared servo loop.

Both indexing and copying memory are time consuming activities for a large number of registers. Indexing also complicates the code significantly. It was decided to keep the code and data as simple and as fast as possible by keeping the position and force servo loops separate at the expense of using slightly more memory for code.

4.7 Command Processing Real-Time Constraints

There is a fundamental limit imposed on the number of characters which may be sent to the gripper controller in a certain period of time. Because the servo loop must always be executed every 8.19 ms, the non-interrupt level software only
executes between the time the servo loop code has completed and the next real-time interrupt. Since all reads from the RS-232 serial port occur at the non-interrupt level, there is a possibility that characters may not be read if characters are sent down too quickly. Thus, in order to guarantee that each character is read by the gripper controller software, it is necessary to wait at least 20 ms between characters. This will ensure that the servo loop has completely executed and that the non-interrupt level software has read the character from the serial port.

In addition to waiting between characters, it takes a minimum of 40ms to process a command. Thus, there must be at least a 40ms delay before any characters are sent down to the 68HC11 following any the input of any command.

4.8 Debugging

The gripper controller can be configured for EPROM or downloading via the RS-232 port. The latter configuration is useful for debugging the software.

4.8.1 EPROM Configuration

The software originally is located all in EPROM. When initialization begins the initRAM subroutine copies EPROM to RAM. The source file `ctl.asm` contains this code.

4.8.2 Debug Configuration

The software is downloaded into RAM at 0xc000. In this configuration, initRAM must not be called since the software is already relocated and the EPROM contains the Buffalo monitor. This source file is derived from `ctl.asm` by deleting the bsr initRAM instruction. This is done automatically by the `Imakefile`. 
A set of software development tools allows the programmer to perform all editing and debugging on a Sun workstation. These software development tools work within emacs and X windows to create an integrated edit-compile-debug environment. The procedure for editing, compiling and debugging is presented in this chapter.

The hardware configuration and the tools needed are shown in Figure 5.1.

This section assumes you are already familiar with UNIX and X windows.

5.1 Initializing the Network Daemon

Before any communication from the Sun workstation to the 68HC11 EVB can begin, a network daemon must first be present on one of the 68020 MV135 processor cards in the VME cage. This network daemon must be present on the same 68020 MV135 processor card that is connected to the 68HC11 EVB via an RS232 serial cable. In the following example, the 68HC11 EVB must be connected to the lower serial port (/tyCo/1).

The network daemon is invoked with the commands

```
rlogin vx2.ral.rpi.edu
ld < /usr2/testbed/CIRSSE/installed/VxWorks/bin/rDevd.o
rDevInit "/tyCo/1"
```

at the VxWorks prompt.

5.2 Creating the 68HC11 Buffalo Monitor Window

A terminal connection to the 68HC11 Buffalo monitor is started with
Figure 5.1: Hardware Configuration
rDevLogin hostname

in any xterm window.

5.3 Constructing an Imakefile

An Imakefile merely lists all the targets and dependencies which need to be generated. In this case, the Imakefile is trivial and only consists of one line.

AllTarget (prog.Y)

5.4 Assembling and Downloading

The resulting program may be compiled and downloaded by issuing the following command.

cmkmf prog.Y

A listing file named prog.lst is created. Lines with errors are marked with a letter from A-Z in the first column. Here is an example.

```
U 0000 7e 00 00 main jmp main2
0003 end

0000 main
```

The U stands for undefined. A complete listing of all error codes is given in the manual page [Colley 87].
A variety of tools have been constructed to aid in developing software for the M68HC11 EVB. These tools provide simple ways to assemble, debug, and download programs.

6.1  rDevLogin - remote device login

6.1.1  Synopsis

rDevLogin hostname

6.1.2  Description

The rDevLogin client redirects terminal input and output to a rDevd server at the specified hostname. The rDevLogin client attempts to open a connection at port 8200 of hostname. Using the select(2), read(2), and write(2) system calls, a full duplex connection is implemented [Sun 88].

6.2  rDevd - remote device daemon

The network server rDevd runs on VxWorks to create a full-duplex connection between a socket and a serial port on the 68020 MV135.

