Karlsruhe Institute of Technology

Improving Usability and Reliability of an IoT-based Controller for a Coffee Machine

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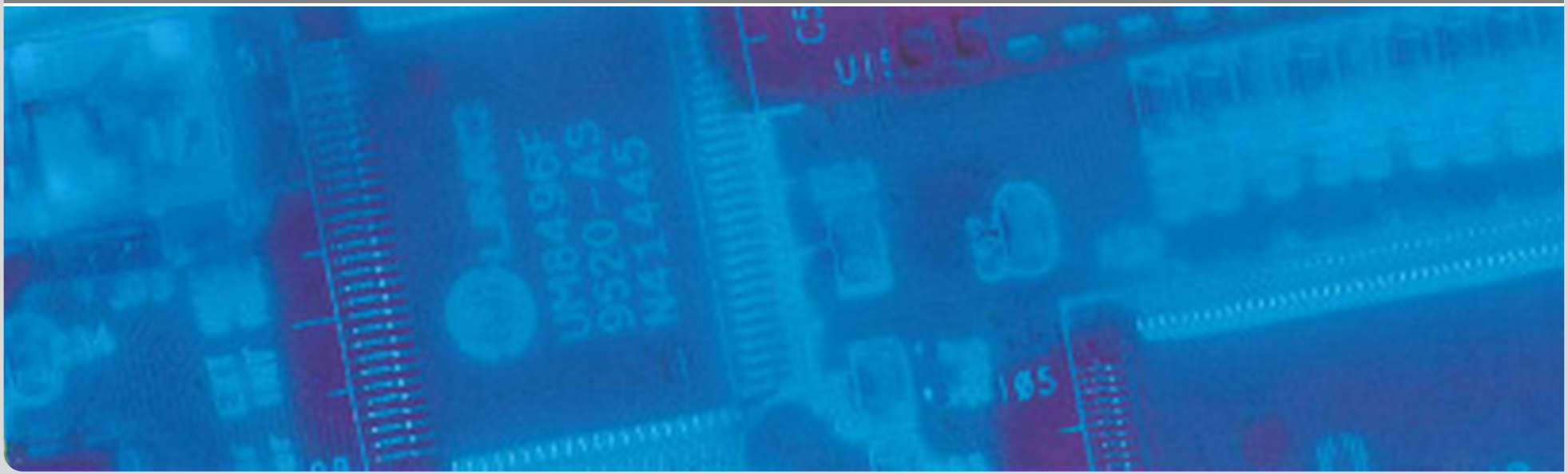
CES - Chair for Embedded Systems

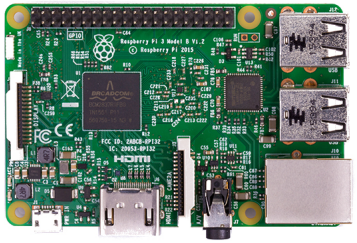


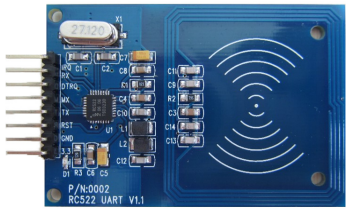
Introducing the Topic

Accounting Server

HTTP

Adapter Board





RFID tag

Goals

Solve existing issues in previous system:

- Fixing bugs
- Redesigning the UI
- Adding missing features

$\rightarrow$ **improve usability and reliability**

Structure of this Talk

Introduction

Problem Analysis

New Design & Architecture

Results

Part 1

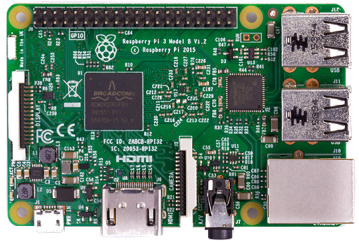
Introduction

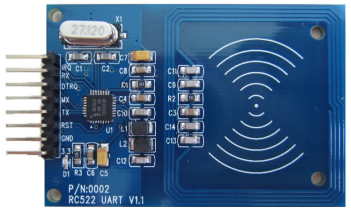
The Components

Accounting Server

HTTP

Adapter Board





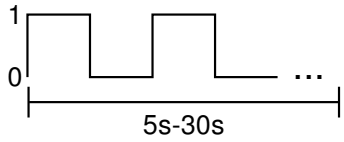
RFID tag

System Details

- Broadcom BCM2837, 4 core Cortex-A53 (ARMv8) 64-bit SoC @ 1.2GHz
- 1GB LPDDR2 SDRAM
- OS: Raspbian GNU/Linux (Debian 10 Buster)
- Language: Python
- GUI: PyQt5 Framework

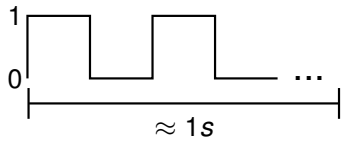
Available Sensors

- **water flow**



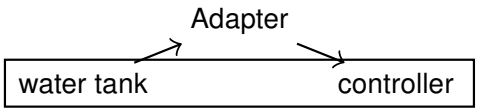
variable frequency, proportional to flow speed

- **grinder**



variable frequency

- **water level/blocking**



input AND output

adapter board connected via GPIO

Accounting Server

Treasury, keeps record of

- Transactions (withdrawals, deposits, coffee bought)
- Users
- RFIDs

Technical:

- Dedicated server, local network
- MySQL database
- Apache + PHP webserver
- Account balance results from accumulating all transaction deltas

Usability & Reliability

Usability is the "extent to which a system, product or service can be

used by specified users

to achieve specified goals

with

- effectiveness
- efficiency
- satisfaction

in a specified context of use" [ISO 9241-11:2018]

