Requirement Specification

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DOCUMENT HISTORY

Version	Date	Changes	Done by	Reviewer
0.1	2022-09-13	First draft	Whole group	Robin Holmbom
0.2	2022-09-23	Revisions as suggested by reviewer	Whole group	
1	2022-10-03		Whole group	
1.1	2022-10-17	Removes superflous requirement	Karl	
2.1	2022-12-06	Changed priority of requirements	Whole group	

1 INTRODUCTION

1.1 Partners

The client is Lars Eriksson from the division for vehicular systems which has ordered the project on behalf of the costumer Fredrik Wemmert from Aurobay. This project is a part of the examination in the course TSRT10 carried out by a conjoined group of Master of Science in Engineering Physics and Mechanical Engineering.

1.2 Purpose and Goals

The purpose of the project is to improve the regulation of an intake throttle in an internal combustion engine. This is to be done by exploring ways of identifying the throttle parameters in real time. One possible way of solving this could be machine learning. This could utilized in order to find a general model for learning the throttle parameters.

The goal is to first explore how the throttle parameters change with time in varying conditions, and how these changes affect the performance of the throttle servo. The goal is further to implement an adaptive regulation algorithm for the throttle servo in order to improve the servo when the parameters change.

The final product should also provide the same drive-ability as a normal throttle. A car equipped with this throttle controller should not require any special skills or adaptation of driving style. In short, it should be like driving a normal car.

For the group it is relevant to practice how to work in projects and how to structure a project within a group. The goal for the project group is further to gain knowledge within relevant technical areas such as machine learning and control theory.

1.3 Usage

The system is meant to be used in vehicles in order to further optimize regulation of the throttle. The optimization needs to be adaptive to the surrounding parameters such as temperature and also change in the parameters for the throttle itself, this includes properties such as viscosity of lubrication and friction.

If time and resources are sufficient, an interactive physical model is to be built with the intent to demonstrate the functionality of the adapting throttle control strategy with the possibility to regulate the throttle angel with a gas pedal.

1.4 Background Information

Most throttles regulators execute a calibration routine in order to determine parameters such as friction, zero point and limp home mode. These can change when the temperature of engine changes, if the outside temperature fluctuates while driving or the altitude of the vehicle is change drastically. The result is a sub optimal regulation which can lead to more emissions and less comfort for the driver. A more successful implementation of an adaptive regulation strategy would further improve the control of throttle regardless of current parameters defining the characteristics of the throttle.

1.5 Definitions

In this chapter some specific concepts necessary to understand the document are stated.

1.5.1 *Limp Home Region*

Limp home region refers to the throttle angle, θ, that the throttle has when the control signal, u, is close to zero. This is a safety function of the throttle for the instance of failing. This suffices the engine with enough air to continue operating albeit in a slow manner.

1.5.2 *Engine Model*

Engine model refers to the examining engine model in the course TSFS09 [1]. This is a model of an engine with some simplifications and linearization to optimize between performance and computing time. The model is constructed in the Matlab extension Simulink.