6.2.1  Synopsis

rDevInit deviceName
6.2.2 Description

The rDevd server listens on two public ports and waits for incoming connections. When it accepts a connection on either port, rDevd provides a byte stream between the client and the device specified by deviceName.

The two ports are used in order to establish two independent paths to send data to the tty device. One port, symbolically named TELPORT, provides a full-duplex connection to the tty device. Another port, symbolically named CMDPORT, provides only a send path to the tty device. This allows TELPORT to be used as an interactive terminal interface to the tty device while CMDPORT can be used to send commands to the tty device. Figure 6.1 shows this arrangement.

The select(2) call is used to look for incoming connections or data. Any input event received by the rDevd server results in two actions.

- an accept action where a connection is established.
- a transfer action where a block of data is transferred.

The inputs detected by select(2) are mapped into the actions in Table 6.1. Both the socket index and destination socket index columns refer to indices into an array of file descriptors. When data to be read appears on one of the file descriptors in the array, either an accept or transfer action is taken using the action column. The array element pointed to by destination socket index is used to store the file descriptor of the new socket connection accepted or store the file descriptor of the socket where data is to be written.

6.3 rDevCmd

The network client rDevCmd runs on SunOS to send a string to the rDevd server. Normally a carriage return always follows the string unless the -n parameter is specified.
Figure 6.1: Network Connections
<table>
<thead>
<tr>
<th>socket index</th>
<th>action</th>
<th>destination socket index</th>
</tr>
</thead>
<tbody>
<tr>
<td>TELNETLISTEN</td>
<td>accept</td>
<td>TELNETMSG</td>
</tr>
<tr>
<td>TELNETMSG</td>
<td>transfer</td>
<td>DEV</td>
</tr>
<tr>
<td>CMDLISTEN</td>
<td>accept</td>
<td>CMDMSG</td>
</tr>
<tr>
<td>CMDMSG</td>
<td>transfer</td>
<td>DEV</td>
</tr>
<tr>
<td>DEV</td>
<td>transfer</td>
<td>TELNETMSG</td>
</tr>
</tbody>
</table>

Table 6.1: Action Table

The client rDevCmd uses the connect(2) system call to initiate a connection on a socket.

6.4 a611floatpp

The utility a611floatpp is a preprocessor which is designed to scan its standard input for occurrences of floating point numbers. If a floating point number is found and does not occur within a comment, it is expanded to its equivalent 3 byte hexadecimal representation in 68HC11 assembler. This preprocessor is used in conjunction with a611 to allow the use of floating point numbers in 68HC11 source code using the floating point routines in the gripper controller software.

6.5 moto2moto

The utility moto2moto reformats Motorola S-records by reading in the original S-records and outputting S-records which are no longer than a specified length. This is needed because the S-records produced by the int2moto utility are too long in length to be read by the Buffalo monitor.

The program operates by reading in each S-record and storing each in a cell of a linked list. Each cell of the linked list is then scanned a second time. The object code for each cell is output until maxBytes are reached. A new S-record is started and more object code is output until no more object code remains in the cell. This
Figure 6.2: Software Architecture

linked list data structure is depicted in Figure 6.2.

Only S-records of type S0, S1, and S10 can be read by moto2moto.

6.6 motooffset

The utility motooffset offsets the base address of Motorola S-records. This is necessary for EPROM programmers which require a base address of 0x0000 in order to read in the S-records correctly.

For example, a program which is normally downloaded and tested in RAM may be located at 0xc000. The S-records would normally start at 0xc000. If this
program is to be downloaded from the EPROM, relocatable startup code must be added to copy the program from EPROM to RAM. The resulting object code is offset by $-0xc000$ \(^2\) to make the first address $0x0000$ so that the object code can be downloaded properly into the EPROM burner.

The operation of the `motooffset` utility is the same as the `moto2moto` utility except that the offset in the argument list is added to each address just before S-records are output from each cell.

6.7 installMan

The Bourne shell script `installMan` installs a manual page in a directory deriving the manual subdirectory and extension from the section header specified in the manual page itself. This is a convenient way to install manual pages.

