BRNO UNIVERSITY OF TECHNOLOGY

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ

DEPARTMENT OF CONTROL AND INSTRUMENTATION

ÚSTAV AUTOMATIZACE A MĚŘICÍ TECHNIKY

AUTOMATED SPRINKLER SYSTEM FOR HOUSEPLANTS

AUTOMATICKÝ ZAVLAŽOVAČ PRO POKOJOVÉ ROSTLINY

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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BRNO 2020

BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

Bachelor's Thesis

Bachelor's study program **Automation and Measurement**

Department of Control and Instrumentation

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Year of study: 3 ***Academic year:*** 2019/20

TITLE OF THESIS:

Automated sprinkler system for houseplants

INSTRUCTION:

1. Research the ways of automation water distribution for houseplants and monitoring of soil parameters.
2. Explore existing automatic irrigation systems available on the market. Describe pros and cons of the existing systems. Define requirements for new irrigation system.
3. Define autonomous components of the new system. Define mechanical actuators and other system components. Choose proper soil quality sensors. Define wireless communication protocol between autonomous system components.
4. Design a control of water delivery system. Select microcontrollers for each autonomous component. Design and implement firmware for each system component.
5. Design and implement PC software for parameter settings and visualization of the system's components status.
6. Implement and demonstrate fully working sprinkler system for houseplants.
7. Evaluate the results, define limitation of the system and suggest further improvements.

RECOMMENDED LITERATURE:

[1] Virius, M. : Jazyky C a C++, Grada 2006, ISBN 80-247-1494-9.

[2] Everett, H.,R.: Sensors for Mobile Robots theory and application, CRC Press 1995, ISBN 1568810482.

Date of project specification: 3.2.2020 ***Deadline for submission:*** 8.6.2020

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ABSTRACT

The main goal of this work is to design, implement and demonstrate intelligent system, that uses micro-controller to benefit in efficiency and functionality. As an example, in this work will be designed system for indoor plants watering, which will be capable to automatically adjust soil moisture level based on feedback sensor information from each plant pot, as well as monitoring other soil and air parameters and storing it in permanent memory for further visualization.

KEYWORDS

Watering system, Internet of Things, microcontroller, Arduino, wireless connection, Python, automation

ABSTRAKT

Hlavním cílem této práce je navrhnout, implementovat a demonstrovat inteligentní systém, který využívá mikroprocesor pro zvýšení efektivity a funkčnosti. Jako příklad bude v této práci navržený systém zalevani rostlin, který bude schopen automaticky upravit úroveň vlhkosti půdy na základě zpětnovazebního senzoru. Informace z každého květináče a sledování dalších parametrů půdy a vzduchu budou uloženy do trvalé paměti pro další vizualizaci.

KLÍČOVÁ SLOVA

Zavlažovací systém, Internet věcí, mikrokontrolér, Arduino, bezdrátové připojení, Python, automatizace

MAKEDONENKO, Oleksandr. *Automated sprinkler system for houseplants*. Brno, 2020, 38 p. Bachelor's Thesis. Brno University of Technology, Fakulta elektrotechniky a komunikačních technologií, Ústav automatizace a měřicí techniky. Advised by Ing. Petr Petyovský, Ph.D.

Typeset by the `thesis` package, version 3.05; `http://latex.feec.vutbr.cz`

Rozšířený abstrakt

V dnešní době jsou spousta domácích spotřebičů a domácích systémů používaných v každodenních rutinách. Jedna z těchto rutin je péče o květiny, nebo přesněji - zalévání květin. A automatice tato řešení již existují, i přes relativně široké využití venkovních variant, vnitřní varianta používaná velmi zřídka. Navíc, tyto systémy ve většině případu jsou časové přepínače, nepoužívají zpětnovazební senzory k rozhodnutí, kdy zalévaní musí zapnut, což může vést k nesprávné činnosti v důsledku chyby uživatele během nastavení zařízení. Hlavním cílem této práce je navrhnout, implementovat a demonstrovat inteligentní systém, který využívá mikroprocesor pro zvýšení efektivity a funkčnosti. Jako příklad bude v této práci navržený systém zalevani rostlin, který bude schopen automaticky upravit úroveň vlhkosti půdy na základě zpětnovazebního senzoru. Informace z každého květináče a sledování dalších parametrů půdy a vzduchu budou uloženy do trvalé paměti pro další vizualizaci. V této práci budou popsány všechny kroky návrhu a implementace systému. To jsou: návrh koncepce, výběr částí systému, výběr mikrořadiče, fyzické propojení součástí, vývoj firmwaru a vývoj softwaru pro PC. Kromě základní funkčnosti bude systém mezi sebou mít bezdrátovou komunikaci několik mikrokontrolérů: několik podřízených jednotek, které budou komunikovat s jedním master prvkem. Chcete-li vyloučit nepohodlí nutností dláždit dráty, z hlavní jednotky do slave, kromě vodovodního potrubí bude použita bezdrátová komunikace.

DECLARATION

I declare that I have written the Bachelor's Thesis titled "Automated sprinkler system for houseplants" independently, under the guidance of the advisor and using exclusively the technical references and other sources of information cited in the thesis and listed in the comprehensive bibliography at the end of the thesis.

As the author I furthermore declare that, with respect to the creation of this Bachelor's Thesis, I have not infringed any copyright or violated anyone's personal and/or ownership rights. In this context, I am fully aware of the consequences of breaking Regulation § 11 of the Copyright Act No. 121/2000 Coll. of the Czech Republic, as amended, and of any breach of rights related to intellectual property or introduced within amendments to relevant Acts such as the Intellectual Property Act or the Criminal Code, Act No. 40/2009 Coll., Section 2, Head VI, Part 4.

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author's signature

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Introduction

Nowadays a lot of household appliances and house-based systems are more commonly used with an intention automation of wide list of everyday routines. One of these routines can be flower care, or more precisely - flower watering. And automated solutions for this issue already exist, however despite relatively wide use for outdoor variant, indoor variant used very rarely. In addition, these systems in most cases are time-based switches, they don't use feedback sensors to decide when to water plants, that can lead to incorrect work as a result of user error during device setting.

The main goal of this work is to design, implement and demonstrate intelligent system, that uses micro-controller to benefit in efficiency and functionality. As an example, in this work will be designed system for indoor plants watering, which will be capable to automatically adjust soil moisture level based on feedback sensor information from each plant pot, as well as monitoring other soil and air parameters and storing it in permanent memory for further visualization.

In this work will be described all steps of system design and implementation, more specifically: concept design, system parts selection, micro-controller selection, physical connection of the parts, firmware development and software development for PC.

