PiBrain Documentation

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Contents

1 Introduction

This document aims to give a complete outline of both the software and hardware used in the PiBrain v0.1-alpha. The documentation will also act as an installation guide, and a place to detail potential future projects. The LaTeX source code for this PDF will be included in the PiBrain repository on GitHub, it is highly recommended that any future work on PiBrain be document here.

1.1 Description

PiBrain is a raspberry pi operated replacement for PLC on the MK-VII thermal evaporator system. The software is written in primarily python 3.8.0, with some auxiliary scripts written in bash. The hardware is a simple 24V to 3.3V logic conversion using ISOs and relays.

1.2 Purpose

The main purpose of PiBrain is to provide an easily modifiable platform for controlling the MK-VII thermal evaporator system. Section 5 focuses on future applications/ideas for what the system could be capable of. The primary focus of this document will be establishing how the hardware was built, and how the software was written with respect to the manual mode.

1.3 Contact information

To contact the original creator (Andrew) please use the following resources:

- Email: evansa@sonoma.edu (only good till 2023)
- Alternate email: andrew.m.evans1989@gmail.com
- Discord: Andrew Evans#4366

To contact the creator of the hardware (Leo) please use the followiing

- Email: lpjanzen@ucdavis.edu

Responses wont be instantaneous, but we will try and get around to it!

2 Software

This section will detail all current pieces of the code along with idea behind the organization and structure of the code. The code is broken up into three categories: bash scripts, state machine, and main. The general idea of the code is that the bash scripts do the operating system level work (automated startup, file clean up, etc see Section 2.1), the state machine does the "organizational" work of the software (running the main logic tree which includes the idle loop see Section 2.2), and lastly main which contains the hardware interfacing code (see Section 2.3). There are some aspects of this layout which could[1] be changed in the future (see Section 5).

2.1 Bash scripts

Currently there are two bash scripts: clear_run_cache.sh, and startCode.sh. Both scripts are incredibly simple and act as a way of automatically running system commands

2.1.1 Clearing output cache

The first script is responsible for clearing the outputfile cache. During run time the code will produce an outfile file which logs changes while the code is running. For example if the vent command is called then it will log the vent command along with a time stamp, see Figure 1.

```
9   2021-07-21 19:35:55.035873 Mechanical pump didn't complete, conditions not met, returning to queue
10  2021-07-21 19:36:00.055460 venting system completed, returning to queue
11  2021-07-21 19:36:29.168215 Shutting system down
```

Figure 1: Example log file

After the runs the bash script will clear this file **NEED TO ADD OPTION FEATURE FOR THIS**. default setting will be to clear the run cache after run.

[1] most likely should be changed

2.1.2 Automated startup

The other script, startCode.sh, is responsible for starting the code on the boot up of the raspberry pi. **NEED TO ADD FILE TO BOOT DIRECTORY**. The hope is that SSH connection to the pi would be minimal, and that in most of the use cases the raspberry pi could automatically start and clear run caches without the need for human intervention, see Section 3.2.

2.2 State machine

Statemachine.py is the organizational backbone of the code fig 2. Any defined command should run through the state machine if possible, however the definitions should occur outside the state machine[2]
EDIT PICTURE OF STATE MACHINE

2.2.1 Imports

The imports are used for getting the date and time for the log file, and for pausing the script. The main reason for wanting a script pauses is that the main loop of the state machine is effectively an infinite loop. Without the pause feature the loop runs much faster than a user could ever hope to make inputs. Documentation for the modules: datetime, time[3]

2.2.2 State machine class

The state machine itself is defined as an object in the code. It has two attributes: outputfile, and inputfile. These names make the purpose pretty obvious, but for those who haven't caught on, it's for setting the input and output file paths. The output file is what the log is written into, and the input file is designed for simulating the machine. The input feature will likely be changed or removed before the final draft of this document **YOU HEAR THAT? YOU SHOULD EDIT THIS OUT LATER**. The state machine itself has three methods: write_to_log, idleTaskCheck, and idle_state. These methods will be discussed in more detail below.