6.8 manc

The Bourne shell script `manc` merely invokes the ordinary UNIX `man` command with the `-M ./CIRSSE/installed/man` option. This provides a short and easy way to obtain manual pages.

6.9 xmanc

The Bourne shell script `xmanc` sets the `MANPATH` environment variable to the "/CIRSSE/installed/man" directory and then invokes the `xman` command. This provides a short and easy way to browse through manual pages in X windows.

\(^2\)the two's complement of $0xc000$
6.10 Public Domain Utilities

6.10.1 68HC11 Assembler

A public domain assembler was used to translate the 68HC11 assembler source to Intel formatted object code [Colley 87].

6.10.2 int2moto

Since the 68HC11 assembler outputs only Intel formatted object code, the assembler output must be passed through the int2moto utility to convert it to Motorola S-record format.
CHAPTER 7
Configuration Management

7.1 Motivation

There are two motivations for developing a configuration management scheme for software at CIRSSE.

- Makefiles are complicated since a diverse programming environment exists.
- Version control.

7.1.1 Complicated Makefiles

The development of software at CIRSSE presents a very diverse number of programming environments to the programmer.

For example, the gripper controller software resides on the 68HC11 EVB running the Buffalo monitor. It must also communicate to the outside world through a cable connected to a 68020 MV135 running VxWorks. The 68020 MV135 must also communicate to a SPARCstation host running SunOS. Software runs on all three of these platforms.

In addition, there are a number of compilers being considered to implement code at CIRSSE. Some of these are Sun's cc, GNU gcc, and GNU g++.

All this diversity complicates the construction of Makefiles. A much simpler method of constructing Makefiles has been developed.

7.1.2 Working Versions of Files

Version control is designed to make sure that working pieces of code are not lost while experimenting with new add ons to the code. This is accomplished by integrating SCCS into the configuration management scheme.
7.2 Imake Configuration Files

In order to make the task of system maintenance as easy as possible, imake has been used to minimize the amount of information necessary to perform all the necessary maintenance tasks. Imake also greatly simplifies the task of specifying rules and dependencies. Instead of designing and maintaining a separate Makefile in each directory which may require information such as common paths to be duplicated in each Makefile, a much shorter Imakefile is specified. This Imakefile consists of cpp macro calls and ordinary make rules, definitions, or dependencies. The ability of macro expansion allows Imakefile's to be several times shorter than Makefile's by isolating all configuration management details from the application programmer.

Configuration management schemes using imake also enable code to be developed either entirely within a single directory, distributed amongst several users or both without going through the hassle of updating duplicated configuration management related information in each Makefile.

In this configuration management scheme, there is only one Imakefile per directory. This Imakefile may be copied directly into the project directory and used as is without any modification. This greatly reduces the amount of effort required for maintenance of the Makefile's in an environment where software is not only being developed in separate directories owned by several different users but is also available in a project directory which is used for shared public access.

7.2.1 Files

There are several include files. The include files are separated so that different parts of the system can be added or deleted easily as needs change or if new software or hardware is added to the system.

- Imake.rules specifies all the generic rules.
• Project.tmpl specifies all the project dependent information such as directory specifics.

• genclass.tmpl specifies all the rules for producing container classes using the GNU libg++ class-generation facility.

• LaTeX.tmpl specifies all the LaTeX rules and definitions.

• UNIX.tmpl specifies all the UNIX related rules and definitions.

• VxWorks.tmpl specifies all the VxWorks related rules and definitions.

• M68HC11.tmpl specifies all the M68HC11 related rules and definitions.

• Imake.tmpl specifies all the rules and definitions common to every Imakefile.

7.2.1.1 Imake.rules

MakeSubdirs(subdirs) is a macro to descend the directories in the subdirs argument and extract an Imakefile and run make to create a Makefile. Make is then invoked using the same targets passed from the parent make.

addClean(targets) is a macro to add the list of files specified by targets to the list of files to be cleaned when performing make clean.

manInstall(manlist) is a macro to install man pages. The cpp C preprocessor is used on these man pages before actually installing them. This allows preprocessor directives such as #include to be used to included shared text between man pages to avoid unnecessary duplication. The argument manlist is a list of man pages, ie. manInstall(ls.man sed.man)

manSo(solinks,manpage) is a macro to create man pages which are sourced to a common manual page. An example of this is the strings (3) set of UNIX functions. The argument solinks is a list of man pages to be sourced to a common manual page. The argument manpage is the name of the sourced manual page, ie.
manSo(strcpy.man strdup.man strings.man). The appropriate section is determined by the section field used in the .TH header of the file *manpage*.