In addition to functionality, system will have wireless communication between several micro-controllers: several slaves units which will communicate with one master unit. To eliminate inconvenience of necessity to pave wires, from master unit to slaves, in addition to water pipe, wireless communication will be used.

1 Automation of plant care problematic

In this chapter will be described methods used for automated plant health monitoring and automated water distribution. As example, described several solutions available on the market.

1.1 Automated water distribution

The main problematic of water delivery to plant is that the plant doesn't require constant water supply, water needs to deliver in portions. Besides, too much water can be harmful for some plants, but others prefer more dry soil. That's why it's more prefer that water delivery system has parameters, which user can change or system itself can adapt to environment.

Automation of this process can reduce human involvement, based on complexity of the system. The core function of all systems of this type is keeping soil in required moisture level. But we can make system more complex with additional functionality, such as environment parameters monitoring, monitoring amount of water, available in supply tank, more flexible parameters etc.

Further will be described approaches how to automate plant watering, with their pros and cons.

1.1.1 Nonelectrical automated solution

This solution has no electronic components, they accomplish the goal of automatic water delivery based on physics laws such as gravity, Bernoulli's principle, water surface tension, capillary effect, soil water absorption etc. [1].

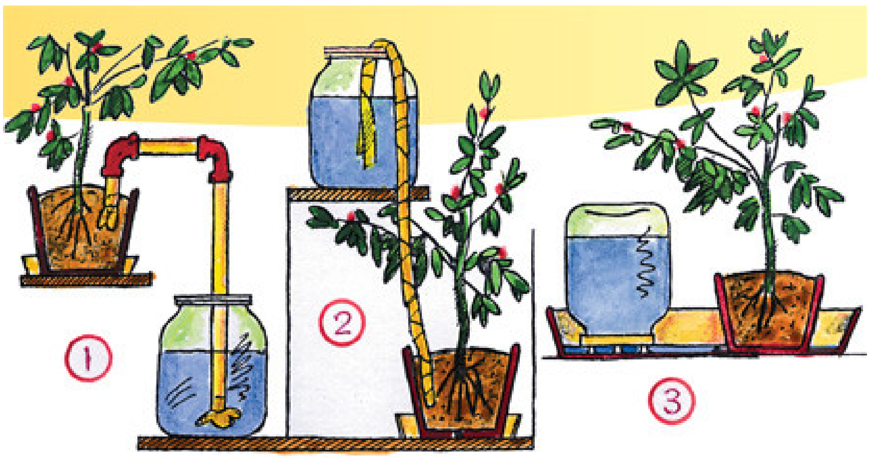

Fig. 1.1: Examples for nonelectrical automated plant watering solutions.

This is very simply solution that can be easily made from improvised materials, therefore it's very cheap. But this approach is very inefficient - majority of water is vaporized before it will be consumed by a plant. Also, systems like this keep soil moisture level on one level and as it was mention before, this environment condition is not suitable for all plants.

This approach is good only in terms of price, but if possible, it's better to make more reliable and flexible system, with controllable electronic components, further described.

1.1.2 Time-based automation

The most common approach in automation of water distribution for plants is time-based systems. These systems are controlled with programmable micro-controller, that turn on and off water pump in time intervals, set by a user.

Advantage of this system as opposed to non-electrical devices is more rational usage of water. If user will correctly set system parameters, it can achieve very good results in making appropriate life condition for a plant. Another advantage of this system is its simplicity and relatively low price, as well as possibility to change system parameters to match conditions needed for the plant.

However, main disadvantage of this system is that it has no feedback information of outside environment. So, it's very possible that system will water plants when it's not required. As a result, it may emphasize all the advantages of this system. And even if system is set correctly, the system is not flexible in adapting to changing environment.

In conclusion, systems of this type can be reasonable for a balance between functionality and price, but it can be improved to be more intelligent.

1.1.3 Automation based on feedback sensors

The most advanced method is to monitor soil moisture level with feedback sensors. In this system micro-controller are programmed with more complex firmware, that can read sensors and, based on their feedback values, control water pump, with predefined logic.

To detect soil moisture level, electrical conductivity sensor or capacitive humidity sensor. Also, it's possible to consider other parameters, for example - day time. With additional integration of additional sensors, it's possible to measure amount of water available in supply tank, detect leakage. To make usage of the system more convenient, micro-controller can has display, communicate with mobile devices or PC.

With this approach can be archived the most optimized solution of plant watering. Automation based on feedback can reduce human involvement to its minimum. But this due to its complexity, system is harder to develop and produce. Not only because it has more components, but also it takes more time and effort to develop firmware, that will use all advantages of this approach.

1.2 Soil and air parameters monitoring

In addition to keeping water level in the soil, other parameters of environments need to be considered for healthy growth of a plant. In this section will be described approaches how to measure and analyze them with electrical sensors.

1.2.1 Soil moisture

Water has much better conductivity, so soil moisture level can be represented by conductivity in the substance. Measurement of conductivity in the soil is similar to measurement in the liquid and there are several ways to measure it with electrical sensors.

First method is to measure volumetric content of water. Two probes allow current to pass between them, then measurement circuit will measure current between two probes. When there is more water in the soil resistance will decrease due to conductivity of water. Its principle is based on Ohm's law. This is low cost method, however it can be unreliable, because if readings may shift if water has more ions and in long run can electrolysis reaction can lead to corrosion of the probes, due to electrolysis reaction between metal probes and water in soil.

$$U = IR \tag{1.1}$$

Another method us to measure capacity. In this case two probes function as positive and negative plate and environment, in our case soil, as dielectric. When resistivity of the soil will decrease, this will change its permittivity and capacity of the sensor will decrease. All other values of the equation - area of overlap (A), distance between the plates (D) and electric constant will remain constant. Only relative permittivity will change that will indicate how moist soil is [2]. This method has advantage over measurement of resistivity, because probes in this case can be not exposed to the soil.

$$C = \varepsilon_0 \varepsilon_r \frac{A}{D} \tag{1.2}$$

1.2.2 Humidity

Measurement air humidity is in some way like measurement moisture level in soil. However, to measure amount of water in air often used term *relative humidity.*

Relative humidity is the ratio of the actual water vapor pressure present in the air at a temperature to the maximum water vapor pressure present in the air at the same temperature.

$$RH = \frac{\rho}{\rho^*} * 100\% \tag{1.3}$$

There are several sensors with different method of measurement of relative humidity. One of them is resistive humidity sensor. Electrodes put of a layer that can adsorb water. When water is absorbed resistivity between electrodes decreases. This is cheap sensor, but its reading is dependent on water composition [3].