2.2.3 write_to_log

This method looks at the return codes thrown by the different tasks and using this determines what message to print into the log file. Tasks return a three-tuple of which the first two elements are booleans, and the last is a string. The

[2] Again, this is something that was not done super well and will be addressed in Section 5
[3] time and datetime are hyperlinks, click to see the documentation

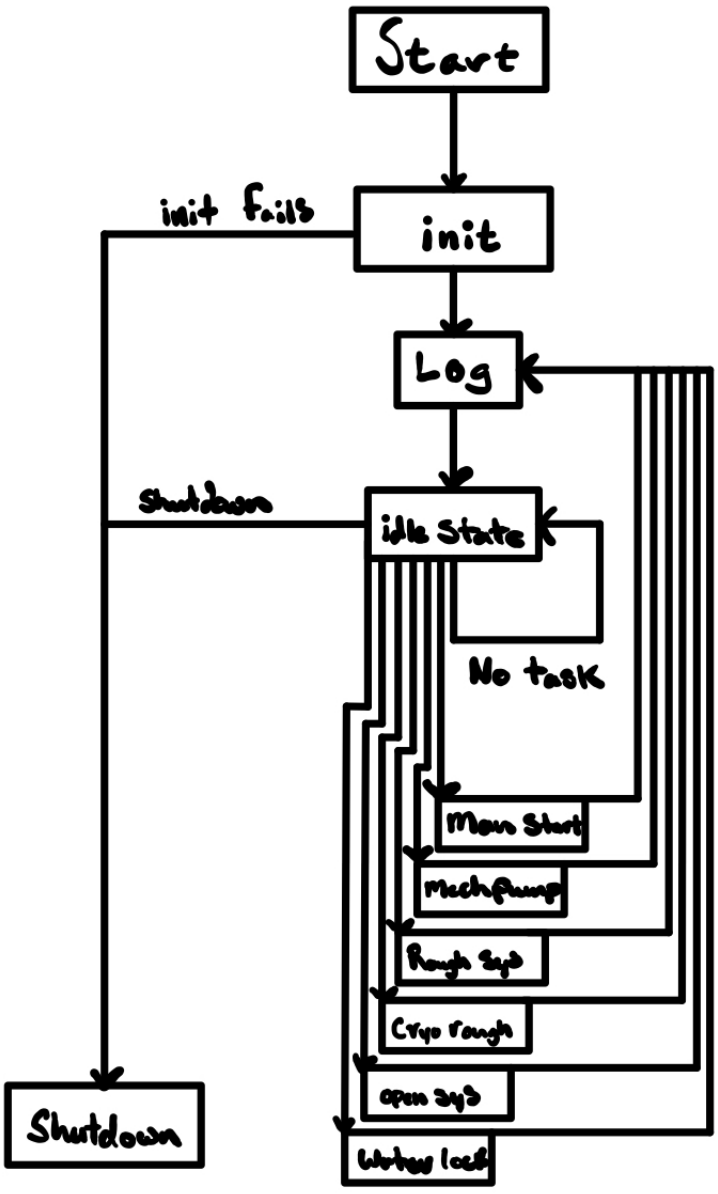


Figure 2: State machine logic

general form of the tuple is:

$$(\text{Expected exit},\ \text{Task completed},\ \text{Name of task})$$

Table 1 shows what the different combinations of trues and falses yield.

- **Key** to table 1:
  OK -the system completed the task
  NC -the task didn't change
  NA -not applicable (combination not set)
  FAIL -an error has occurred

	T	F
T	OK	NC
F	NA	FAIL

Table 1: Return statement logic

While this system works it is definitely another point in the code which should be reworked in the future, see Section 5.

2.2.4 idleTaskCheck

This method simply compares the last task with the current task looking to see if there had been a change in the task's state. If the task's state had changed then the function writes this to the log file. This was designed so that the log file would only report changes in task, reducing the overall space used on the raspberry pi.

2.2.5 idle_state

the idle_state method is the heart of the state machine. The method is responsible for all code that is updated every loop. There are eight inputs to this method (excluding the self input). All the inputs that start with "task" are the actual logical functions defined in main passed into the method. The update_pins input is the pin reading function defined in main called readPinsLoop. The first variable (called delay) inside the idle loop gives the ability to set the delay on the actions in the loop in seconds. During the loop the state machine pauses and waits one second between each prompt. This is to ensure that the code is not overworking the raspberry pi. After the delay is set the code initializes all the "task#_last"'s this is done so that the idleTaskCheck method will work on the first loop, and so that the code will write all of task's states to the log file upon startup.
After the initialization of the idle loop the variable machine_on is set to true and the code enters the while loop. This loop is infinite and will only close when machine_on gets set to false. This can happen in only two cases.