`installFile(flags, file, dir)` is a generic installation macro to invoke the install utility with the given *flags* to install the file specified by *file* into the specified directory *dir*. Note that only one file may be specified, i.e. *file* may not be a list of files. When using `installFile`, absolute paths should be avoided since these make the *Imakefile* dependent on where the source tree is located.

`AllTarget(targets)` is a macro to cause all *targets* to be built. Note that *targets* can be a list as well as an individual *target*.

`LintTarget(incs, srcs)` is a macro to run the lint processor on all C source files specified by *srcs*. *Incs* is a list of all #include files that are necessary for compilation. The *incs* argument is necessary in order for the rule to generate the appropriate dependencies.

### 7.2.1.2 Project.tmpl

*Project.tmpl* contains all the directory specific information. This information normally varies from project to project.

The make variable **PROJDIR** is the official project directory.

It is recommended that relative paths be used to reference any local configuration files so that programs can be moved to and from **PROJDIR** without changing any *Imakefiles*.

**INSTALLDIR** is the installation directory used to install all programs, scripts, and other target files.

**CONFIGDIR** is the configuration directory used to store all configuration management related files. These are all the files necessary to create *Imakefiles*. 
7.2.1.3 UNIX.tmpl

UNIX.tmpl contains all the UNIX specific rules.

UNIXBinTarget(target,inclist,objlist) is a macro to link a group of cc
object files specified by objlist into one executable. Explicit rules are not necessary
to compile .c files into .o files. This is taken care of by the implicit suffix rules in
/usr/include/make/default.mk. Inclist is a list of #include files for the C sources.
Their presence is necessary for a proper dependency. Target is the name of the
executable file.

UNIXBinCCCTarget(target,inclist,objlist) is a macro which is the same
as UNIXBinTarget except that objlist is the name of a group of g++ object files
to be compiled into one executable.

UNIXLibTarget(target,inclist,objlist) is a macro which is the same as
UNIXBinTarget except that target is the name of a library archive (.a) instead of
an executable. The object files in objlist are combined to form the library archive
specified by target.

UNIXBinInstall(binary) is a macro to install a UNIX binary executable.
UNIXLibInstall(library) is a macro to install a UNIX library archive.
UNIXHInstall(include) is a macro to install the #include file specified by
include.

UNIXShInstall(script) is a macro to install a UNIX script.

7.2.1.4 VxWorks.tmpl

VxWorksBinTarget(target,inclist,objlist) is a macro to generate the rule
to link the list of object files specified by objlist and to generate the proper #include
dependencies from the #include files specified by inclist.

VxWorksLibTarget(target,inclist,objlist) is a macro which is exactly
the same as VxWorksBinTarget. Its purpose is to logically separate object files
used as libraries from those object files which actually use those libraries.

Note that for either VxWorksBinTarget or VxWorksLibTarget, target must never be a file in objlist. This would create a circular dependency which would cause make to fail. To create a single object file from a single C file just leave the objlist argument empty.

For example, VxWorksBinTarget(singleTarget.o, singleTargetInc.h, ), will create singleTarget.o from singleTarget.c.

VxWorksBinInstall(binary) is a macro to install the object file specified by binary. Note that binary can only be a single file.

VxWorksLibInstall(library) is a macro to install the object file specified by library. Note that library can only be a single file.

VxWorksHInstall(include) is a macro to install the #include file specified by include. Note that include can only be a single file.

VxWorksShInstall(script) is a macro to install a VxWorks script.