Reliability

- Result of usability
- High availability

Part 2

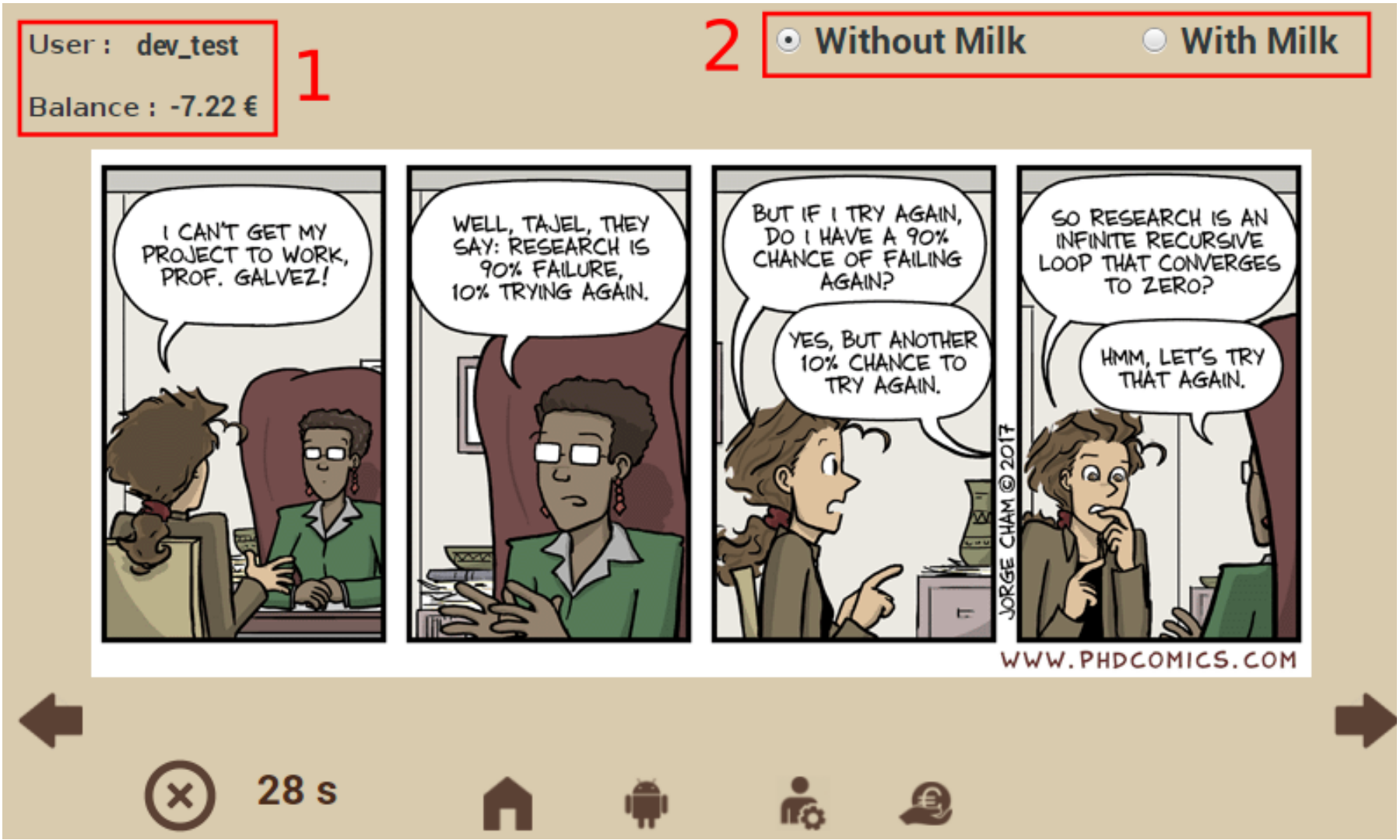
Problem Analysis

21 Issues Identified

- GUI related
  - Size of controls
  - Focus on information
  - Timeouts
- Bugs
  - Application unresponsive/freezing
  - Coffee not registered or recognized as hot water
  - Offline orders not synchronized
  - High CPU usage
- Missing features
  - Support for new KIT-Card
  - Dispensing limit for consumption
  - Various buzzer sounds
  - 3D-printed case

GUI Problems

Screenshot from previous system

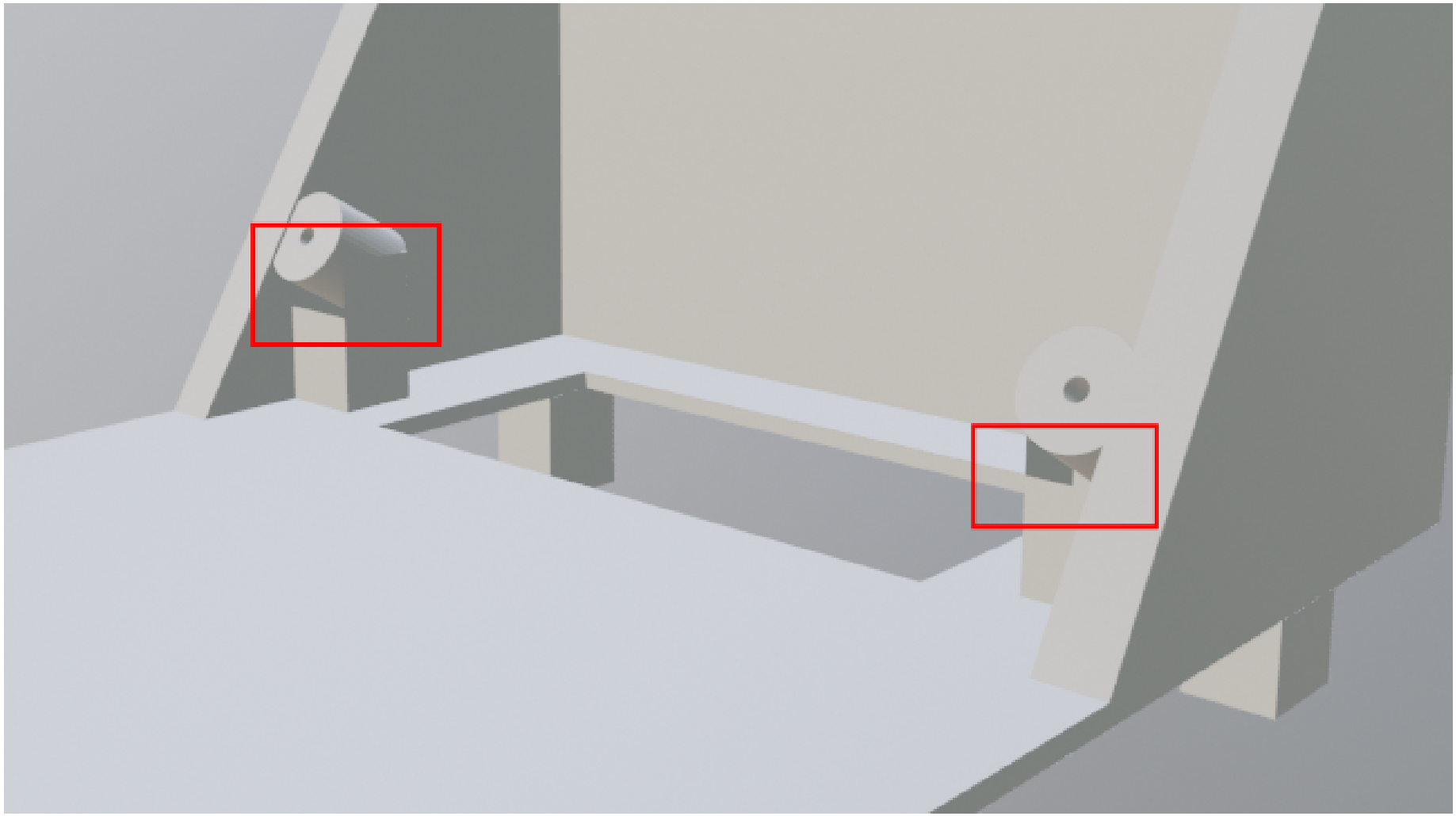


Reading GPIO + Managing State + IPC

```
1  def printLog(array):
2      ...
3      if not os.path.isfile("/home/pi/CoffeeMachine/UI/maintenance.txt"):
4          global previousGrinder
5          if GPIO.input(grinderPin) == 0 and previousGrinder == 1 and not currentOrder == 'coffee':
6              if os.path.isfile("/home/pi/CoffeeMachine/UI/order.txt") :
7                  with open("/home/pi/CoffeeMachine/UI/order.txt", "r") as j:
8                      temp = j.readline()
9                  if temp == "water\n":
10                     os.remove("/home/pi/CoffeeMachine/UI/order.txt")
11             with open("/home/pi/CoffeeMachine/UI/order.txt", "a+") as f:
12                 f.write("coffee\n")
13                 f.close()
14             with open("/home/pi/CoffeeMachine/UI/stop.txt", "a") as f:
15                 pass
16             currentOrder = 'coffee'
17             previousGrinder = 1
18         elif GPIO.input(grinderPin) == 1 and previousGrinder == 0:
19             previousGrinder = 1
20         elif not (GPIO.input(waterFlow1Pin) == previousWaterFLow1) or not (GPIO.input(waterFlow2Pin) ==
   previousWaterFLow2):
21             previousWaterFLow2 = GPIO.input(waterFlow2Pin)
22             previousWaterFLow1 = GPIO.input(waterFlow1Pin)
23             idleCount = 0
24             if not os.path.isfile("/home/pi/CoffeeMachine/UI/order.txt"):
25                 with open("/home/pi/CoffeeMachine/UI/order.txt", "a+") as f:
26                     f.write("water\n")
27                 currentOrder = 'water'
28             elif not os.path.isfile("/home/pi/CoffeeMachine/UI/unlock.txt") and os.path.isfile("/home/pi/
   CoffeeMachine/UI/order.txt") and currentOrder == 'water':
29                 with open("/home/pi/CoffeeMachine/UI/unlock.txt", "a") as f:
30                     pass
```

