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FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

DOCUMENT INFORMATION	
Subject	Mapping robot car
Group	13
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Creation Date	11.2.2022
Revision Date	

PROJECT INFORMATION	
Course name	Embedded systems project
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Document status	[x] Draft
	[ ] Proposal
	[ ] Inspected and approved
Revision history	1.0 Draft proposal

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1. INTRODUCTION

1.1. Course Information

Embedded systems course in University of Oulu requires a project which consists of these requirements:

Requirements:

- A robot with at least two driving wheels
    - Simple differentially steered 2-wheel robot
    - Frame can be a commercially available simple robot frame with motors & wheels (additional budget ~30 €)
- Should include at least 6-DoF IMU
- Some way for obstacle detection (sonars, IR sensors, ...)
- UI on the robot itself

Optional features:

- Navigation (plan how to get to target & avoid collisions)
- Onboard battery charger (charge from USB or AC-DC adapter)
- Mapping capabilities (at least in a 2D plane)

1.2. Project information

Given requirements to the course, our design team chose to do a 3-wheel robot car, which will be moved with a phone via Bluetooth, or it will move autonomously. These states can be switched through a button. States are represented by LEDs. MCU will control H-bridge, which drives DC-motors. These motors are connected to wheels. Third wheel will move freely. While robot is moving, it will avoid obstacles by using IR-sensors. 6-DoF IMU gyro-sensor will provide acceleration data, where the robot will parse mapping data. MCU was chosen to be a STM-32 based development kit and on top of it, we will design a shield, where all the connectors, IC-chips, active and passive components will be placed. Electronics will be powered by two 4.2 V 5 Ah LiPo batteries and we will design battery charger on shield, where user can charge the batteries with micro-USB charger. One battery will go to power MCU and second will power DC-motors through H-bridge.

1.3. Human Resources

Project team consist of 4 people: Ville Savolainen, Niko Alatalo, Niko Tolsa and Samu Lähdesmäki. Division of work is specified in Table 1.

Table 1: Division of work

Documentation and management	Ville Savolainen
Electrical design	Niko Alatalo
Software design	Samu Lahdesmäki
Mechanical designer	Niko Tolsa

1.4. Acronyms And Abbreviations

PCB	Printed Circuit Board
IR	Infra-Red
STM32	32-bit ARM processor microcontroller
Ah	Ampers per hour
V	Voltage
6-DoF IMU	6 Degrees of Freedom Inertial Measurement Unit
IC	Integrated Circuit
LiPo	Lithium Polymer
Micro-USB	Micro sized Universal Serial Bus
PC	Personal Computer
I^2S	Inter-IC Sound, electrical serial bus interface standard
USART	Universal Synchronous/Asynchronous Receiver-Transmitter
SPI	Serial Peripheral Interface
SDIO	Secure Digital Input Output
CAN	Controller Area Network
FMC	Flexible Memory Controller
PDM	Pulse Density Modulation
ADC	Analog to Digital Converter
JTAG	Joint Test Action Group
SWD	AMR's Serial Wire Debug
OTG	On the Go, USB specification which allows USB devices to act as a host
DFSDM	Digital Filter for Sigma-Delta Modulator
ST-MEMS	ST company's Micro Electromechanical System
TFT LCD	Thin-Film-Transistor Liquid-Crystal Display

2. Requirements

2.1. Functional Requirements

F-Req 1	Device must have LEDs which dictate the state of the robot
F-Req 1.1	Autonomously or user-controlled state LED
F-Req 1.2	Autonomously driving state when mapping is ongoing or ready
F-Req 1.3	Battery charging state
F-Req 2	Device must have a power and state switches
F-Req 3	MCU must take power from battery
F-Req 4	Software must not crash
F-Req 5	MCU must be paired to phone
F-Req 6	Phone must move robot
F-Req 7	Robot must detect and avoid obstacles
F-Req 8	Robot must drive autonomously
F-Req 9	Robot must draw a floor plan map
F-Req 10	Robot must save floor plan to SD-card
F-Req 11	Robot must be able to be charged through micro-USB

2.2. Electrical Requirements

HW-Req 1	Device must use 5 V and 3.3 V operating voltages
HW-Req 2	Battery voltage must be regulated to 5 V
HW-Req 3	Device must have a battery charging module
HW-Req 3.1	Battery charging module must recognise battery charge status and stop charging when batteries are full
HW-Req 4	H-bridge must provide stable power to DC-motors
HW-Req 5	Device must provide 5 V to IR-sensors
HW-Req 6	Device must provide 3.3 V to Bluetooth trans receiver
HW-Req 7	Device must provide 3.3 V to gyro