Case 1: If any of the tasks return statements throw a first element false, this is defined as an emergency halt. For more information on the tuple edit

code system see Section 2.2.3.

Case 2: If the stop pin **MIGHT CHANGE** is called.

Case 1 can only be called if the update_pins function doesn't return a false. False is returned from the function if case 2 will happen. This was designed this way so that if a stop code is called it wont try and run all the tasks. This method could be improved, see Section 5.3.

2.3 Main

Main is where the code is run from and where the definitions of the pins and processes are. If additional logic is added to the code the definitions should be put in main. In the future the code written in main could be split into two separate files so that the definitions are done in another file see Section 5.4 for more detail.

2.3.1 Manual mode

The code currently supports a manual mode. This means that the user must toggle switches on the actual deposition machine itself, which sends signals to the raspberry pi, and then finally the pi decides if it is "safe" to turn on the called process. This means that without explicitly telling the pi what to do nothing will happen. This system is capable of being fully automatic, for more detail on this project please see Section 5.8.

2.3.2 Imports

This piece of code currently imports the following packages: time, datetime, StateMachine, and os. For more information on time, and datetime see Section 2.2.1. The package Statemachine is the code described in Section 2.2. The last package imported, as mentions, is os. os lets the user interface with the operating system. The documentation can be found here: os.

2.3.3 bcolors

This class allows for text color to be set by adding attributes of this class to strings. This code is an adaptation of the code found at the following **source**. An example of the code being used can be found in figure 3.

print(bcolors.FAIL+"Oh god the computer is on fire"+bcolors.RESET)
>>>Oh god the computer is on fire

Figure 3: Example use of bcolors

Note to the reader, if bcolors.RESET isn't called the code will remain in the last color you set, even after the code is exited.

2.3.4 IO_Devices

The IO_Devices class was build to hold the structure of an input or output device as one object. The object has 5 attributes: name, state, pin, ras_pin, and IO_type.

- name - what the pin corresponds to, see Table 4
- state - whether the pin is high or low
- pin - the number of the pin according to Table 4
- ras_pin - number of pin on the raspberry pi
- IO_type - whether the pin is an input or output

The initialization[4] of IO_Devices also has some logic for choosing whether to set the GPIO pin to be read or write.

The first method (other than init) is the setHigh method. This method sets output pins high. It first checks to see if the the pin is an input or output pin and then if it is an output pin then it checks if it is already set high. If the pin is already set high then it prints that it is maintain high, if it isn't already set high it prints that it is setting the pin high and then sets the state of the pin to high. If the pin is an input it does not set it high and prints a warning that you are attempting to set a read pin. This could more optimally be forced by creating an IO_Device parent class with input and output children classes where the input class would not contain the setHigh and setLow methods, see Section 5.9.

Next is the setLow method. This method serves the exact same purpose as the setHigh method but sets the pin low. These two methods could technically be done in one method taking an argument for setting high vs low, however, this was decided against to improve readability.

2.3.5 Tasks

The tasks are the main functions which the machine communicates to the state machine. Potential changes to this organization are discussed in Section 5.4. The general idea is that the tasks contain simple logic conditions which result in setting pins using the setHigh/Low methods and then the task returns a three-tuple as discussed in Section 2.2.3. To see the logic for each task see Fig 6.

[4]For more information on classes and initialization click the word initialization

There are three task that do show up on Fig 6. These tasks do not correspond to a piece of the physical machine, but rather they are used for lower level actions. The three functions are: readPinsLoop, shutdownSys, and system_status.

readPinsLoop checks a text file to see if the pin in the file is set to true. This will be changed in the final build to actually read from the pins!

shutdownSys sets all the output pins to low. This done to not draw power while the system is off, and also make the raspberry pi safe to handle once the system is shutdown.

system_status is a debugging tool used to quick output the status of all the pins. This function is only used when testing the code, but with some minor modification could print to a new text log file acting as a more powerful debugging tool see Section 5.11.