Another sensor is capacitive sensor. It's based on the same principle, environment in this case is air, is not dielectric. Instead used material that changing its permittivity when humidity is changed. This is far better method then resistive sensor, which can provide table results over long usage and its output voltage is near linear [3].

1.2.3 Light intensity

Light intensity can be measured in lux unit, it's represented luminous power per area.

Lights intensity sensor can be based on photodiode or photo-resistor [4]. Sensor based on photo-diode measure electric current on the diodes' PN junction. Its work based on photoelectric effect, light causes to create pair of electron-hole, which create current flow.

Sensors with photo-resistors measure resistivity of its resistor. It's made of material that changes its resistivity when it's absorbing light.

1.3 Automated water distribution systems available on the market

On the market of plant care already exist plenty devices and systems that can help to automate plant watering. There is a variety based on price, purpose and location. Further will be described some of these systems.

We can divide this system into two groups - systems with closed proprietary system and systems that are based on open cloud with IFTTT (If This Then That) principle.

1.3.1 Proprietary solution

Following plant watering systems are made with specific could system that can be used only with products from specific vendor or these systems can work on their own.

Kickstarter project - Edyn Garden

Edyn Garden is a Kickstarter project successfully funded in 2014, designed for outdoor gardens. System is made of soil sensor and water value, wirelessly connected to cloud. It's required household water pressure to work.

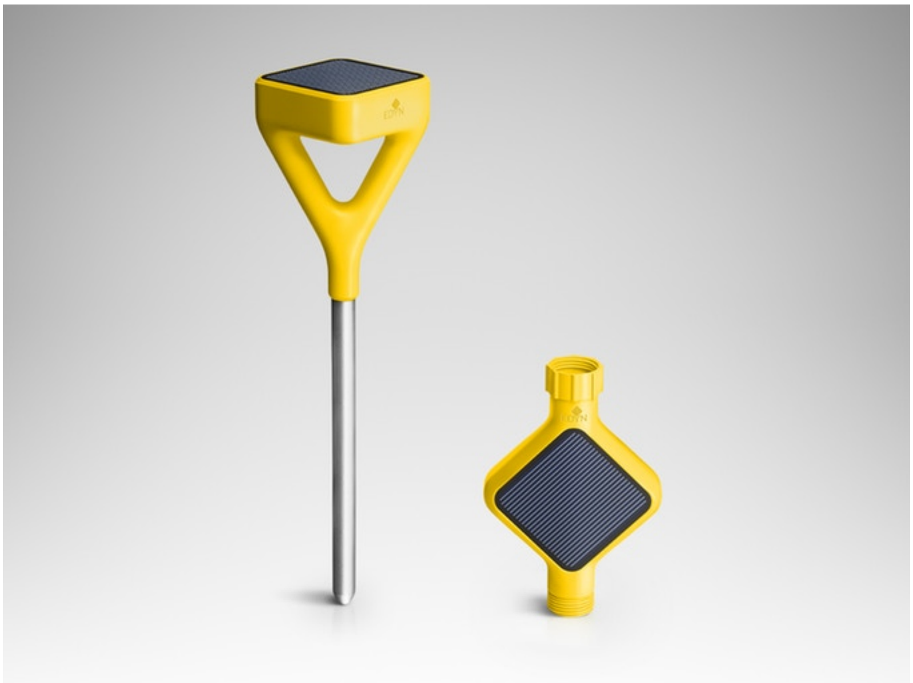

Fig. 1.2: Edyn Garden sensor and valve.

Edyn sensor can detect soil moisture levels as well as temperature, humidity, light intensity, soil nutrition and pH level. All this info can be reported to user's smart device. Sensors and values are powered with solar battery. Its sensor can measure not only soil moisture level, but also light intensity, humidity and nutrition level

In reality, users reported incorrect work of the sensor and as a result incorrect work of entire system. In 2016, Edyn went bankrupt, that's why majority of functions is unavailable nowadays.

Kickstarter project - PlantLink Lush

PlantLink Lush is also a Kickstarter project, in concept it's very similar to Edyn Garden. It's also made for outdoor garden. The system is completely modular all part can be bought separately. The part of the system are sensor, valve and base station. Complete system is prices around 140 USD.

Fig. 1.3: PlantLink Lush family devices.

PlantLink sensor can measure only soil moisture level. This system lacks some of the preferred functions, but it can offer nothing rather than measurement of the soil moisture. Today support for this system has been discontinued.

Automated system for garden - Gardena smart system

Gardena smart system is an ecosystem of devices aimed to automate a lot of aspects of outside garden care, water redistribution is one of them as well.

Fig. 1.4: Gardena smart system devices.

The system is made of sensor and water valve, which are controlled via gateway with wireless connection. Gardena sensor can measure temperature, light intensity and soil moisture level. All Gardena smarts devices are part of their ecosystem, so for user it's very convenient to control all their devices from one place. For user interface it uses mobile application. It's possible to plan when system need to water plants or set moisture level, when sprinklers will be activated.

The price of the system is the main disadvantage, price for one sensor, one valve and hub can be around 400 USD, with additional 130 USD for every new sensor. Next disadvantage is that components that are wirelessly connected are powered from battery, so it's required to constantly replace them. Also, system is incapable of any logging and parameters monitored by sensors are quite poor for requested price.

Automated pod - Parrot pot

Parrot pot is a device in from of pot, that is capable to monitor indoor plant environment and water it automatically.

Fig. 1.5: Parrot pod.

It has several sensors to measure, soil moisture level, light intensity, temperature and fertilizer level. The price for each pot is around 50 USD. This system is capable to log all measure values and inform user if one of them is not suitable for a plant.

Disadvantage of this approach is that for every plant is required to buy completely new pot, so it lacks modularity in contrast to the previous systems. As another flaw of this "all-in-one" approach is that the size of the pot can't be changed, so not all plants will fit in it and as indirect flow of the size is that there is not a lot of space where to store water.

1.3.2 IFTTT cloud systems

IFTTT systems are internet cloud systems, that can read and control IoT devices, based on behavior defined by user.

Main advantage of the systems of this type, is that it's completely modular, users can use third party companies' devices to expand system.

However, systems of this type require permanent internet connection. The lack of autonomy can make these systems unusable for some situations and places.

Today, exist several examples of these systems: Amazon Alexa, Apple HomeKit and Google Assistant. Difference between these systems isn't big. Every system can provide wide virility of supported devices and similar functionality. Main difference between them is integration to services owed by company manufacturer.