2.3. Software Requirements

SW-Req 1	MCU must receive data from modules
SW-Req 1.1	MCU must receive Bluetooth data
SW-Req 1.2	MCU must receive IR data
SW-Req 1.3	MCU must receive acceleration data from gyro
SW-Req 2	MCU must send control signals to H-bridge
SW-Req 3	Software must understand moved distance
SW-Req 4	Robot must try to circulate confronting obstacles
SW-Req 5	Robot must build a picture-file of moved distance and direction

2.4. Mechanical Requirements

Me-Req 1	Shield must have connectors to modules
Me-Req 1.1	Shield must have connectors to MCU
Me-Req 1.2	Shield must have connectors to IR-sensors
Me-Req 1.3	Shield must have connectors to H-bridge
Me-Req 1.4	Shield must have connectors to gyro
Me-Req 2	IR-sensor must have fastening to frame of the robot

Me-Req 3	Shield must have fastening to frame of the robot
Me-Req 4	Batteries must have fastening to frame of the robot
Me-Req 5	DC-motors must have fastening to frame of the robot and to wheels
Me-Req 6	Wheels must have a fastening to the DC-motors

2.5. Optional Requirements

Op-Req 1	Robot will send map to phone

3. Implementation Specification

3.1. General

Robot-car will move across the room autonomously or controlled by mobile phone, avoid collision, and map the room's floor plan.

3.2. Hardware

3.2.1. MCU

Processor of the robot is ARM Cortex M4 core based STM32F412ZGT6 microprocessor evaluation kit. MCU busses and connections consists of “four I^2C buses, four USART ports, five SPI ports with two multiplexed full-duplex I^2S buses, SDIO interface, USB OTG full-speed 2.0 port, two CAN buses, FMC parallel interface, two digital filters for sigma-delta modulators, PDM interface for two digital microphones, one 12-bit ADC, dual Quad-SPI interface, JTAG and SWD debugging support.” [1]

Hardware features of kit are “USB OTG FS, microSD card, full-duplex I^2S with an audio codec and stereo jack for headset including analog microphone, DFSDM with a pair of ST-MEMS digital microphones on board, Quad-SPI Flash memory device, 1.54" TFT LCD using FMC interface with capacitive touch panel.” [1]

Power supply for kit is 5V DC max 500 mA from USB connector, 5 V DC from the user USB FS connector CN3, 6 V to 9 V DC from VIN pin or 5 V DC from +5 V pin.

Programming and debugging of kit are possible through USB-cable connector from CN6 to PC.

3.2.2. Power setup

The MCU is powered with a 4.2 V battery which is regulated to 5 V using a regulator IC. Battery will be charged through micro-USB with charging module.

3.2.2.1. Charging Module

Battery is recharged with TP4056 constant-current linear charger. Module will sense battery voltage, derive 500 mA charging current and stop charging when battery voltage is 4.2 V. First protype will be used this module as black box.

3.2.3. Shield

PCB will be designed with KiCad-software, and its purpose is to connect evaluation board to all modules and components.

3.2.4. Bluetooth module

For Bluetooth module, project will use HC-05 module. Module uses SSP for wireless Bluetooth connection. It uses Bluetooth V2.0+EDR for connection which allows 3 Mbps data rate in 2.4 GHz frequency. Module operational voltage is 3.3 V which will be provided from evaluation kit.

3.2.5. IR-sensors

IR-sensor for this project will be bought from Spelektroniikka. They will be operated by 4-5 V and there will be 5 sensors so that robot can detect obstacles in front, sideways and in the side of the robot.

3.2.6. H-bridge

H-bridge will be used to control DC-motors. For this project will be used L298. Operating the bridge, MCU will provide enable signals to rotate each wheel in both directions. Second battery will provide power to H-bridge and through it will power go to DC-motors. Module needs 2.5-46 V supply voltage, 4.5-7 V logic supply voltage (VSS), input low voltage of -0.3-1.5 C and input high voltage 2.3-VSS. Control logic of module is represented in Figure XX.

Inputs		Function
V_{en} = H	C = H ; D = L	Forward
	C = L ; D = H	Reverse
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't care

3.2.7. DC-motors

2 x 3-6 VDC bought with frame. Power supply to them is brought from H-bridge and will be regulated 5 VDC.

3.2.8. 6 DoF IMU

This project will use GY-521 MPU-605. It will provide acceleration data to software, which will calculate moved distance by it. Module has "3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor" [2] For connecting MCU, it uses I^2S bus. Device operates power supply voltage range of 2.375-3.46 V (VDD). VLOGIC pin which provides digital signal to MCU voltage is 1.8V±5% or VDD.

3.3. Software

3.3.1. UI

Robot will start when the user pushes a state switch from off state to Bluetooth controlled state or autonomous driving state. Red LED will start blinking until the software is ready. Green led will indicate that the robot is ready to receive data from a phone or mapping is done. Mapping data will be saved to a micro-SD card and the user will plug the card into the computer and find the floor map in a txt-file.