7.2.1.5 M68HC11.tmpl

M68HC11.tmpl contains macros, rules and definitions to generate Makefile's for the 68HC11 attached to one of the serial ports on the MV135 running VxWorks. There are several macros in M68HC11.tmpl which are used only for constructing other macros within M68HC11.tmpl they should NOT be used any other way. These macros are M68HC11asmToObj, M68HC11objToX, and M68HC11XToY. These macros are used only to construct the implicit rules necessary to generate downloadable Motorola S-records for the 68HC11 Buffalo monitor.

M68HC11BinInstall(XFile) is a macro to install a Motorola S-record object file (.X). Note that there are implicit suffix rules for generating .X files.

M68HC11Clean(base) is a macro to add base.obj, base.lst, base.X, and base.Y to the list of targets to be cleaned. Note that base is a basename such as
“hello”, not “hello.c”. Note that there may be more than one base in the argument, ie. \texttt{M68HC11Clean(base1 base2)}.

\texttt{M68HC11Window()} is a macro to open an \texttt{xterm} (1) window which invokes \texttt{rDevLogin} (1) to connect \texttt{xterm} (1) to the 68HC11 EVB Buffalo monitor. The window may be created with the command \texttt{cmkmf Window}.

\texttt{M68HC11Download(baselist)} is a macro to download the .Y files specified in \texttt{baselist} to the 68HC11 EVB. Note that the names in \texttt{baselist} should not contain .Y. This extension is automatically added. The downloading can be accomplished by the command \texttt{cmkmf Download}.

7.2.1.6 \texttt{LaTeX.tmpl}

\texttt{LaTeX.tmpl} defines the implicit suffix rules to generate a .ps or .dvi file from a \LaTeX .tex or xfig .fig file. In addition, \texttt{LaTeX.tmpl} defines macros.

\texttt{LaTeXClean(base)} is a macro to add base.aux, base.log, and base.dvi to the list of targets to be cleaned. Note that there may be more than one base in the argument, ie. \texttt{LaTeXClean(base1 base2)}.

7.2.1.7 \texttt{Imake.tmpl}

\texttt{Imake.tmpl} is a file that is the template for all \texttt{Makefile}'s generated from \texttt{Imakefile}. All \texttt{Makefile}'s generated from \texttt{imake} have the following targets:

- clean - clean all targets except installed targets
- lint - run the lint processor on all C source files
- all - generate all targets, but do not install anything
- install - generate all targets and install
The *clean* target is useful when the source code is working and installed targets are all that is needed. This reclaims disk space used by intermediate object files and other unnecessary files generated during the build.

The *lint* target is useful for checking all the C source code using the lint utility.

The *all* target is useful for testing if things compile correctly during editing and an installation is not desired because the code is not finished. Since the *all* rule does not perform any install, it may fail if some of the local targets depend on installed targets that have not yet been installed. In other words, it is not recommended that a make *all* be done on a whole directory unless it is certain that the required targets are installed.

The *install* target is useful for performing entire rebuilds or making sure that everything is up to date.

### 7.2.1.8 Directory Structure

- **CIRSSE** - Project directory
- **CIRSSE/installed** - installed files
- **CIRSSE/installed/M68HC11** - installed 68HC11 files
- **CIRSSE/installed/VxWorks** - installed VxWorks files
- **CIRSSE/installed/UNIX** - installed UNIX files
- **CIRSSE/installed/man** - installed manual pages
- **CIRSSE/src/config** - configuration management info
- **CIRSSE/src/apps** - application (object code that calls “library functions”)
- **CIRSSE/src/lib** - libraries
- **CIRSSE/src/samples** - sample Imakefiles
7.2.2 Caveats

The #include path is set using the -I option. -ICIRSSE/installed/UNIX/h is added to CPPFLAGS whenever any of the macros in UNIX.tmpl are used and -ICIRSSE/installed/VxWorks/h is added to CPPFLAGS whenever any of the VxWorks target macros in VxWorks.tmpl are used. Thus, if these macros are not used, the proper #include path is not added.

7.2.3 Bugs

You cannot mix macros from UNIX.tmpl and VxWorks.tmpl. You must maintain UNIX and VxWorks source code in different directories. This bug arises because there can only be one value of CPPFLAGS per Makefile.

7.2.4 See Also

In UNIX man pages imake (1), cpp (1), man (1), xman (1) [Sun 88, manual pages] [X11 89, manual pages].