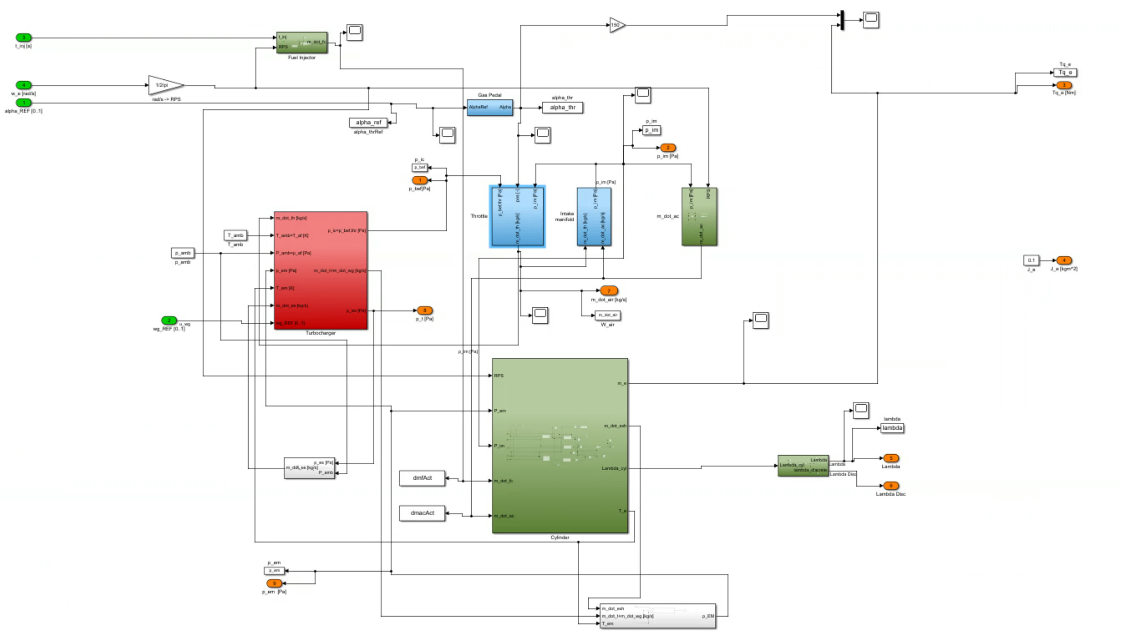

Figure 1: An overview of the complete engine block done in Matlab/Simulink. The model includes fuel injector, gas pedal, throttle, intake manifold, cylinder, turbocharger and lambda sensor.

1 The engine simulink model is provided by *Vehicular Systems Institution* at Linköpings University.

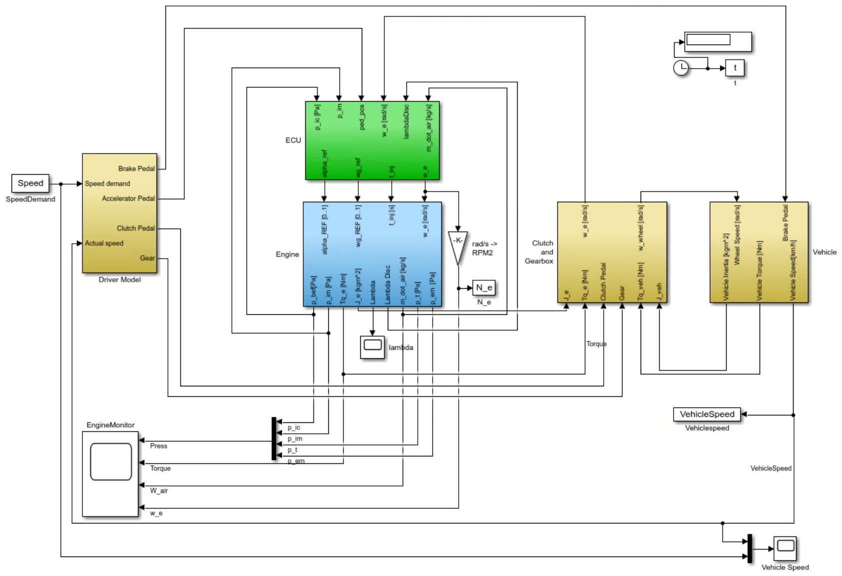

Figure 2: An overview of the complete vehicle model containing ECU, engine, driver model, gearbox and clutch and a block for the vehicle as a moving mass.

1.5.3 *Delivery Points*

Throughout the project some dates are set for delivery of specific parts of the product. The points are in the requirements denoted BPX where X is replaced by a number. Specified times for the points can be found in Table 1.

Table 1: Times for BPX.

Point	Time
BP1	Start of course, 1/9-2022
BP2	At latest 3 weeks after start, 21/9-2022
BP3	2-3 weeks after BP2
BP5	About 1 week before final delivery to customer
BP6	Deadline 19/12-2022

1.5.4 *Requirements*

The *requirements* stipulate what will or should be done in the project. The structure of a requirement is shown in Table 2. Requirement is the identifying number for the whole requirement. Version shows if the requirement has been updated. Description describes the actual requirement. Priority is either 1 (must be full-filled) or 2 (preferably fulfilled).