2 Design of the automated system for plant care

Based on existing examples available on the market I made my own concept of the system. In the following sections will be described requirements for the system, overall concept and selection of the component needed for this system.

2.1 Functionality and structure description

First of all, it's needed to determine requirements and functionality for the system.

Requirements for the system are following:

- Autonomy
- Modular, flexible design
- Wireless communication between modules
- Watering based on sensor values
- Additional environment values measurement
- Possibility of configuration and control with PC
- Possibility of event and measurement logging

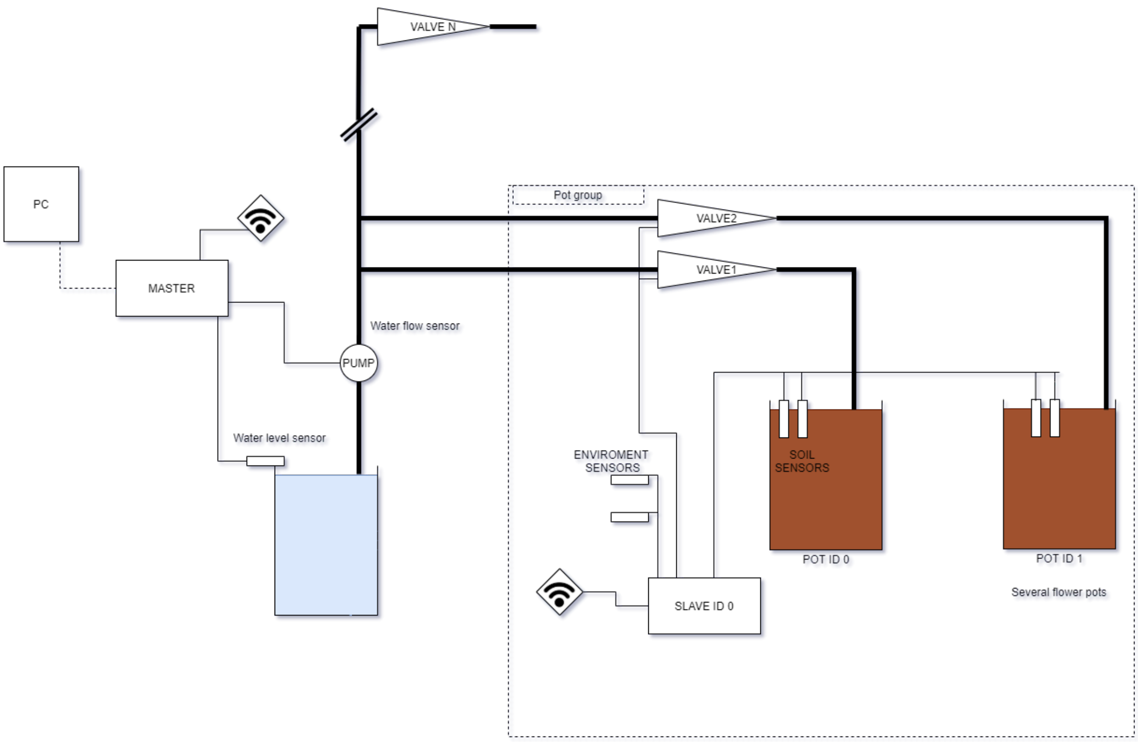

Fig. 2.1: System concept

Based on this concept the system is made of one master and one or several slaves. Master controls water pump, measure if there is enough water in supply tank and can communicate with PC via serial connection.

Also, master communicating with slaves using wireless connection, with particular requests master can receive from slave's sensor values or control valves, which are physicality connected to slave.

Each slave has environment sensors and separate sensors for each pot, also for each pot is assigned water valve to make possible to choose which pot will be watered.

2.2 Mechanical parts and sensors description

Here is listens and described electrical and electromechanical components that are necessary to build this system.

To deliver water from supply tank to pots I will use 12V DC water pump to be able to direct water flow to specific pot 12V DC solenoid water valves will be used, one for each pot.

Following environment physical properties will be measured, air temperature, air humility and light intensity.

As an air temperature and air humility I chose HTU21D sensor, that is capable to measure air temperature from –40 to 125 °C (± 0.3 °C) and relative humidity from 5% to 95% (± 2%). To measure light intensity BH1750 is used, with measurement range of 1 - 65535 lux. All these sensors are connected via I2C bus connection

For each pot assigned to slave it needed a pair of following sensors: analog capacitive soil moisture sensor and water-resistant temperature sensor. As a temperature sensor DS18B20 that is capable to measure temperature between -55°C and +125°C with ±0.5°C accuracy in range from -10°C to +85°C. This sensor is connected with 1-wire bus connection, that can be useful in case of connection of larger number of this sensors.

To detect lack of water in supply tank ultrasonic distance sensor HC-SR04 is used. Firstly, sensor will measure distance of the empty tank then this sensor will measure distance to water level, and if it will be close to empty value system will be able to detect it.

To make logging more convenient and to implement functionality based on date and time Real-time clock module DS3231 is used. This module is capable to power itself with on-board battery to avoid loss of date and time during power cut.

2.3 Wireless communication description

For wireless communication it's required to have low-power solution that can communicate in both sides.

For this task I chose 2.4 GHz nRF24L01 radio module due to its low price, two-way communication possibilities, automatic massage verification, low power consumption, easy handling and possibility to assign address for each module.

To communicate with salves master will send specific sequence of bytes. Size of massage will be maximum 6 bytes. First byte will always be operation code, subsequent bytes meaning will differ based on what information slave is required to receive for this specific task.

Response from slave will be made via acknowledge function massage, that can be changed based on what data is needed to be transmitted back to master. Size of this massage can be up to 32 bytes, like transmitted one, but size of this massage will be reduced to 4 bytes, to speed up communication and 4 bytes would be enough to send value from any sensors connected to slave.

2.4 Microcontroller selection

For this system it's required at least two microelectronics for master and slave respectively.

Clearly almost every microcontroller can handle tasks to ensure operability of the system. Hoverer for it was not clear how much memory will be necessary for the firmware. Also, this microcontroller will be required to store information about certain parameters and needed to be able to write and store log information about system work and sensor values.

For easy handling and wire availability of libraries I decided to choose between Arduino based microcontrollers.