2.3.6 Pin definitions

The pins are fully defined in the code, however for the sake of convenience their names and numbers will be listed in Table 2. In the current build two pins remain free (20, and 21 on the raspberry pi).

3 Hardware

There are two main pieces of hardware that make up the PiBrain, there is the raspberry pi, the "Brain", and there is the PCB, the "nervous system". This section will aim to cover the specifics of each. Attached with this PDF there will be schematics of the hardware, with CAD files. The main goal of this is to have easy documentation to help with repairs and future work. There will also be a subsection detailing the computer that the PiBrain is replacing and hardware which PiBrain will control.

3.1 Overview

This board interfaces between a Cooke MK-VII Vacuum Deposition Machine and a Raspberry Pi Zero w. It has been designed to replace the Omron Sysmac C20, and thus copies the input/output schema of the C20.

Input COMs should be connected to +24V. Raspberry Pi inputs are **normally high** (3.3V). When an IN is connected to ground, the corresponding LED will illuminate and the corresponding Raspberry Pi pin will be pulled low (0V).

When Raspberry Pi outputs are low (0V), the corresponding OUT will be open circuit. When the Raspberry Pi output goes high (3.3V), the corresponding LED will illuminate, and the corresponding OUT will be connected to a

Name	Input/Output	Pin number	GPIO number
Start	Input	0000	26
Stop	Input	0001	19
Crossover	Input	0002	13
Auto	Input	0003	06
On_Reset	Input	0004	05
Manual	Input	0005	00
Vent	Input	0006	11
Rough_S2	Input	0007	09
COM			
HI_VAC_Valve	Input	0008	10
Cryo_Rough	Input	0009	22
Cryo_Purge	Input	0010	27
Vacuum_In	Input	0011	17
Rough_SW	Input	0012	04
Water_Lock	Input	0013	03
Vent_Auto	Input	0014	02
-NONE-	Input	0015	14
COM			
OUT0	Output	0500	14
OUT1	Output	0501	15
OUT2	Output	0502	18
OUT3	Output	0503	23
OUT4	Output	0504	24
OUT5	Output	0505	08
OUT6	Output	0506	07
OUT7	Output	0507	01
COM			
OUT8	Output	0508	12
OUT9	Output	0509	16
-NONE-	Output	0510	20
COM			
-NONE-	Output	0511	21
COM			

Table 2: PLC codes and GPIO numbers grouped by COM

COM via a relay.

NOTE: Internal and external inputs and outputs are completely isolated from each other. The mounting hole in the upper right (labeled GND) is connected to internal ground and can be connected to external ground if desired.

Name	Value	Units
Input Voltage ($V_{COM\text{-}INX}$)		
Maximum operating	-15	V
Typical operating	-24	V
Minimum operating	-30	V
Absolute Maximum	30	V
Absolute Minimum	-30	V
Input current I_{INX}		
Typical forward (-24V)	10	mA
Maximum Output Switching Voltage	30	V
Output Current		
Maximum Per Output	5	A
Maximum Per COM	16	A

Table 3: Electrical characteristics

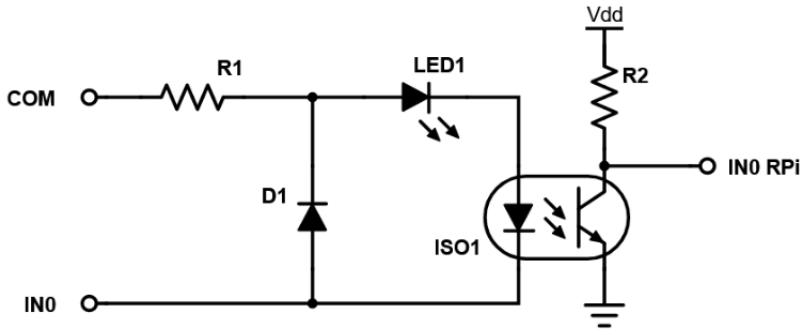
3.2 Raspberry pi

The "Brain" of this project so to speak is a Raspberry Pi Zero w[5]. This controller runs all the software described in Section 2. Table 2 contains all the information on how the GPIO pins on the raspberry pi correspond to the functions in the software.