Unfinished Case

Top part of previous model

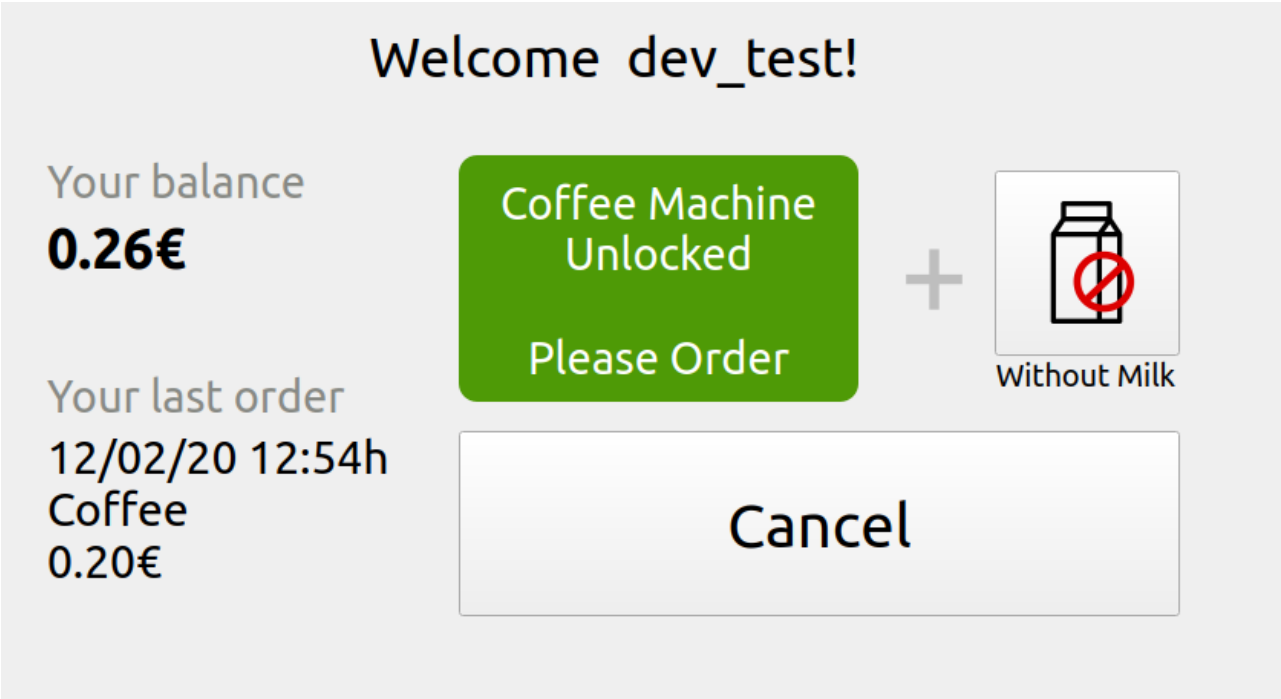


Part 3

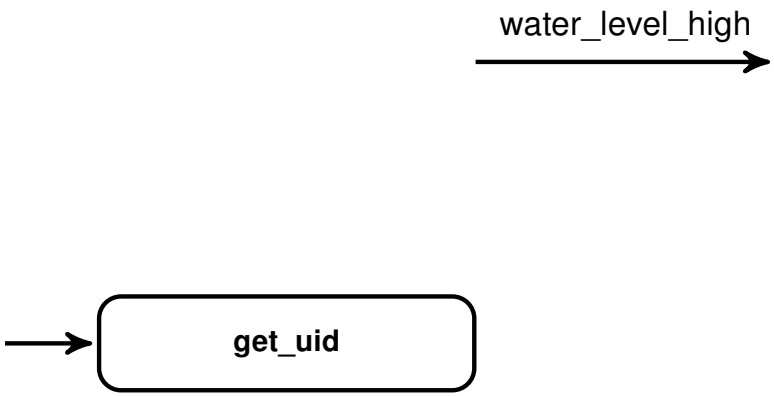
New Design & Architecture

New GUI

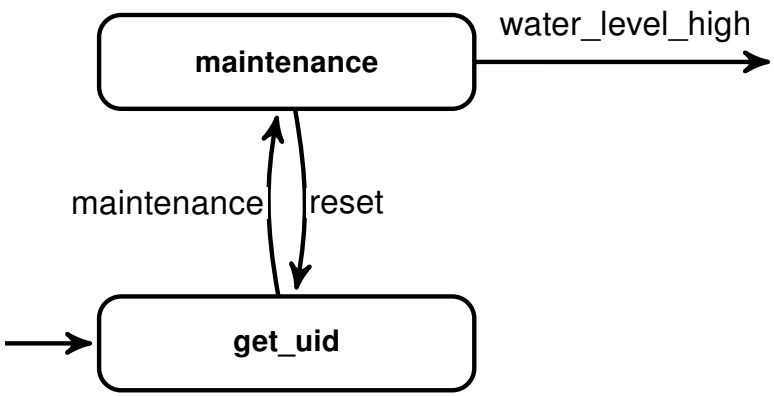
- Focus on important information
- Large buttons, suitable for touch
- Visual feedback for each step in ordering process



The State Machine



The State Machine



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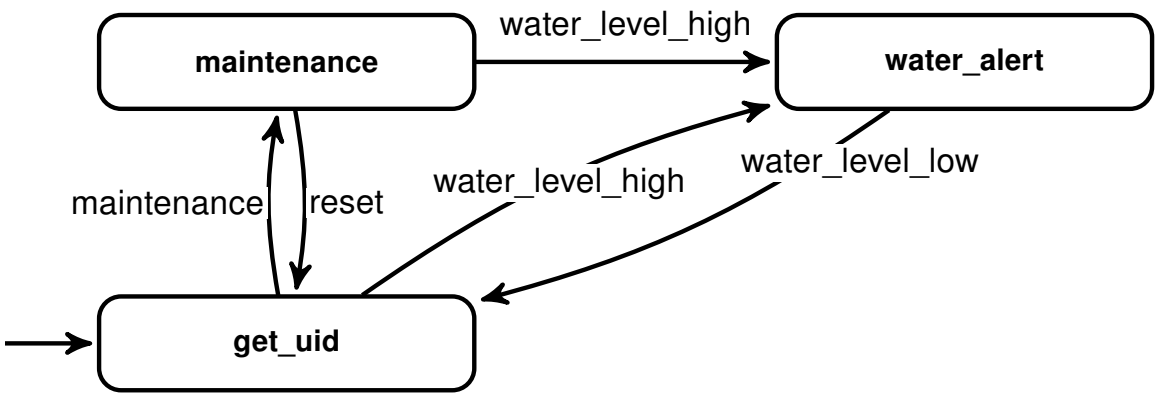

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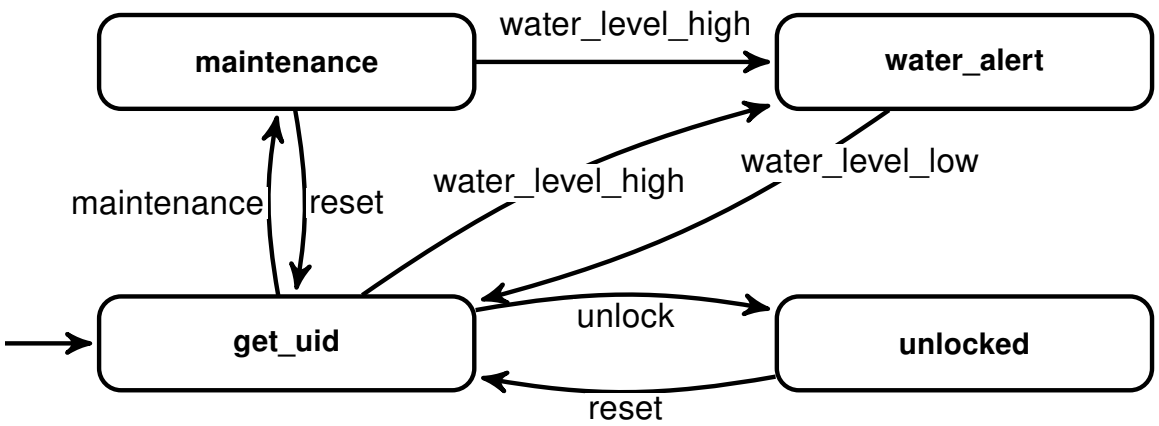