Because of relatively big EEPROM size of 4 KB, which will be needed for logging, I chose Arduino Mega board with Atmel ATmega2560 microcontroller, with following specifications:

- Clock Speed - 16 MHz
- Flash Memory - 256 KB of which 8 KB used by bootloader
- SRAM - 8 KB
- EEPROM - 4 KB
- Number of analog pins - 16
- Number of digital pins - 54 (of which 15 is PWM)

3 Implementation of the system, firmware and software design

In this chapter will be described further features of the system related to hardware also, described hardware realization and connection of all parts of the system. Described written firmware and software. What problems I encounter during system realization, solution for them and further system improvement suggestions.

3.1 Functionality of the system

The system can work in 3 modes: no automation, cooldown mode and daytime mode.

No automation - watering only possible with direct command. Cooldown mode - systems checks if plant needs water, by checking soil moisture sensor, after determent period. Daytime - systems automatic decides when to water plant based on current time of the year and current time. On summer times system will water plants in the evening, in winter at the morning. In this case plats are watered maximum once a day, soil moisture sensor also checked. Successful and failed warring events are logged to EEPROM.

There are two lockout states. During lockout automatic watering is disabled. Every lockout is logged to EEPROM. Lockout 1 - supply water tank is nearly empty; water refill is required. Lockout 2 - after watering attempt there is no change on soil moisture levels, so system can assume that water distribution pipes has a failure. To reset lockout, it's required to push button on master board or send request with software via PC.

Every hour system logs all sensor values from slaves, logs can be dumped from master and salve with respectful PC software. In addition, PC software can read and change parameters in the system, dump logs, clear logs, read and display sensor value and issue a force watering command.

3.2 Hardware implementation

To connect all parts for master controller and slave controller I made circuit board for master and slave respectably. These boards have all that is needed for correct work of each component.

Fig. 3.1: Assembled system

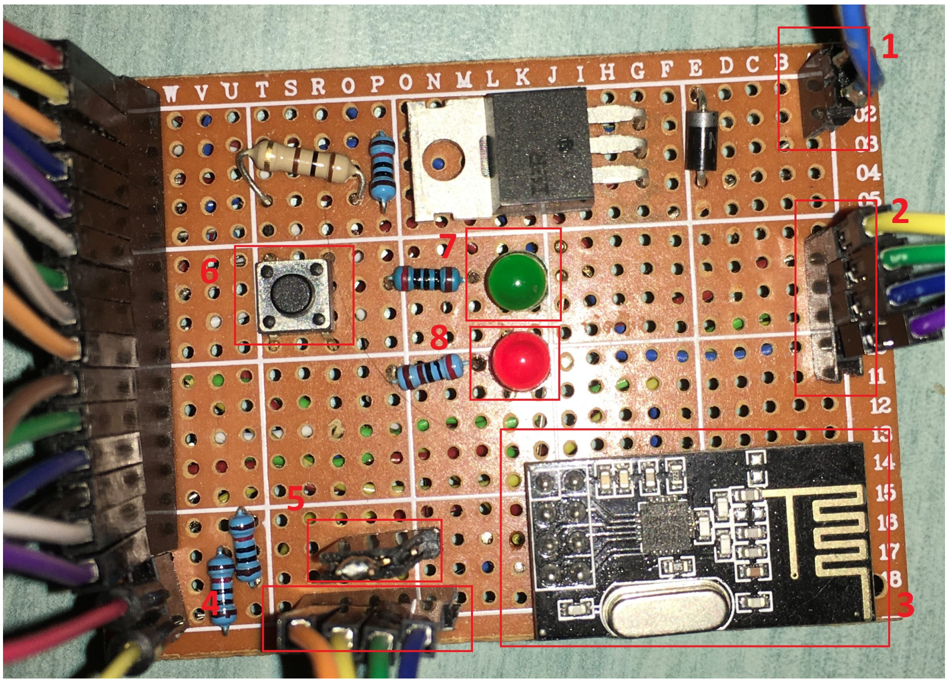

Fig. 3.2: Master board

On further list is described components placed on master board and marked on Fig. 3.2:

1. 12V DC water pump connection.
2. Ultrasonic distance sensor HC-SR04 connection.
3. 2.4 GHz nRF24L01 radio module.
4. RTC DS3231 connection.
5. X1 and X2 jumpers.
6. Button.
7. LED1 (green).
8. LED2 (red).

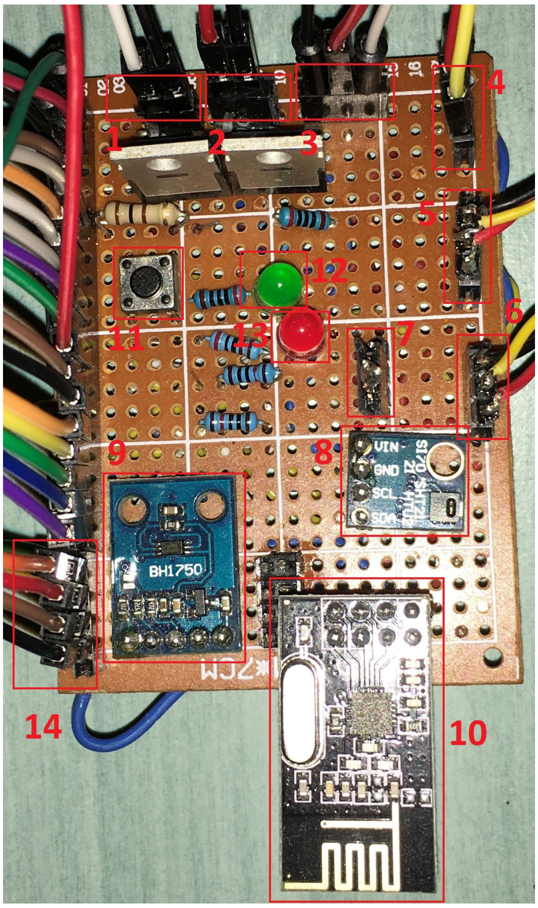

Fig. 3.3: Salve board

On further list is described components placed on slave board and marked on Fig. 3.3:

1. 12V DC valve 2 connection.
2. 12V DC valve 1 connection.
3. Analog capacitive soil moisture 1 sensor connection.

4. Analog capacitive soil moisture 2 sensor connection.
5. DS18B20 soil temperature sensor 1 connection.
6. DS18B20 soil temperature sensor 2 connection.
7. X1 and X2 jumpers.
8. HTU21D air temperature and air humility sensor.
9. BH1750 light intensity sensor.
10. 2.4 GHz nRF24L01 radio module.
11. Button.
12. LED1 (green).
13. LED2 (red).
14. RTC DS3231 connection.

For electrical schematics of master board and salve board see attachment A (Fig. A.1 and Fig. A.2).