7.3 Imakefile

An Imakefile is merely a collection of cpp macros and make definitions and rules which are processed by imake to create a Makefile that will generate all the necessary commands in order to perform certain maintenance on software.

After constructing an Imakefile, it is possible to perform the following commands to do different types of maintenance tasks.

- cmkmf clean - clean all targets except installed targets
- cmkmf lint - perform lint checks on all code
- cmkmf all - build all targets but don't install anything
• cmkmf install - build and install all targets

Note that care must be taken when using cmkmf all because some targets may depend on other installed targets which will not be installed by cmkmf all. This kind of build is only useful if all installed targets needed are already in place.

The easiest way to learn what macro calls to put in Imakefiles to perform different tasks is to look at some examples. It is easiest to copy an existing Imakefile and edit it.

7.3.1 VxWorks Library

Here is an example of a simple Imakefile to create all the necessary rules and dependencies for a VxWorks library consisting of only one object module. No .c files appear anywhere except in the LibTarget macro in the Imakefile because make automatically checks for .c files automatically from the implicit suffix rules in /usr/include/make/default.mk. This Imakefile can be found in ./src/samples/VxWorks/lib/single/Imakfile.

/**/# Comments prefixed by C comment delimiters like this line are
/**/# copied into the Makefile generated by imake.

/

* Normal comments like this do not show up in the Makefile
*/

AllTarget(sampleSLib.o sampleSLib.v)

VxWorksLibTarget(sampleSLib.o , sampleSLib.h, )
VxWorksLibInstall(sampleSLib.o)
VxWorksHInstall(sampleSLib.h)
VxWorksShInstall(sampleSLib.v)
LintTarget(sampleSLib.h, sampleSLib.c)

Note the comma at the end of the second argument. The third argument is blank.

If there is more than one object file in a VxWorks library then the _Imakefile_ would look like this. This _Imakefile_ can be found in .src/samples/VxWorks/lib/multiple/Imakefile.

/**/# Comments prefixed by C comment delimiters like this line are
/**/# copied into the _Makefile_ generated by _imake_.

/
*/

AllTarget(sampleMLib.o sampleMLib.v)

VxWorksLibTarget(sampleMLib.o, sampleMLib.h, functions.o subroutines.o)

VxWorksLibInstall(sampleMLib.o)
VxWorksHInstall(sampleMLib.h)
VxWorksShInstall(sampleMLib.v)
LintTarget(sampleMLib.h, functions.c subroutines.c)

Note that for _VxWorksLibTarget_ the first argument, the library, must be unique from any of the object files in the second argument, i.e. the names of the input and output files must all be unique. This is necessary to avoid circular dependencies.
7.3.2 VxWorks Binary

The *Imakefile* for VxWorks binaries is no different from the *Imakefile* for VxWorks libraries. The only functional difference is that the targets are put in a different directory during installation.