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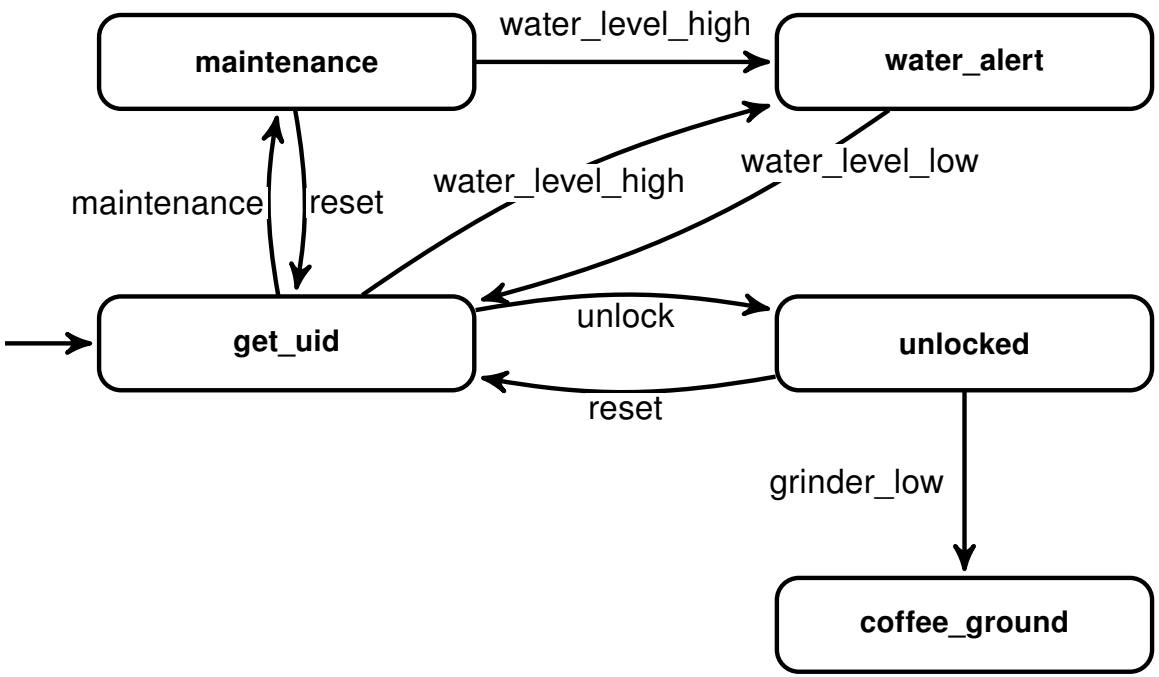

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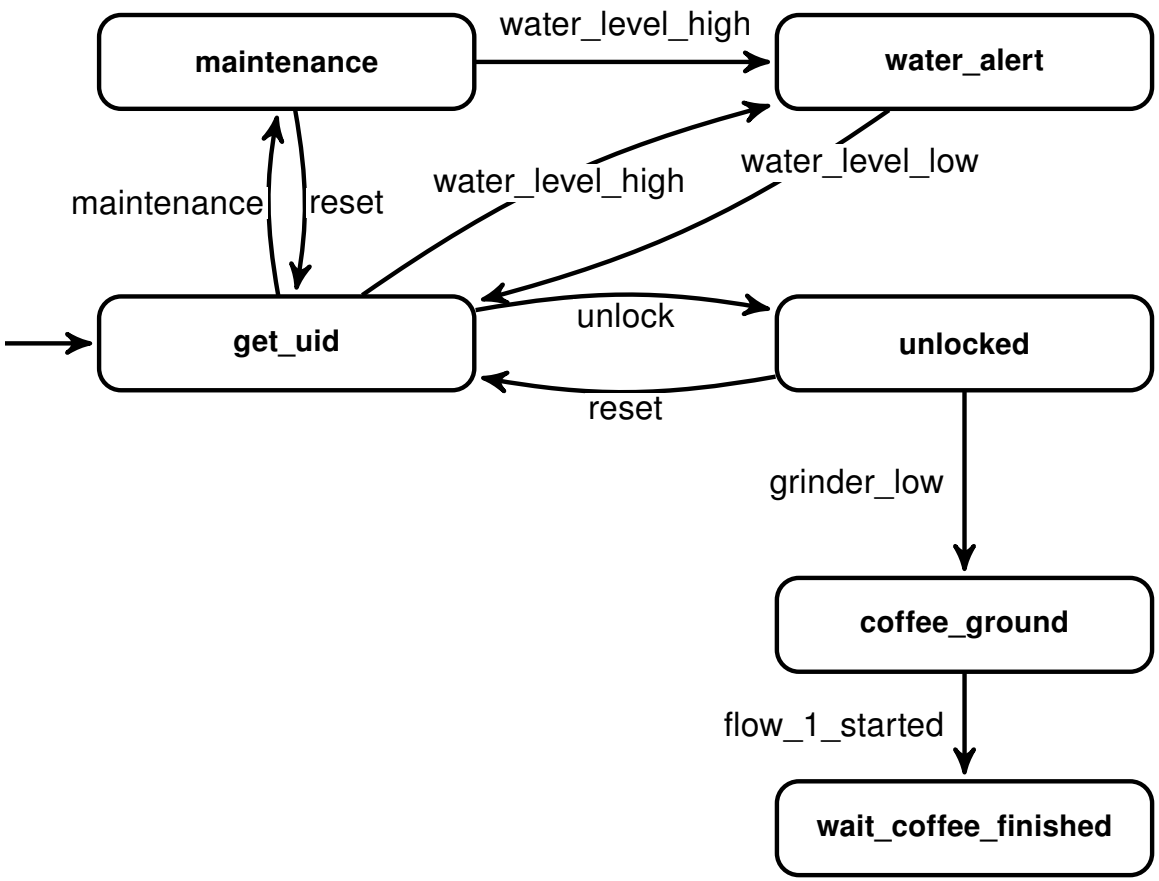

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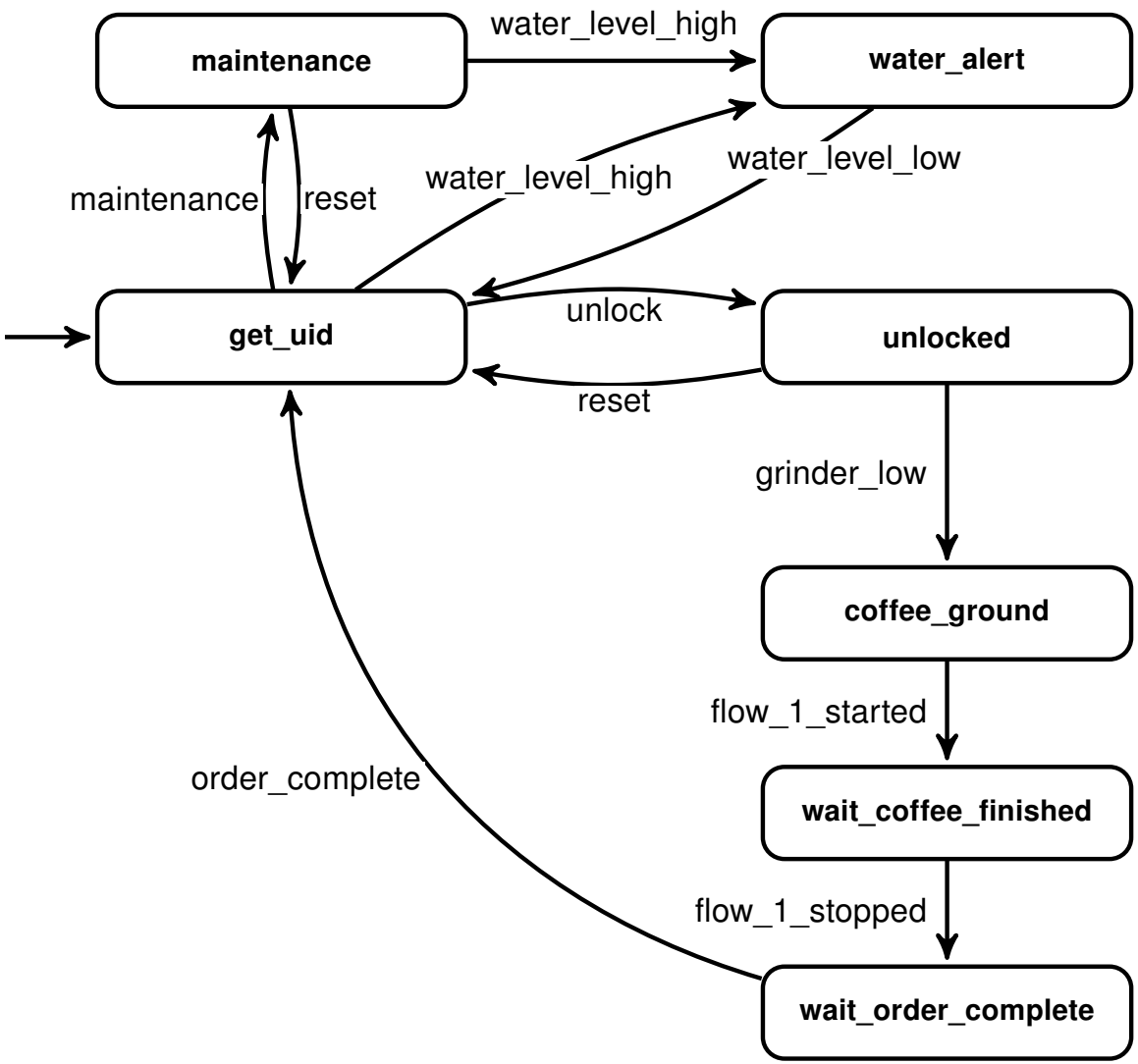