Further in this section will be described hardware solutions and decisions. On master and slave boards there are indications - LEDs. Green led indicate that system is working, red LED can signalize different things on master board blinking red LED indicate lockout, on slave board this LED light indicate that enabled connection to PC. On both boards constantly turned on red LED signalize that EEPROM is out of empty space.

There is a control part on each board - button. Between buttons digital pins and ground there are 10 kOhm pull-down resistor to ensure a known state for a button signal. Button on master board is responsible for lockout reset, on slave board it will enable connection to PC mode.

I2C bus and 1-Wire bus data pins are connected to 5V with 7.4k - 10k Ohm pull-up resistors

Jumpers X1 and X2 on master and slave boards are needed to change supply voltage for RTC DS3231 module between 5V and 3.3V, to avoid DS3231 failure, when different battery is used (additional information at subsection 3.4.1).

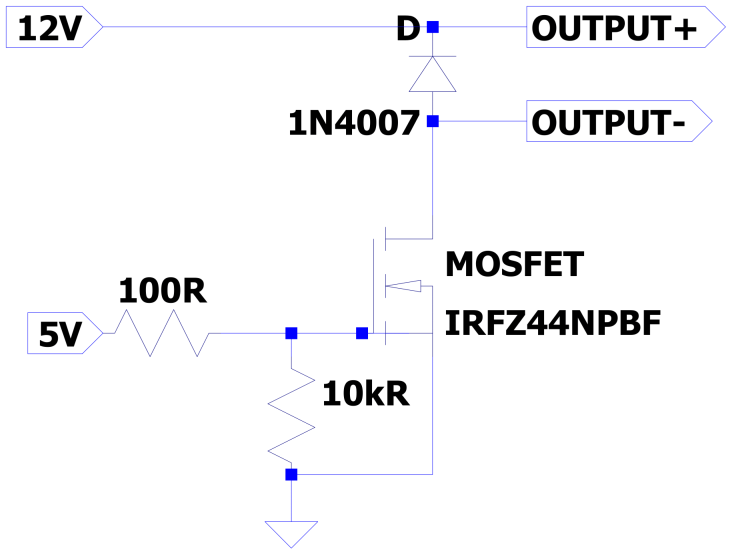

Fig. 3.4: 12V control circuit

To control components that are require 12V input voltage (pump and valves) is used circuit shown on Fig. 3.4. With controllable digital pin it is possible to turn on and off 12V voltage, which will power pump or valve. Diode between output pins is protecting MOSFET transistor from self-inductance voltage. [5]

3.3 Firmware design

To implement functionality of the system I programmed firmware separate master and slave variant both are available in attached CD, including required libraries. To upload firmware to microcontroller It's required to use Arduino IDE.

3.3.1 Firmware for master unit

After starting up firmware works infinite loop, this loop contains further steps.

1. Master updates date and time form RTC DS3231.
2. If system is in lockout, start blinking red LED same times as a current lockout number, then one green LED blink. Also skips steps 3 and 4.
3. Measures distance from ultrasonic sensor, sets lockout number 1, if distance is close to what was saved as an empty supply tank distance.
4. Checks if any plant require water, depending on selected mode.
5. If any plant was watered recently checks that soil moisture values has changed, if not sets lockout 2.
6. Update all sensor values every hour.

7. Checks if day changed to allow to water plants again during daytime watering mode.
8. Reads massage from PC, if there is one executes command.

Possible PC commands will be described in software description.

It's required 15398 bytes of flash memory space and 582 of SRAM to run this firmware.

3.3.2 Firmware for slave unit

After starting up firmware works infinite loop, this loop contains further steps.

1. Reads massage from master via nRF24L01, if there is one executes command.
2. Checks if button is pressed, if so, goes to PC communication mode.

Possible PC commands will be described in software description.

Possible request from master sent via nRF24L01:

1. Closes all valves, except one that was selected by master.
2. Opens all valves.
3. Prepares and sends back slave related sensors values (air temperature, air humidity, light intensity).
4. Prepares and sends back pot related sensors values (soil temperature, soil moisture).
5. Clear history log.
6. Set time to RTC.

It's required 16068 bytes of flash memory space and 764 of SRAM to run this firmware.

3.4 Software design

Software is used to control the system with a PC, this software can be found on attached CD. For PC software I chose Python 3.8 as a programing language, due to its great usability in serial communication tasks and built in GUI framework - Tkinter.

For serial communication with microcontrollers I used PySerial 3.4 library. Python software is made of 3 files: *ardfunc.py*, *mastercontrol.py* and *slaveconfig.py*.

Ardfunc.py is a library file with difference function used to communicate with master and salves. *Mastercontrol.py* - program used to control master, set parameters, read sensors values, log history from EEPROM etc. *Slaveconfig.py* - program made to setup slave, also it used to read log history from EEPROM. *Mastercontrol.py* and *slaveconfig.py* are packed into Windows executable file using PyInstaller, so it's possible to use this software without any additional requirements like installed Python.

3.4.1 Master control software

After establishing connection with master, program will offer following functionality.

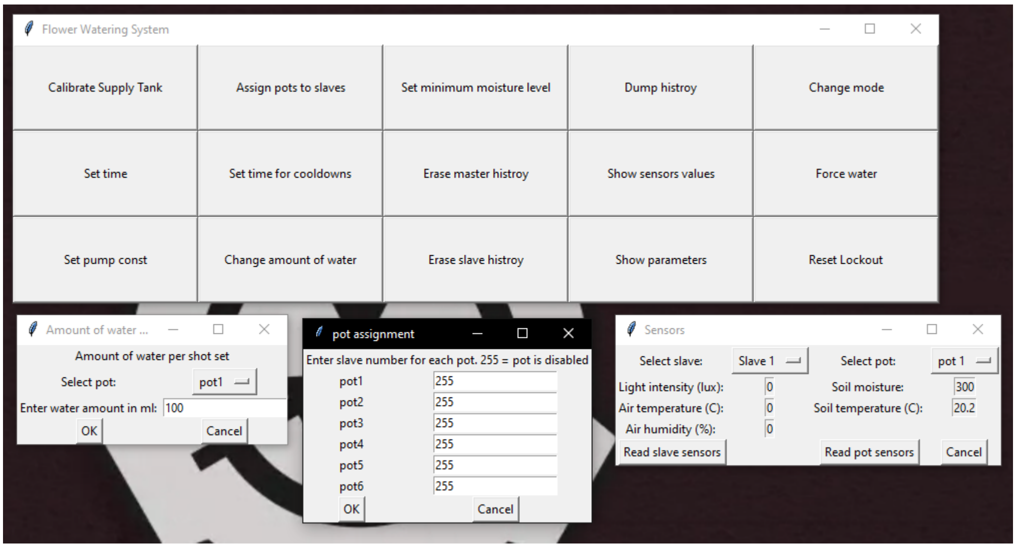

Fig. 3.5: Example of the master software windows.