Table 2: Requirement structure.

Requirement	Version	Description	Priority

2 SUMMARY OF SYSTEM

The system consists of several parts, both hardware and software components. The hardware components are a Raspberry PI, a motor control board (H-bridge), an A/D-converter and a throttle with a built-in servo motor. The software components are a motor simulation, one or more regulation algorithms, interface code for the GPIO pins on the Raspberry PI and eventual extra programs for the machine learning parts.

2.1 Rough Description of Product

The product will work like a normal throttle but with reduced effect of hysteresis and external states such as temperature or altitude, allowing it to be controlled with a much higher accuracy.

The final product will mainly consist of an improved algorithm for throttle regulation. The algorithm can then be adapted to be used in different motor controls.

An experimental setup with the algorithm incorporated will also be part of the product. It will consist of a motor simulation in Matlab Simulink to be run on a Raspberry Pi. This setup will regulate a real throttle and be used to test the performance of the regulator.

2.2 Product Components

The hardware components needed for the project are:

- Raspberry Pi 3
- A/D - converter
- H-bridge
- Voltage regulator 5 V
- Voltage regulator 3.3 V
- Potentiometer for manual reference signal.

The components of the system are connected in accordance to Figure 3 below

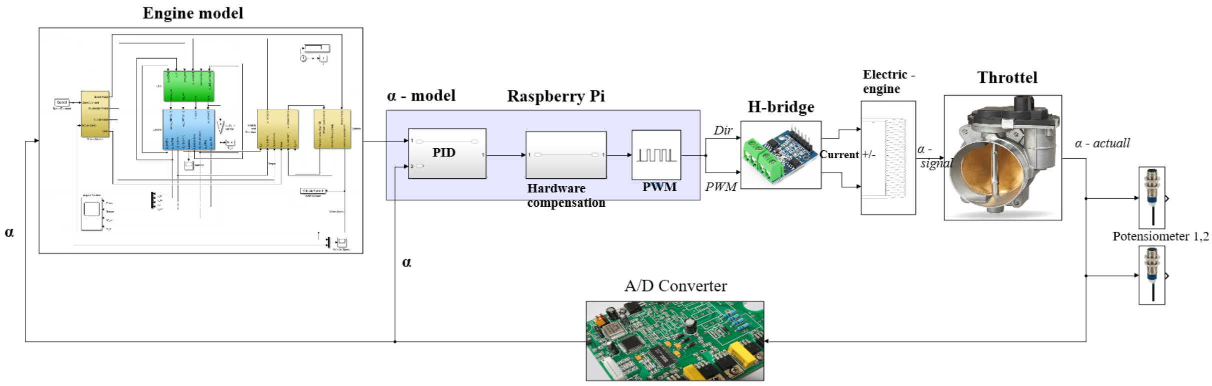

Figure 3: Representation of the system with components.

2.3 Dependency to Other Systems

The throttle is mainly controlled by the throttle controller. The controller computes the throttle plate reference angle. This angle can be calculated from the accelerator pedal position or the cruise control demanded torque. It is also important to remember that the throttle is one of the most vital parts of an internal combustion engine. This means that it is also highly dependent on other systems present in the engine (and vice versa). The throttle is the part that regulates the air flow to the engine and therefore the torque and power since the lambda value always has to be 1 in order for the after treatment of exhaust gases to work properly. The amount of air that is moving into the engine is dependent on the ambient pressure before the throttle, the pressure in the intake manifold after the throttle and the throttle angle. Precise operation is therefore vital for proper control of the engine.

2.4 Included Subsystems

The throttle and its controller consist of several subsystems namely:

- Software
  - Vehicle model software (from TSFS09)
  - Throttle controller
  - Machine learning software
- Hardware
  - Raspberry Pi
  - Throttle
  - A/D converter
  - Potentiometer(s)

Table 3: General requirements on the throttle regulation.