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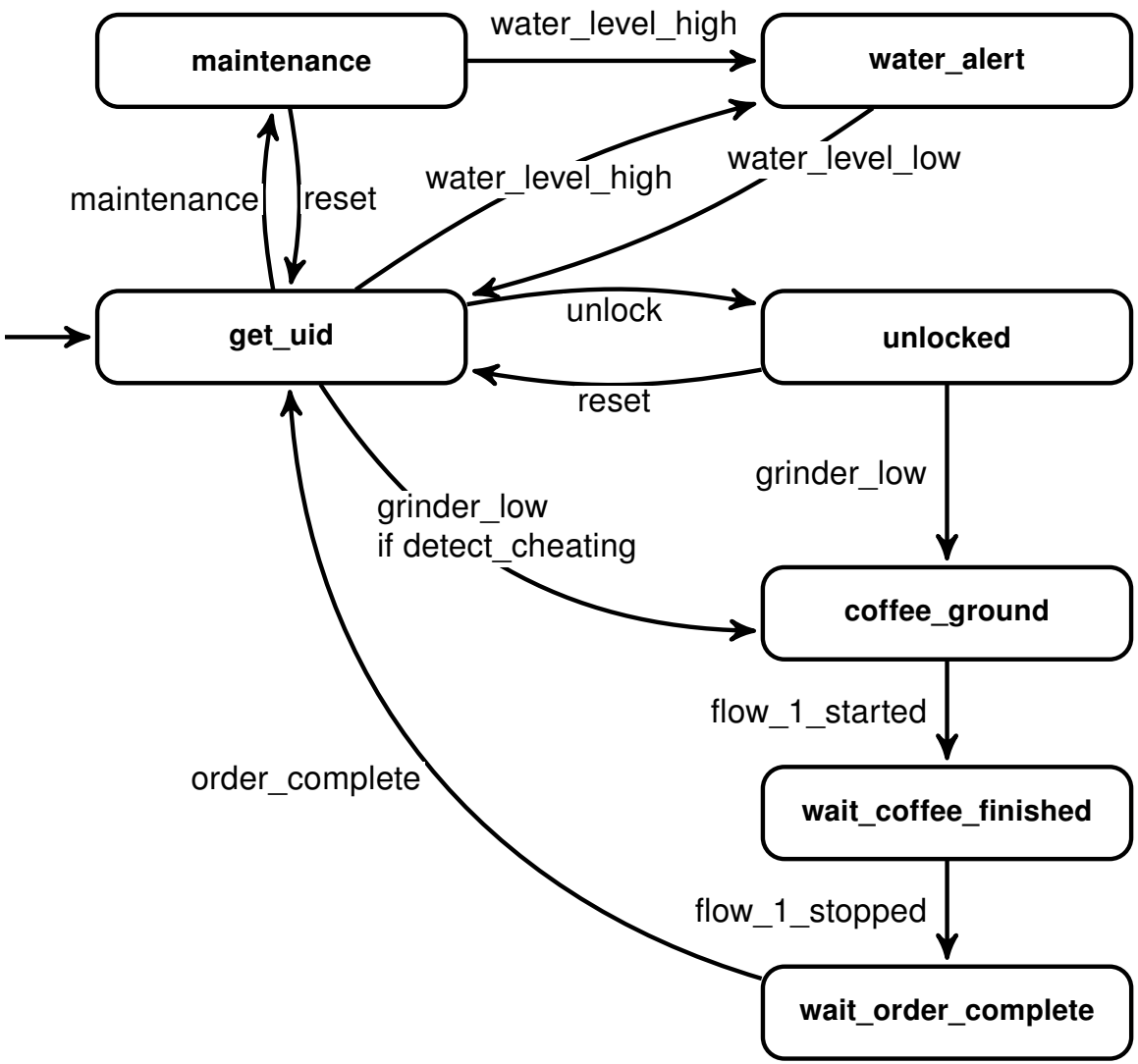