With this software it is possible change following parameters for master:

- Recalibrate distance of empty water tank, by new measurement with ultrasonic sensor.
- Change pump constant.
- Change cooldown time for every pot.
- Change amount of water needed for plant for one water shot.
- Set minimum allowed soil moisture level for every pot.
- Assign pots to slaves

Also, it can read and save history log from EERPOM, erase history logs from master and slaves.

This software is capable of reading and showing all parameters and any sensor value. Other functionality, set time to RTC, reset lockout, change watering mode and force water chosen pot.

3.4.2 Slave configuration software

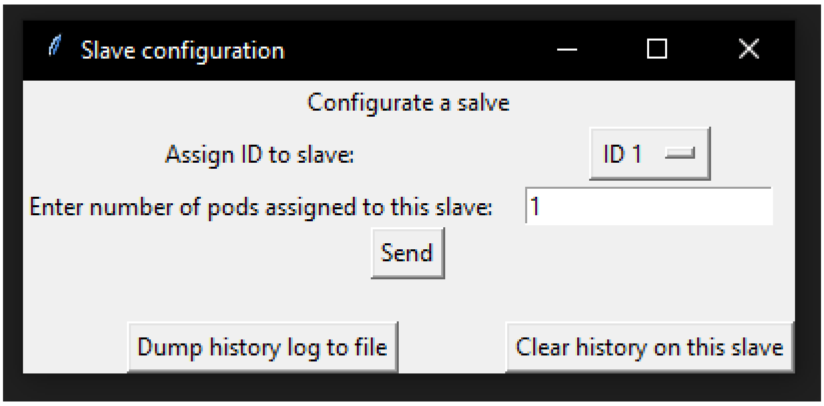

Fig. 3.6: Example of the slave software window.

Software for salve is capable for 4 things.

- Change slave ID
- Determine how many pots are assigned to this slave
- Save history log from slaves' EERPOM
- Erase history log

3.5 Problems and ways to improve the system

In this section is described problems, suggestions to resolve them and further ideas for improvement.

3.5.1 Resolved problem

RTC DS3231 is required to have LIR2032 battery, this battery is alike to CR2032, however the difference between them is that the LIR2032 is rechargeable and DS3231 circuit will try to charge it.

But CR2032 battery can't be changed and if DS3231 will try to charge it this will result in compete DS3231 circuit failure. To make it useable with CR2032, its required to power DS3231 with no more than 3.3V. That's why there are jumpers X1 and X2 on master and slave board, that can choose working voltage for DS3231.

3.5.2 Existing problem

nRF24L01 radio module seems to be a very sensitive circuit, any disruption on power voltage will result in circuit failure.

During heavy test of the system, 3 modules of nRF24L01 stops working, it is possible to use special protection shield for nRF24L01 or, I can suggest, to connect 10 uF capacitor between 3.3V and ground.

3.5.3 Ways to improve the system

It is possible to improve existing system in different ways, both in hardware and software approach.

It's will be useful to implement new sensors and hardware to expand functionality. Also, make system on one board, using different microcontroller.

Unprotected radio communication is a major security flow, it's possible to use encryption for communication between master and salves.

It is possible to improve GUI design of the software programs to make it more use friendly.

Conclusion

The goal of this work was to made an automated sprinkler system houseplants.

At the beginning I researched systems that are already exits on the market and how automation for sprinkler system can be implemented.

After defining the concept I select components for the system, which included, sensors, electromechanical components, microcontroller and wireless module.

Then I assembled the system and wrote firmware for every microcontroller with flexible functionality, that was described in this work.

In addition to firmware, I programmed software, that allows conveniently manage the system.

As in conclusion this system is capable to automatically destructible water between pant based on their soil moisture in several modes, fault protection and modular flexibility.

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List of symbols, physical constants and abbreviations

IFTTT	If This Then That
RTC	Real-time clock
GUI	Graphical user interface
IoT	Internet of Things