3.3 PCB

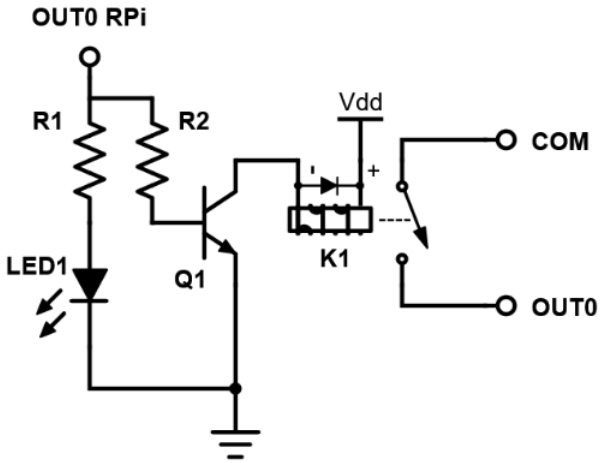
This section will give detail on the PCB which the raspberry pi is attached to. This Piece of hardware is designed to allow the raspberry pi to communicate with the deposition machine without being on a 30V circuit.

[5] Click for a link to the website



(x16)

Figure 4: Input schematic. COM is connected to +24V. When IN0 goes low, LED1 and ISO1 will turn on, pulling down IN0 RPi to 0V. When IN0 is high or disconnected, IN0 RPi will be pulled up to 3.3V by R2.



(x12)

Figure 5: Output schematic. When OUT0 RPi goes high (3.3V), LED1 will light and Q1 will actuate K1, connecting OUT0 to COM.

3.4 Case

3.5 Deposition machine

3.5.1 PLC

This is a direct copy of what was used to run the PLC, and what the PiBrain was adapted from. **Disclaimer:** This table is not fully understood[6].

Input 0 CH	IN	Terminal #	Input device	Output 5 CH	Out	Terminal #	Output device
0 PB3	0000	A0	START (PB3)	0	0500	A10	AUTO
1 PB4	0001	B0	STOP (PB4)	1	0501	B10	MANUAL
2	0002	A1	CROSSOVER	2	0502	A11	VENT
3 S8 AUTO	0003	B1	AUTO (S8)	3	0503	B11	R VAL?
4 PB1	0004	A2	ON/RESET	4	0504	A12	-NONE-
5 S8 Manual	0005	B2	MANUAL	5	0505	B12	CRYO ROUGH
6 S1	0006	A3	VENT	6	0506	A13	CRYO PURGE
7 S2	0007	B3	ROUGH (S2)	7	0507	B13	HI VAC?
8 S3	0008	B4	HIGH-VAC VALVE (S3)	8	0508	B14	WATER LOCK
9 S4	0009	A5	CRYO ROUGH (S4)	9	0509	A15	ROUGH PUMP
10 (S5) unmarked	0010	B5	CRYO PURGE	10	0510	B15	-NONE-
11	0011	A6	VACUUM IN	11	0511	B16	-NONE-
12 S6	0012	B6	ROUGH SW (S6)				
13	0013	A7	WATER LOCK				
14 PB5	0014	B7	VENT-AUTO				
15	0015	A8	-NONE-				

Table 4: Return statement logic

For more information on what the codes in Fig 6 please see Section 2.3.6

4 Installation

At the time of this documents creation the PiBrain is not installed on the deposition machine. This task will be left as work for the next person to take on this project[7]. The installation should happen in two parts: fitting, and wiring. The PiBrain will be put inside a case which will have mounting holes, bolts will be fit through the mounting holes into newly drilled holes in the deposition machine[8]. The wiring will relatively trivial compared to the rest of the process as long as the user labels the wires before they remove them from the original hardware.

[6] That is not a joke

[7] I hope that you enjoy your work on PiBrain :)

[8] With some clever design the PiBrain case could attach to the deposition machine in the same way that the PLC attached to the machine!