Step [%]	Static error [%]	Settling time [ms]	Overshoot [%]
90	< 0.125	< 200	< 0.5
50	< 0.125	< 200	< 0.5
10	< 0.125	< 100	< 0.125

2.5 General Requirements on the System

The system fulfills the customers control specifications for step responses and tracking for varying operating conditions. The tracking requirement is a tracking error of less than 2.5%. The step response requirements are listed in Table 3 below.

3 SOFTWARE

The needed software for the product can be separated as follows:

- Throttleservo model
- TSFS09 vehicle model
- Controller
  - PID implementation
  - Adjustment mechanism
  - Machine learning algorithm

3.1 Interface of Software

The software will mainly be written in Matlab code and the interface will thus be the Matlab IDE. Some Python coding will be used for the communication between the computer, Raspberry Pi and throttle.

3.2 Requirements on Software

Requirement	Version	Description	Priority
1	1	The software will include some method based on machine learning	1
2	1	The software will have an adaptive regulator	1
3	1	The software will be able to utilize the vehicle model and run different drive cycles	1
		cont. on next page	

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Requirement	Version	Description	Priority
4	1	The software will be able to run "hardware in the loop" (HIL) simulations	1
5	1	The software will be able to run in a real engine	2

4 RASPBERRY PI

4.1 Description of Raspberry Pi

The Raspberry Pi allows for computations to be made to simulate the environment of an engine, regulate the control signal and data collection for analysing the results. Schematics can be found in the Appendix A.1 [2]. The Raspberry Pi used is of the model Raspberry Pi 3 model B. It has the following specifications[2]:

- Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
- 1GB RAM
- BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
- 100 Base Ethernet
- 40-pin extended GPIO
- 4 USB 2 ports
- 4 Pole stereo output and composite video port
- Full size HDMI
- CSI camera port for connecting a Raspberry Pi camera
- DSI display port for connecting a Raspberry Pi touchscreen display
- Micro SD port for loading your operating system and storing data
- Upgraded switched Micro USB power source up to 2.5A

4.2 Design Requirement

Requirement	Version	Description	Priority
6	2	The vehicle model will run in real time on a computer and communicate with the Raspberry Pi	1
7	1	The Raspberry Pi will communicate results to a computer in real time	2
8	2	The Raspberry Pi will be able to change simulation parameters in real time while running	2
9	1	The Raspberry Pi will be able to collect and store data for analysis	1

4.3 Functional Requirements on Raspberry Pi

Requirement	Version	Description	Priority
10	2	The Raspberry Pi will be connectable to the A/D converter, H-bridge and a computer	1

5 THROTTLE

5.1 Description of Throttle

The group has been provided with two different throttle servos. The exact specifications for each servo is not yet known by the group, but they are supposed to work well with the other components.

5.2 Functional Requirements on Throttle

Requirement	Version	Description	Priority
11	1	The throttle should be able to be actuated without running with the actual ECU and engine for testing (hardware in the loop)	1

6 GENERAL REQUIREMENTS

Requirement	Version	Description	Priority
12	1	The throttle servo will be able to follow a reference signal using the given regulation algorithm	1
13	1	The motor simulation will be able to provide the regulation algorithm with a reference signal	1
14	1	The motor simulation will be able to read measurements from the throttle servo	1
15	1	It will be possible to log and store measurements, reference signal and control signal during a simulation	1
16	1	Data will be collected for at least three fundamentally different situations (for example different operating temperatures) for two throttle servos (one new, one used) in different conditions	1
17	2	The collected data will be analyzed in order to discover the influence of the surroundings on the performance of the controller	1
18	1	The collected data will be analyzed in order to discover the influence of the model parameters on the performance of the regulator	1
19	2	A mechanism for updating the regulation parameters from measurements during a drive cycle will be implemented	1
20	2	An analysis will be done to find out what exitation of the throttle is needed to identify necessary parameters.	1
21	2	Several models for updating the regulation parameters from measurements during a drive cycle will be implemented and compared	2
22	1	The performance of at least one model will be demonstrated in a "hardware in the loop"-simulation	1
23	1	The adaptive control will be able to handle several standardized drive cycles while fulfilling the requirements	1
24	1	At least one model will be demonstrated in a regulator in a real engine	2