List of appendices

A Electrical schematics

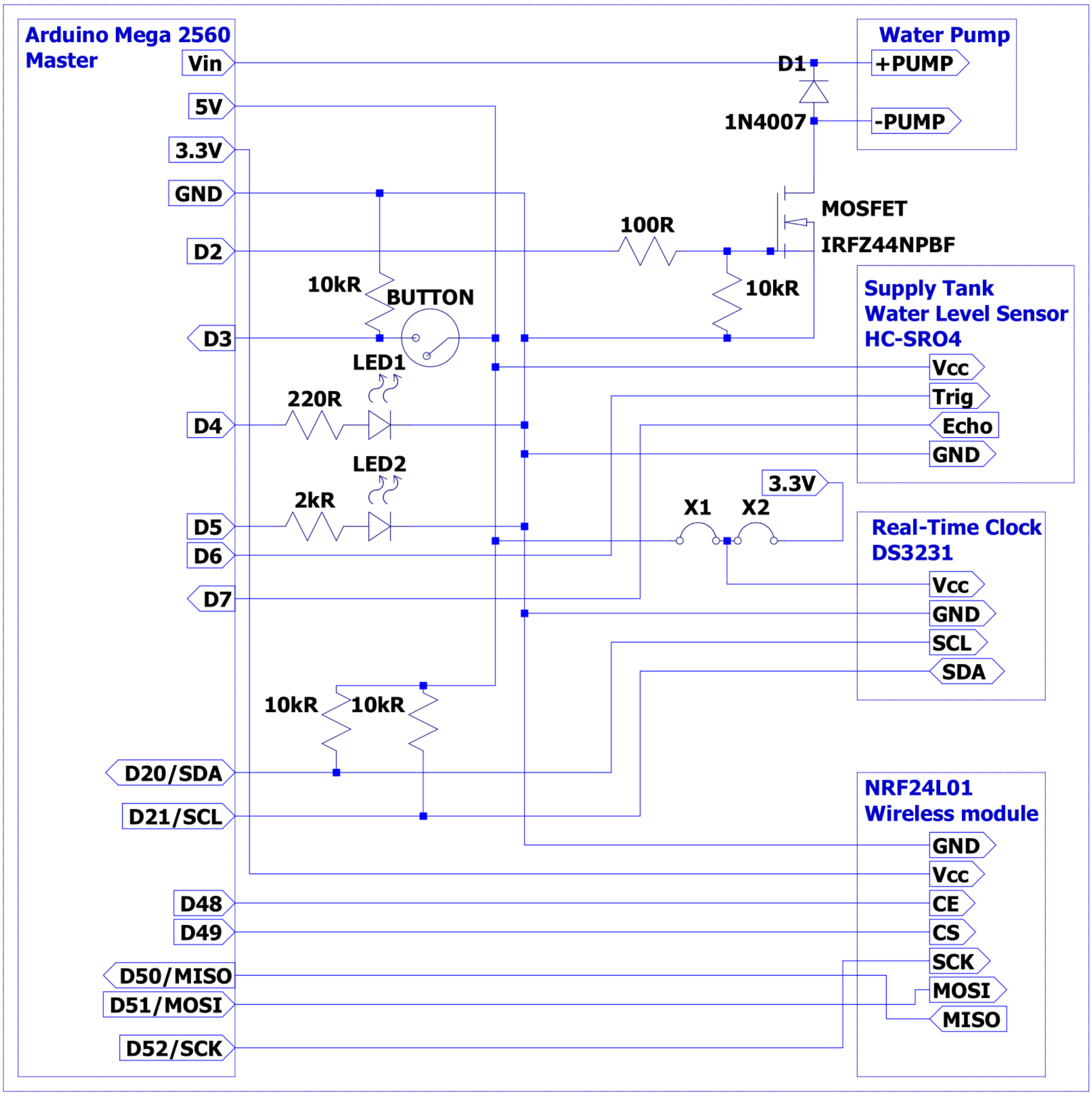

Fig. A.1: Schematic of the master

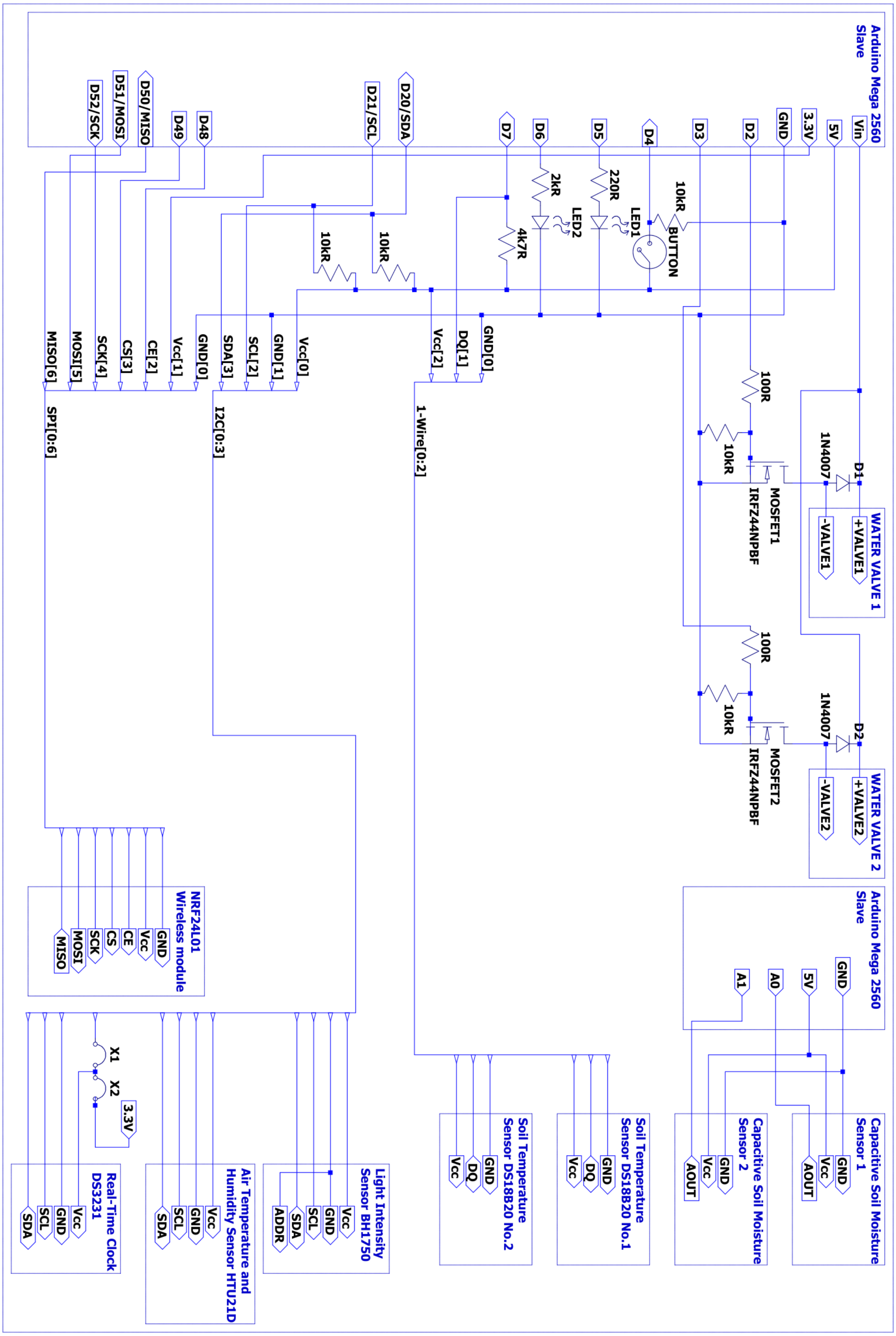

Fig. A.2: Schematic of the salve

B Contents of the attached CD

```
/ ........................................ the root directory of the included CD
├── FW ........................................................... firmware
│   ├── libraries
│   │   ├── Adafruit BMP280 Library.zip
│   │   ├── Arduino-Temperature-Control-Library-master.zip
│   │   ├── BH1750FVI.zip
│   │   ├── iarduino RTC-1.3.4.zip
│   │   ├── lib list.txt ............................ List of libraries with versions
│   │   ├── OneWire-master.zip
│   │   ├── RF24.zip
│   │   └── SparkFun HTU21D Humidity and Temperature Sensor Breakout.zip
│   ├── master fw
│   │   └── master fw.ino
│   └── slave fw
│       └── slave fw.ino
├── schematics
│   ├── master sch.pdf
│   └── slave sch.pdf
└── SW ........................................................... software
    ├── source
    │   ├── ardfunc.py
    │   ├── mastercontrol.py
    │   └── slaveconfig.py
    ├── mastercontrol.exe ............................ Program for master control
    ├── slaveconfig.exe .......................... Program for slave configuration
    └── version info.txt
```