3.3.2. OS

The OS will start when the state switch is turned on. In an autonomous state, software will drive the robot to the nearest wall in 100 mm distance from it, turn the robot so that the robot's left sensor will be on the right distance from the wall. After that, it will start following the wall so that the left IR-sensor will be on the right distance and the front IR-sensors will not collide with obstacles.

3.3.3. Mapping

IR-collision and acceleration data will be parsed to map. Acceleration data will give a moving distance. $\frac{a*t^{\wedge}2}{2}$, where a is acceleration and t is moved time. Presumably robot will start moving from stopped state. This data will be combined with IR-collision data.

3.3.4. Bluetooth pairing

HC-05 Bluetooth module will work as trans receiver. Phone can be paired to robot.

3.3.5. Moving

The MCU will give an enable signal to DC-motors, and the motors will rotate. Moving data will come from a mobile app through Bluetooth or from software (autonomous). When moving DC-motors manually through apps it will have a feature to give data for motors separately. This is how the robot can move towards and control which motor is rotating, and this is how it can turn around by giving data to only one motor. When using software both motors are rotating, and the robot is moving forward.

3.3.6. Collision avoidance

With IR-sensors, the robot senses when there is a wall or obstacle coming in so it can detect which way it needs to go.

3.3.7. Autonomously Driving

Robot will turn around to another direction where there is no wall, or an obstacle detected. After the robot has detected the whole room, it will make a map from it and then stop.

4. Testing

4.1. Hardware unit tests

HW T1	DC-motors will rotate with enable signals
	IR-sensors will send data
	Battery will provide regulated voltage
	Gyro will send data to MCU
HW T2	MCU rotates Motors
	MCU will receive IR-sensor data
HW T3	MCU moves robot
HW T4	Charging module will receive and charge power
HW T5	Charging module will charge batteries
	Charging module will have a battery status indicator

4.2. Software unit tests

SW T1	MCU will send enable signal to a DC-motor controller
SW T2	MCU will receive IR-data
	MCU will receive gyro data
SW T3	MCU will receive Bluetooth data
	Phone will be paired to the MCU
SW T4	Phone will move robot
	Robot will detect obstacles
	Robot will know it moved distance
SW T5	Autonomous driving
SW T6	Mapping

4.3. System tests

F-T1	F-Req 1.1	Autonomously or user-controlled state LED will blink
F-T2	F-Req 1.2	Autonomously driving state when mapping is ongoing or ready
F-T3	F-Req 1.3	Battery charging state
F-T4	F-Req 2	Device must have a power and state switches
F-T5	F-Req 3	MCU must take power from battery
F-T6	F-Req 4	Software must not crash
F-T7	F-Req 5	MCU must be paired to phone
F-T8	F-Req 6	Phone must move robot
F-T9	F-Req 7	Robot must detect and avoid obstacles
F-T10	F-Req 8	Robot must drive autonomously
F-T11	F-Req 9	Robot must draw a floor plan map
F-T12	F-Req 10	Robot must save floor plan to SD-card
F-T13	F-Req 11	Robot must be able to be charged through micro-USB

5. Schedule

Milestone	Info	DL
0.1	BOM	11.2.2022
0.2	Requirements	
0.3	Project report template	
0.4	List of features	
1.1	Schematic template	15.2.2022
2.1	Part order	18.2.2022
3.1	HW T1	
3.2	SW T1	
4.1	HW T2	
4.2	SW T2	
5.1	HW T3	
5.2	SW T3	
5.3	PCB	
6.1	HW T4	
6.2	SW T4	
7.1	HW T5	
7.2	SW T5	
8.1	SW T6	

6. Bill of Materials

Item	Functionality	Quantity	Location	Status	Info	Datasheet
STM32	CPU+DSP	2-3	Samu	OK		1
IR-sensors	Receive IR signal	5	To be ordered	NOK		2
6-DoF IMU	Location	1	To be ordered	NOK		3
Sonar	Avoid collision	1	To be ordered	NOK		4
PCB	Connections	1	To be designed	NOK		
Frame	Development kit	1	To be designed	NOK	DC-motors and wheels	5
Batteries	Power to system	2	Ville	OK	3.4 V Li-Po 5 Ah	
H-bridge	Motor control	1	To be ordered	NOK		6
Micro-USB	Battery charger	1	To be ordered	NOK		
Switch	Power off/on	1	To be ordered	NOK		
HC-05	Bluetooth Rx/tx	1	Niko	OK		7
LED	Status indicator	5	To be ordered	NOK		

7. Workload

8. References

[1] Discovery kit with STM32F412ZG MCU pdf, ST, opened 18.2.2022

[2]