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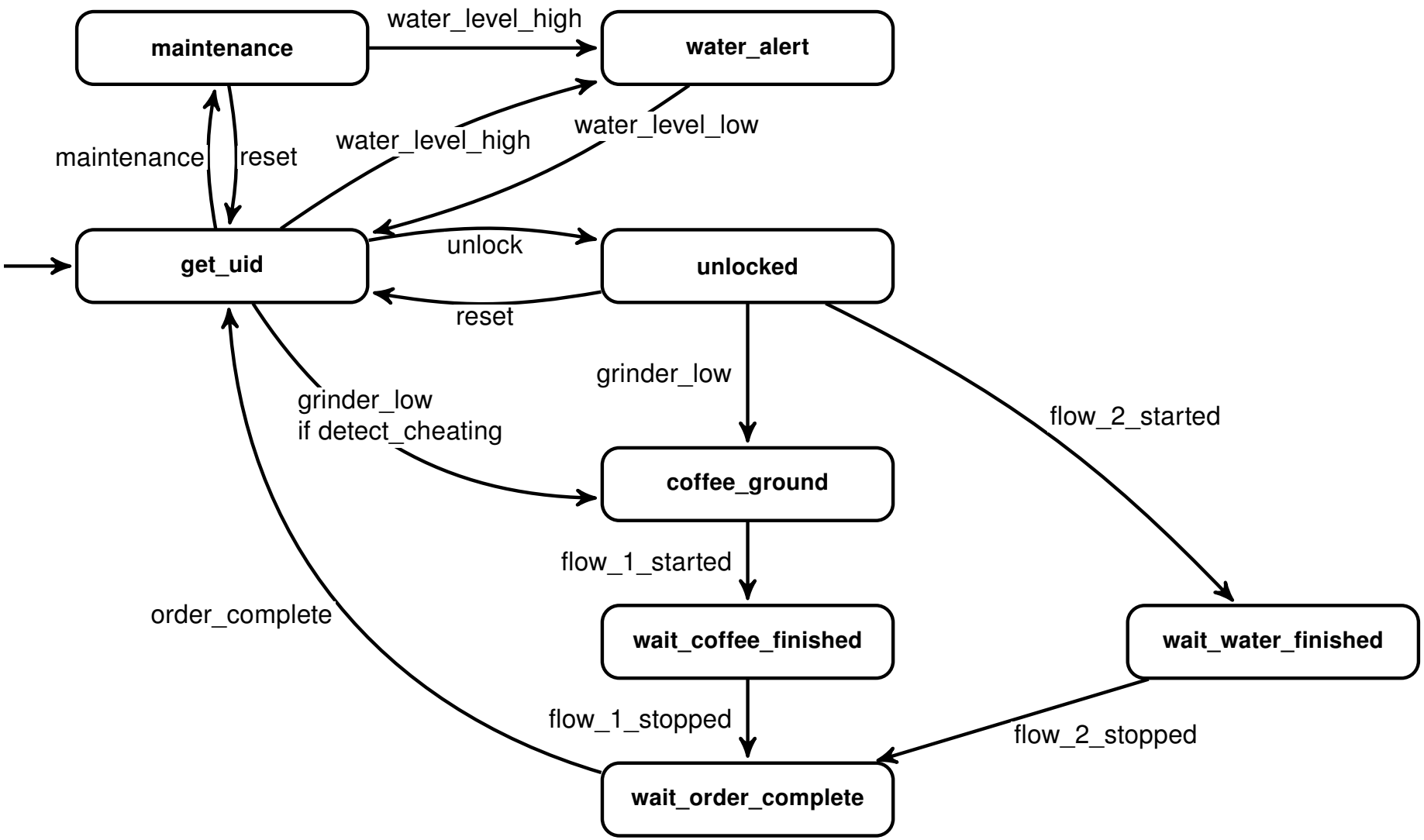
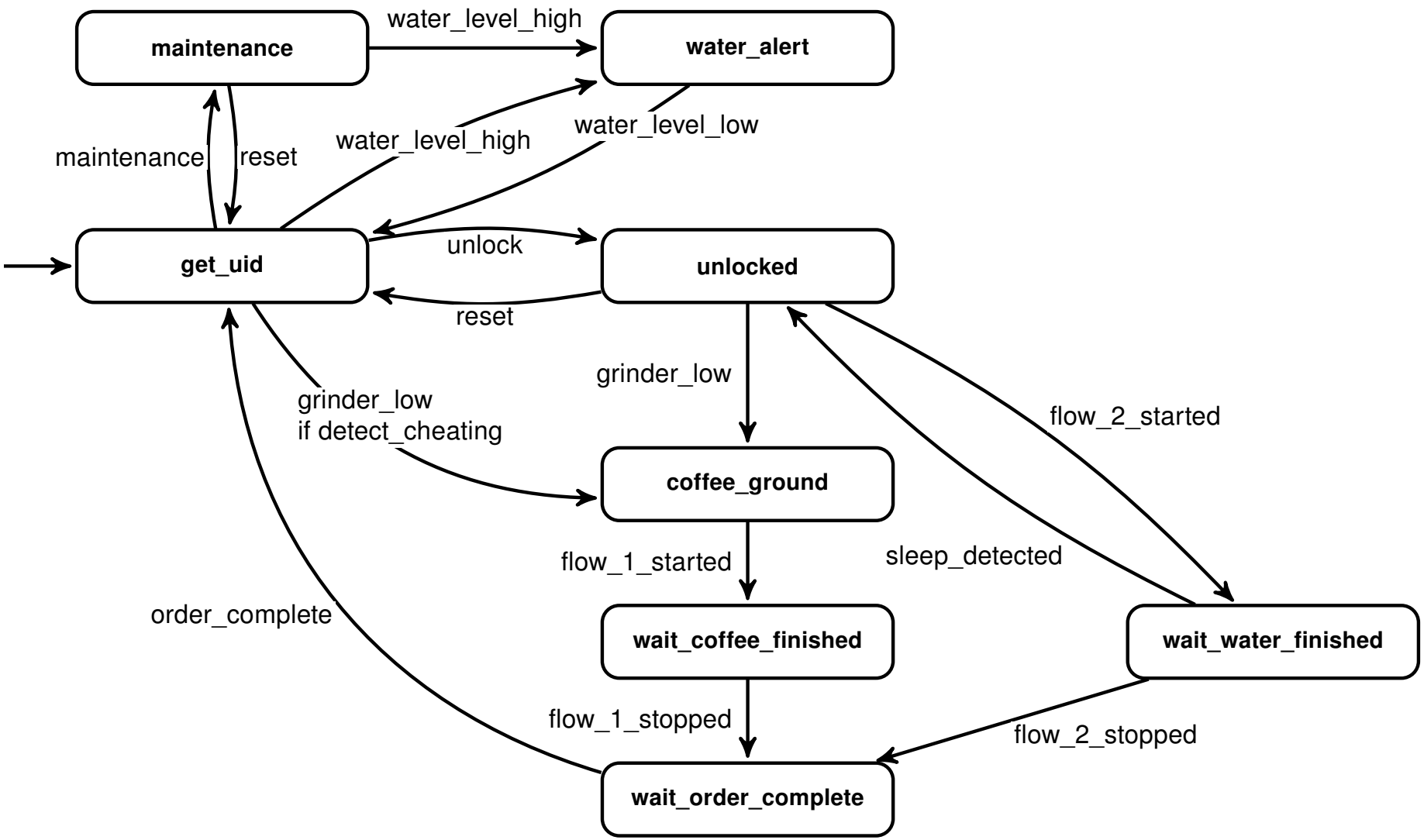
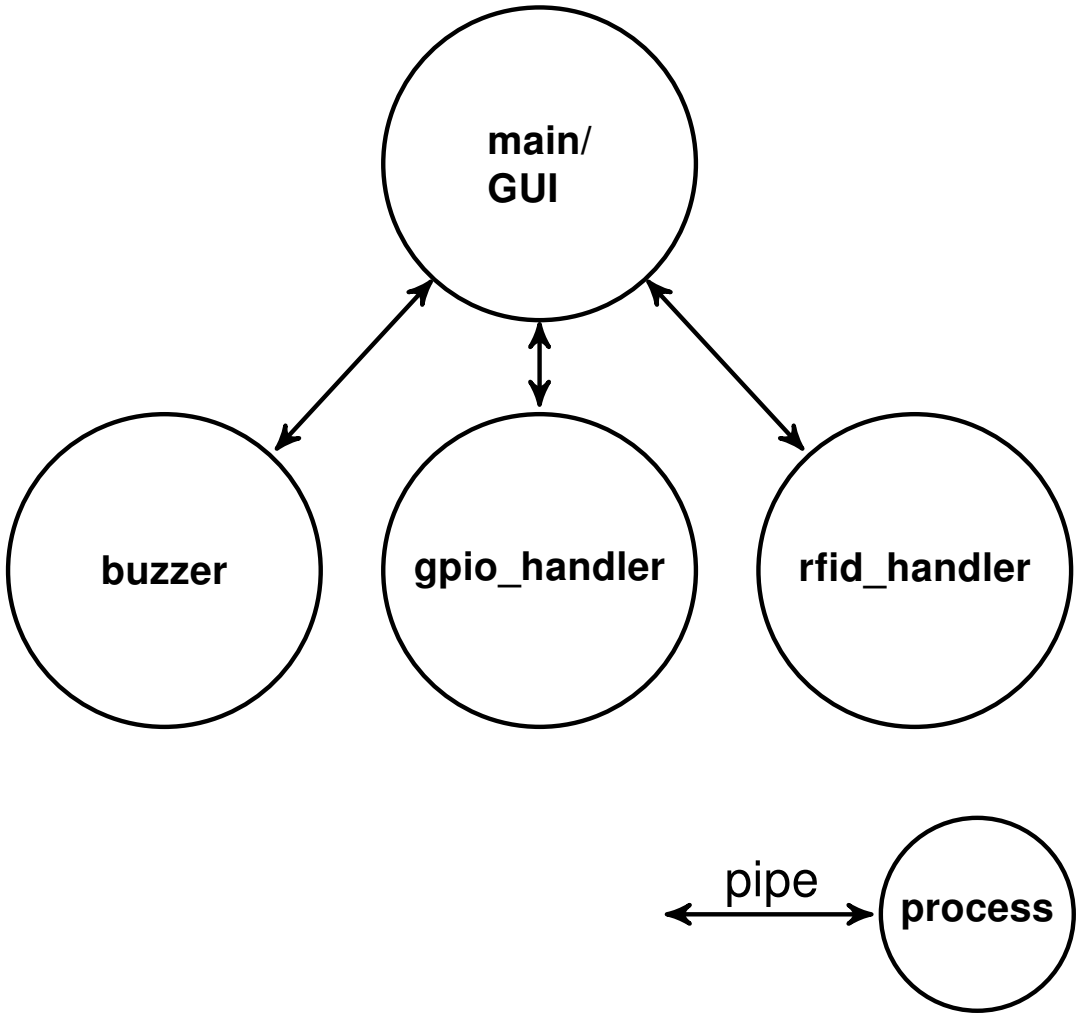