Here is an example of an *Imakefile* to create all the necessary rules and dependencies for a VxWorks binary when dealing with only one object file. No .c files appear anywhere except in the LintTarget macro in the *Imakefile* because *make* automatically checks for .c files automatically from the implicit suffix rules in /usr/include/make/default.mk. This file can be found in ./src/samples/VxWorks/bin/single/Imakefile

```make
/**/# Comments prefixed by C comment delimiters like this line are
/**/# copied into the Makefile generated by imake.

/

* Normal comments like this do not show up in the Makefile
*/

AllTarget(sampleSBin.o sampleSBin.v)

VxWorksBinTarget(sampleSBin.o, sampleSBinConst.h sampleSBinDecl.h, )
VxWorksBinInstall(sampleSBin.o)
VxWorksHInstall(sampleSBinConst.h)
VxWorksHInstall(sampleSBinDecl.h)
VxWorksShInstall(sampleSBin.v)
LintTarget(sampleSBinConst.h sampleSBinDecl.h, sampleSBin.c)

Note the comma at the end of the second argument. The third argument is
If there is more than one object file in the VxWorks binary then the *Imakefile*
would look like this. This *Imakefile* can be found in
`./src/samples/VxWorks/bin/multiple/Imakefile`.

`/**/#` Comments prefixed by C comment delimiters like this line are
`/**/#` copied into the Makefile generated by *imake*.

`/*
 * Normal comments like this do not show up in the Makefile
 */

AllTarget(sampleMBin.o sampleMBin.v)

VxWorksBinTarget(sampleMBin.o,sampleMBinConst.h sampleMBinDecl.h,main.o io.o)
VxWorksBinInstall(sampleMBin.o)
VxWorksHInstall(sampleMBinConst.h)
VxWorksHInstall(sampleMBinDecl.h)
VxWorksShInstall(sampleMBin.v)
LintTarget(sampleMBinConst.h sampleMBinDecl.h , main.c io.c)

7.3.3 UNIX Library

Here is an example of a simple *Imakefile* to create all the necessary rules
and dependencies for a UNIX library, consisting of only one object module. No
.c files appear anywhere except in the *LintTarget* macro in the *Imakefile* because
make automatically checks for .c files automatically from the implicit suffix rules in
`/usr/include/make/default.mk`. This file can be found in `./src/samples/UNIX/lib/Imakefile`

`/**/#` Comments prefixed by C comment delimiters like this line are
/**/# copied into the Makefile generated by imake.

/*

* Normal comments like this do not show up in the Makefile
*/

AllTarget(sampleLib.a)

UNIXLibTarget(sampleLib.a, sampleLib.h, functions.o subroutines.o)
UNIXLibInstall(sampleLib.a)
UNIXHInstall(sampleLib.h)
LintTarget(sampleLib.h, functions.c subroutines.c)

7.3.4 UNIX Binary

Here is an example of an Imakefile to create all the necessary rules and dependencies for a UNIX binary consisting of only one object module. No .c files appear anywhere except in the LintTarget macro in the Imakefile because make automatically checks for .c files automatically from the implicit suffix rules in /usr/include/make/default.mk. This file can be found in ./src/samples/UNIX/bin/Imakefile.

/**/# Comments prefixed by C comment delimiters like this line are
/**/# copied into the Makefile generated by imake.

/*

* Normal comments like this do not show up in the Makefile
*/
AllTarget(sample)

UNIXBinTarget(sampleBin, sampleConst.h sampleDecl.h, main.o input.o output.o)
UNIXBinInstall(sampleBin)
UNIXHInstall(sampleConst.h)
UNIXHInstall(sampleDecl.h)
LintTarget(sampleConst.h sampleDecl.h, main.c input.c output.c)

7.3.5 Making subdirectories with no local targets

There may be times when there are subdirectories which themselves contain \texttt{Imakefiles} which generate more targets.

Here is an example of an \texttt{Imakefile} that generates all targets in the subdirectories. This file can be found in ./src/samples/Imakefile.

\texttt{MakeSubdirs(UNIX VxWorks localTarget custom)}

7.3.6 Making subdirectories with local targets

Sometimes local targets exist in a directory in addition to subdirectories. In this case all the targets in the subdirectories must be built before the targets in the local directory are built.

Consider the following directory hierarchy.

.:
Imakefile b/
a/ sampleLocalTarget.c

a:
Imakefile sampleSubdirATarget.c

b:
Imakefile sampleLocalTargetB.c

Targets in directories a and b must be built before the local target sampleLocalTarget is built.

The Imakefile to accomplish this is shown below. This file can be found in ./src/samples/localTarget/Imakefile

MakeSubdirs(a b)

/*
 * This local target is built after
 * the subdirectories a, and b are built
 *
 * The standard targets for non-leaf directories are
 * clean lint all install. They cause all the
 * corresponding targets in subdirectories a and b
 * to be built.
 *
 * The targets clean.local neat.local lint.local
 * all.local and install.local are built after the
 * subdirectories are built.
 */

AllTarget(sampleLocalTarget)

UNIXBinTarget(sampleLocalTarget,,sampleLocalTarget.o)
UNIXBinInstall(sampleLocalTarget)

The subdirectories beneath the \textit{localTarget} directory merely contain ordinary \textit{Imakefiles} which build targets normally. They are shown below for completeness. This \textit{Imakefile} for subdirectory \textit{a} can be found in \texttt{./src/samples/localTarget/a/Imakefile}.

\/ 
\* This target is built before the directory above. 
\* 
\* The standard targets for leaf directories are 
\* clean lint all and install 
\* 
\* Note there are no local include files so the second argument to 
\* UNIXBinTarget and the first argument to LintTarget are empty. 
\*/

AllTarget(sampleSubdirATarget)

UNIXBinTarget(sampleSubdirATarget,,sampleSubdirATarget.o)
UNIXBinInstall(sampleSubdirATarget)
LintTarget(,sampleSubdirATarget.c)

This \textit{Imakefile} for subdirectory \textit{b} can be found in \texttt{./src/samples/localTarget/b/Imakefile}.

\/ 
\* This target is built before the directory above. 
\* 
\* The standard targets for leaf directories are 
\* clean lint all and install
Note there are no include files so the second argument to UNIXBinTarget and the first argument to LintTarget are empty.