7 PERFORMANCE REQUIREMENTS

Requirement	Version	Description	Priority
25	3	Static error on step response will be max 0.125%	2
26	1	The settling time (+- 5%) will be less than 200ms for step greater than 50%	2

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Requirement	Version	Description	Priority
27	3	The settling time (+- 5%) will be less than 100ms for step smaller than or equal to 50%	2
28	3	The overshoot will be less than 0.5% pos for step greater than 50%, otherwise less than 0.125 % pos	2
29	2	When tracking a continuous reference the error should never be greater than 2.5 % pos with a reasonable ramp of in signal (for example during drive cycle)	2

8 REQUIREMENTS ON CONTINUED DEVELOPMENT

Requirement	Version	Description	Priority
30	2	All code will be well documented, commented according to Google code standard and available through a git repo	1

9 REQUIREMENTS ON RELIABILITY

Requirement	Version	Description	Priority
31	1	The controller is stable for all possible environments	1
32	1	The engine model does not request a throttle angle outside of the possible range of motion of the throttle	1
33	2	The controller will not signal the throttle to overshoot its end positions	1

10 ECONOMY

Requirement	Version	Description	Priority
34	1	Each member in the project group will spend 240 hours on the project	1

11 REQUIREMENTS ON SAFETY

Requirement	Version	Description	Priority
35	1	The throttle will never be used without the protective shields	1

12 REQUIREMENTS ON DELIVERIES

Requirement	Version	Description	Priority
36	1	A verbal presentation of the system will be presented at BP2	1
37	1	At the final delivery a verbal presentation of the work and result will be held	1
38	1	The project will be presented on a web page, finished at BP6	1
39	1	The project will be presented with a movie on YouTube, finished at BP6	1

13 REQUIREMENTS ON DOCUMENTATION

There are several documents to be produced, and to be delivered at specific delivery points.

Requirement	Version	Description	Priority
40	1	A specification of requirements will be delivered at BP2	1
41	1	A project plan with time plan will be delivered at BP2	1
42	1	A first version of the design specification will be delivered at BP2	1

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Requirement	Version	Description	Priority
43	1	A final version of the design specification will be delivered at BP3	1
44	1	A plan for tests will be delivered at BP3	1
45	1	A protocol of tests will be delivered at BP5	1
46	1	A user manual will be delivered at BP5	1
47	1	A technical report will be delivered at BP6	1
48	1	A report of final reflections will be delivered at BP6	1
49	1	A Poster presenting the work will be delivered at BP6	1
50	1	Reports of project status and time will be delivered each Friday during the project	1
51	1	Any eventual issues with software and hardware will be documented	1