The State Machine



Leveraging Multiple CPU Cores

- 4 cores available
- Bidirectional pipes
- Predefined messages e.g, CMD_PAUSE, CMD_RESUME, CMD_LOCK, E_GOT_ID

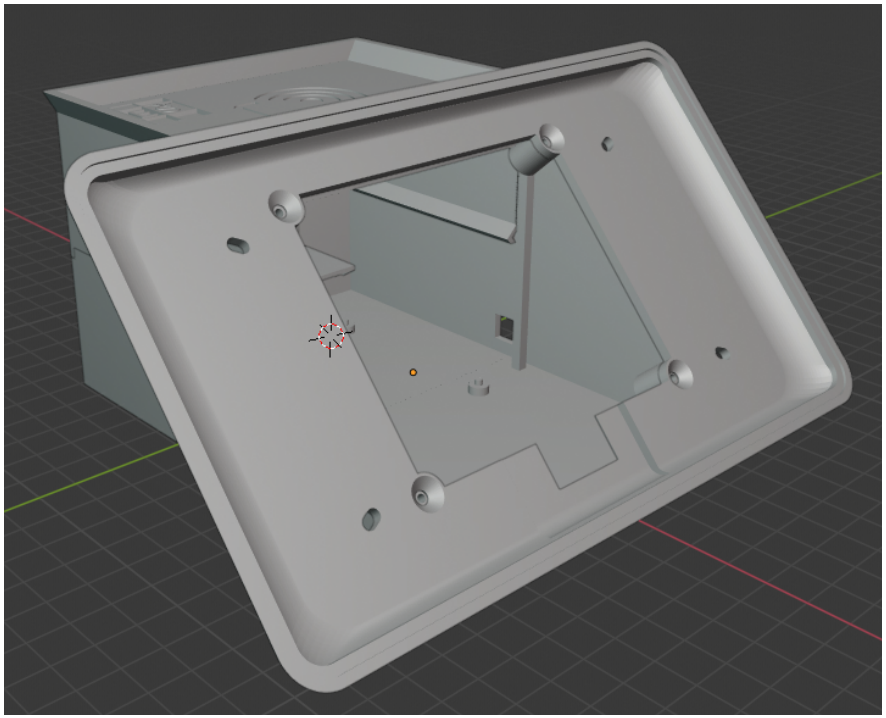


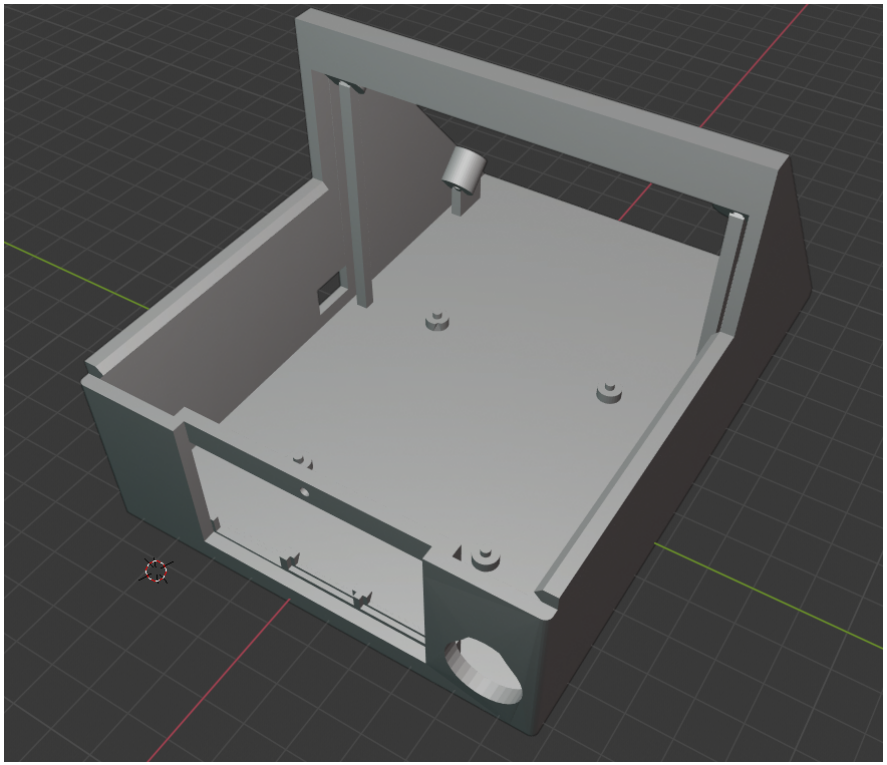
Changes in GPIO Handling

- **Callbacks** instead of **polling**
- Using pigpio library instead of RPi.GPIO
  - Supports callbacks through hardware interrupts
  - Noise filters

3D-Printed Case

- Designed with Blender
- Stereolithography printer, resin fluid hardened by laser
- Challenges: Non-manifold geometry i.e. "not watertight", walls too thin/unstable, characteristics of the material





Part 4

Results

Printing Costs

- Resin tank: €65.45
- 1L grey resin: €160.65

$$\frac{\text{resin tank } €65.45 + \text{resin } €160.65}{1000ml} = €0.2261\,/\,ml$$

- Top part: 90.79ml => €20,53
- Bottom part: 150.08ml => €33.93
- Screen frame: 53.60+ml => €12.12
- Total €66.58