```
AllTarget(sampleSubdirBTarget)

UNIXBinTarget(sampleSubdirBTarget,,sampleSubdirBTarget.o)
UNIXBinInstall(sampleSubdirBTarget)
LintTarget(,sampleSubdirBTarget.c)
```

### 7.3.7 Making local targets only

When code is being developed in very large source trees, sometimes only a local build is desired because traversing the entire tree is too time consuming. For this reason, there is a way to build only the local targets in a non-leaf directory. Instead of using the `clean`, `lint`, `all`, and `install` targets which compile all the subdirectories and the local targets, you can use the `clean.local`, `lint.local`, `all.local`, and `install.local` targets to build the targets in the local directory only.

Be very cautious when doing this since building things in this manner may cause the subdirectories to be out of date with respect to the local targets. For this reason, it is recommended that a `cmkmf clean` and `cmkmf install` be done after you are finished working on a particular directory to make sure all the targets from that node down are all up to date.

### 7.3.8 Custom rules and dependencies

There may be cases where none of the predefined macros are adequate to serve your needs. Since `imake` is merely a preprocessor to `make`, you are free to
incorporate whatever make rules and definitions you desire.

Since local targets may have a suffix of .local if the current directory is a leaf directory, the following make variables have been defined so that the standard targets may still be defined in a consistent manner. They are merely set to the values of the standard targets, but are suffixed by .local if MakeSubdirs() appears at the beginning of the Imakefile.

- CLEAN_TARGET - defined as clean or clean.local
- LINT_TARGET - defined as lint or lint.local
- ALL_TARGET - defined as all or all.local
- INSTALL_TARGET - defined as install or install.local

Use relative paths so that your Imakefile isn’t dependent on where the source tree is installed. For example, use ../progdir/neatProg instead of /home/userdir/projdir/progdir/neatProg.

Here is an example of an Imakefile that contains custom rules and dependencies. This file can be found in ./src/samples/custom/Imakefile.

```bash
/*
 * A customized Imakefile
 */

AllTarget(a b c)

a:

echo "Making target a"
```
touch a

b:
echo "Making target b"
touch b

c:
echo "Making target c"
touch c

/*
 * These make variables are defined as clean all install uninstall and
 * lint if the macro MakeSubdirs() is NOT used, i.e. the current
 * directory is a leaf directory. Otherwise these make variables are
 * defined as clean.local all.local install.local and uninstall.local.
 */

$(CLEAN_TARGET):
echo "Cleaning targets"

$(ALL_TARGET):
echo "Making special all targets"

$(INSTALL_TARGET):
echo "Installing targets"

$(LINT_TARGET):
echo "Making lint targets"

addClean(a b c)
CHAPTER 8
Conclusions

The VxWorks gripper library functions isolate the application layer from the details of the gripper protocol so that future changes in gripper controller parameters do not cause invalidate large portions of code.

The gripper controller software provides a simple command interface to the 68HC11 EVB and enables the gripper to either “grab” objects which come between the fingers of the gripper or unconditionally servo at a position or force set point.

The software development environment enables programs to be compiled and downloaded with one simple command. This environment can be used to maintain the gripper controller software and serve as a basis for developing any new software for the 68HC11 EVB.
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