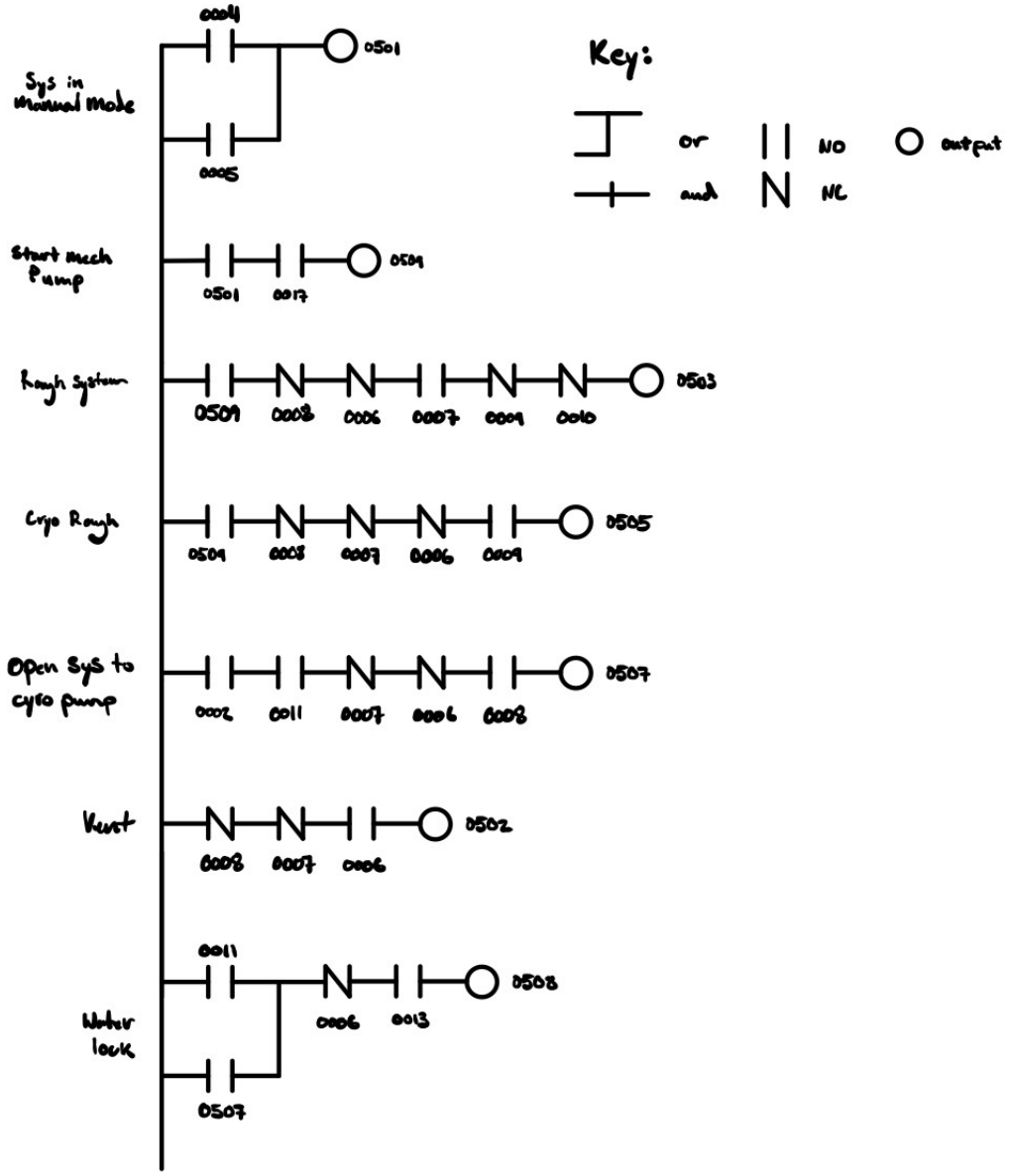


Figure 6: Ladder logic for the PLC

5 Future work

There is a lot of work that still needs to be done and that could be done. This software and hardware

5.1 Combination of bash scripts with python

5.2 write_to_log rework

5.3 Idle exit

5.4 Main file split

5.5 Deposition controller pi

5.6 Web interface

5.7 GUI interface

5.8 Automatic mode

probably will need another pi, blah blah blah, pi network....

5.9 IO_Device class change

5.10 Allowing for hard exits

no code currently shutdown the machine completely. This should be changed.

5.11 System file log

Creating a logging system with the system_status function that is stored locally on the pi.