Total cost estimate incl. prototypes > €300

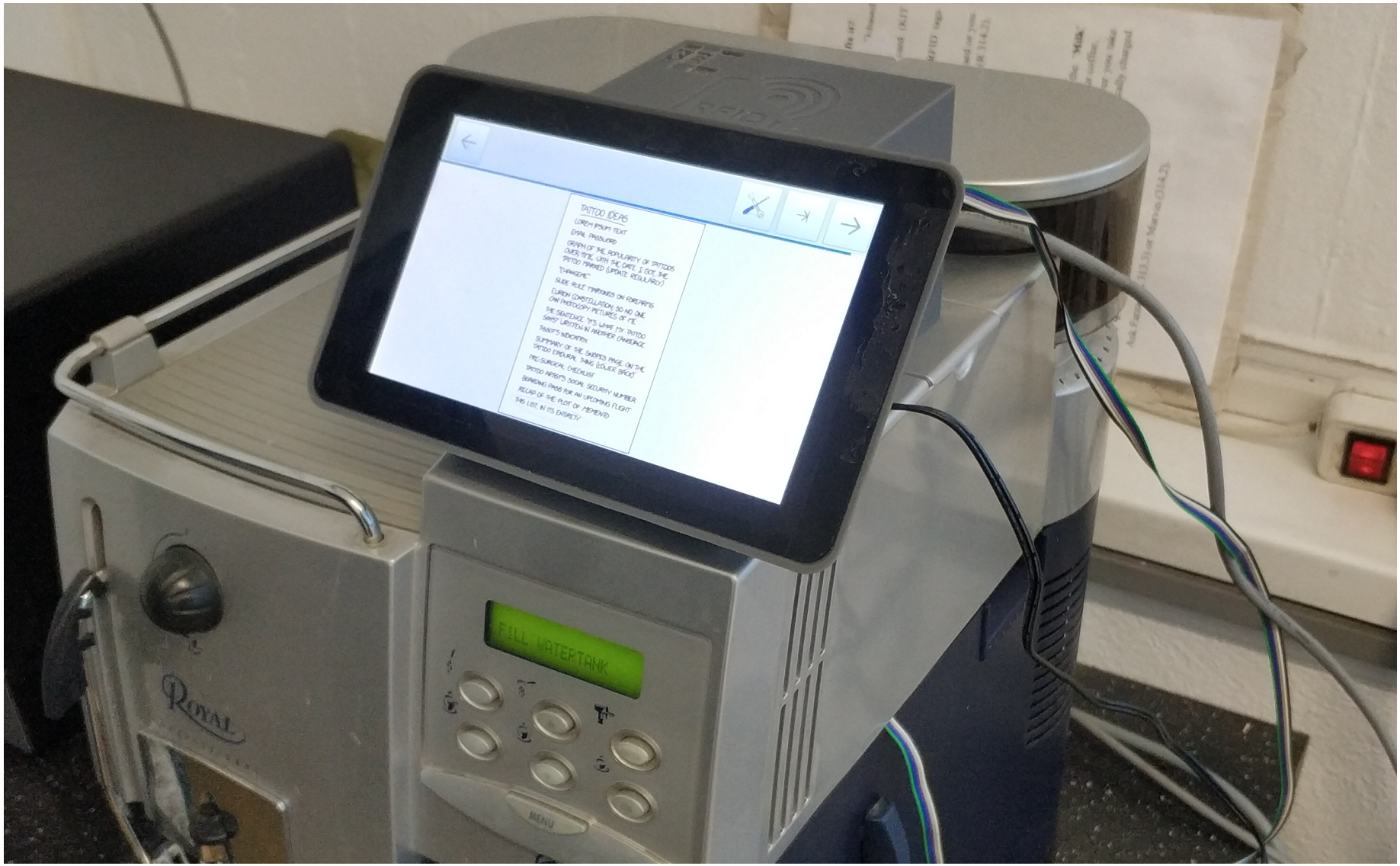
Reduced CPU Usage

Measurements made with `ps` command one hour after boot

	%CPU	python module
Old	98.1	inputGPIO.py (GPIO & buzzer)
	12.4	inputGPIO.py (RFID)
	0.1	main.py (GUI)
	0.0	inputGPIO.py (locking)
New	5.9	pigpiod (GPIO)
	16.3	main.py (RFID)
	0.7	main.py (GUI)
	0.4	main.py (GPIO & locking)
	0.0	main.py (buzzer)

% CPU is the “cpu utilization of the process in "##.#" format. Currently, it is the CPU time used divided by the time the process has been running (cputime/realtime ratio), expressed as a percentage." [ps(1) manpage]

The (Almost) Final System



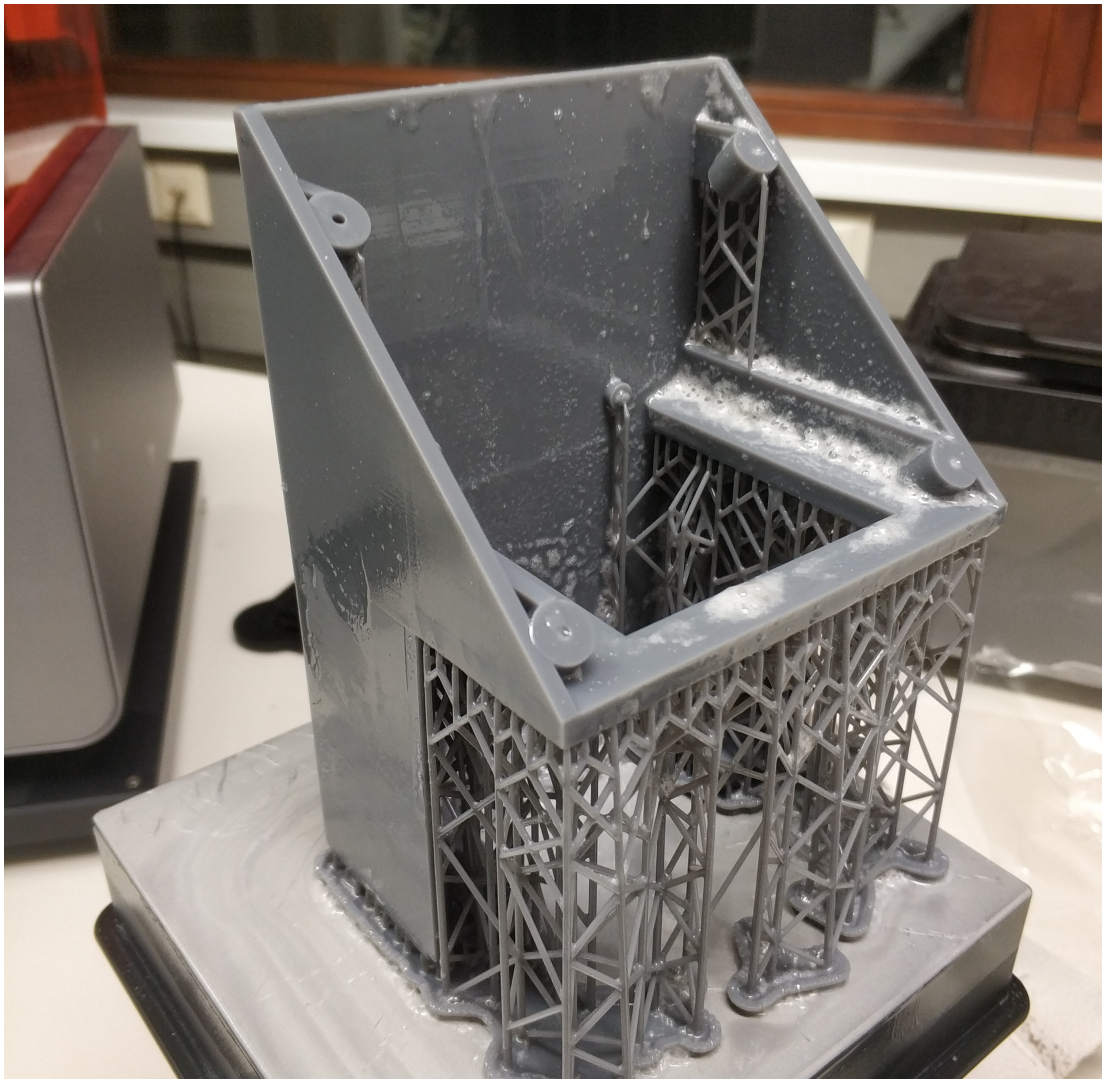
Conclusion

21/21 issues resolved
However: Occasionally coffee brewed without grinder signal
But: workaround in place

- **18/21 issues directly address usability**
- Removed bugs, increased reliability
- System observed to run for 1 month without restart
- Offline mode
- Dispensing limit
- Better handling of warm up

→ **goal of improving usability and reliability accomplished**

3D-Printed Case

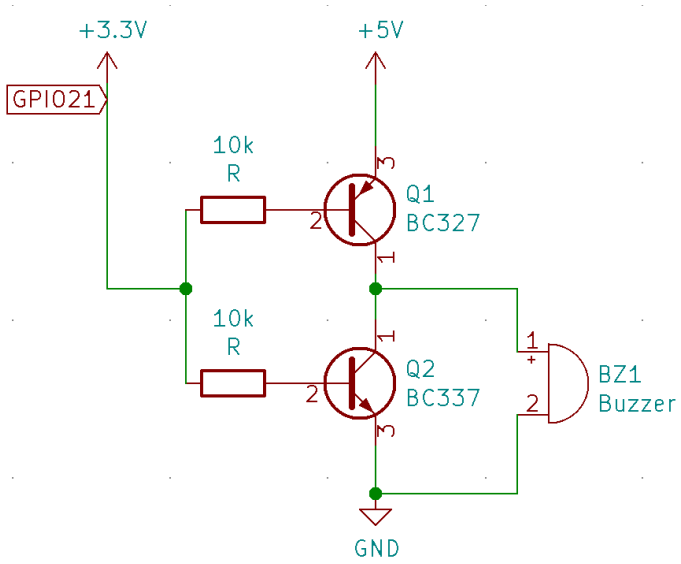


New Buzzer

- Moving piezo christal
- Changing input voltage from low to high -> "clicking" sound
- Frequency Modulation

- 440Hz is A4

Buzzer



Amplifier Circuit