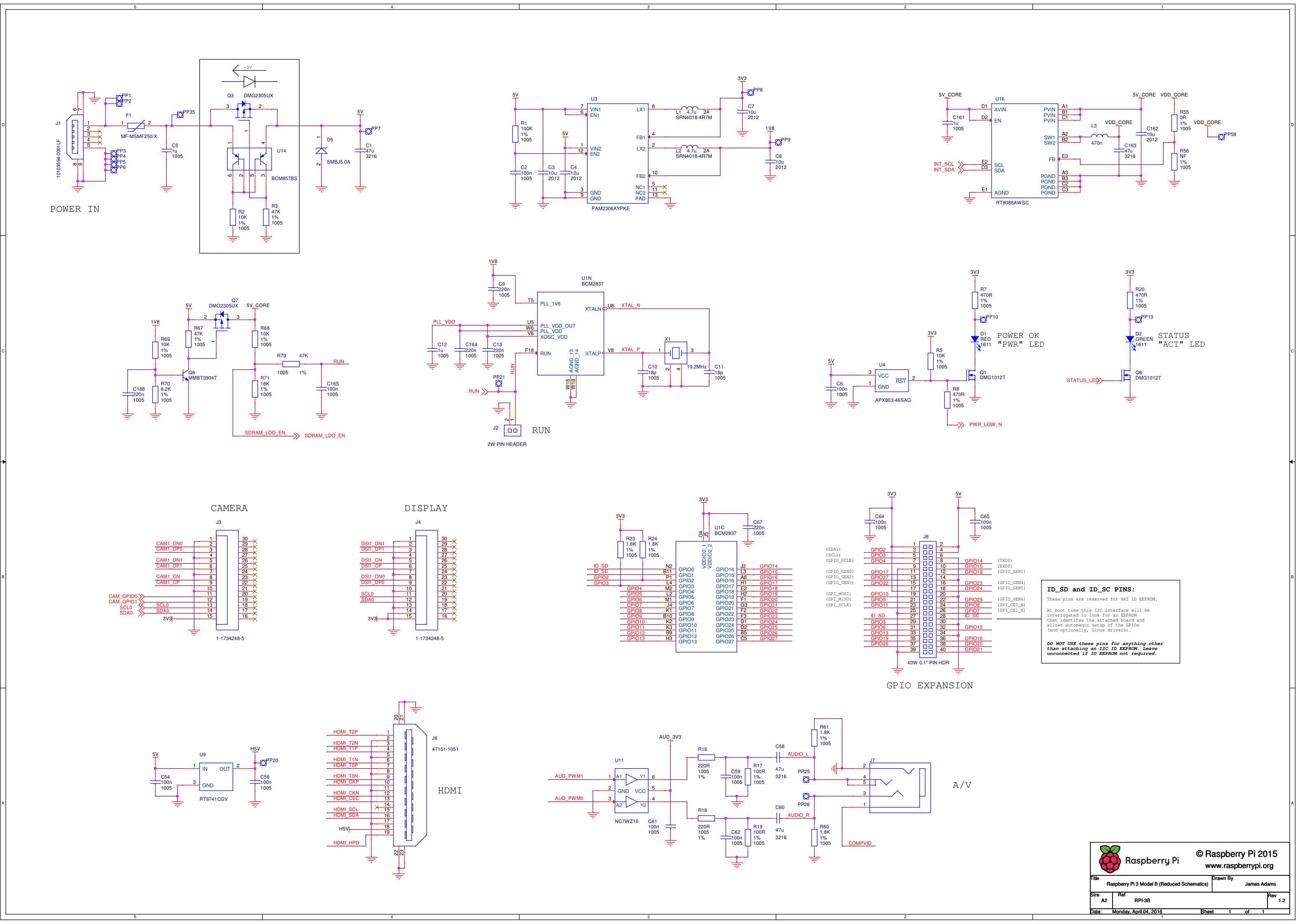
REFERENCES

[1] Model-Based Throttle Control using Static Compensators and Pole Placement,A. Thomasson and L. Eriksson, IFP Energies nouvelles (2011). [article]

[2] raspberrypi.com, (2022-09-06) [website]

A APPENDIX

A.1 Raspberry Pi Schematics


POWER IN
RUN
CAMERA
DISPLAY
GPIO EXPANSION
HDMI
A/V
POWER OK "PWR" LED
STATUS "ACT" LED
ID_SD and ID_SC PINS:
These pins are reserved for HAT ID EEPROM.
At boot time this I2C interface will be interrogated to look for an EEPROM that identifes the attached board and allows automagic setup of the GPIOs (and optionally, Linux drivers).
DO NOT USE these pins for anything other than attaching an I2C ID EEPROM. Leave unconnected if ID EEPROM not required.
Raspberry Pi
© Raspberry Pi 2015
www.raspberrypi.org
Title Raspberry Pi 3 Model B (Reduced Schematics)
Drawn By James Adams
Size A2
Ref RPI-3B
Rev 1.2
Date: Monday, April 04, 2016
Sheet 1 of 1