Function description for CNC mill, V1.00
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General description

Implementation of a mechatronic CNC mill.
Raspberry PI is used to operate the mill, a graphical GUI is implemented.
Teensy4.0 is used to control the real time CNC machine.

A G-Code file can be loaded with the GUI, the file will be readed and then transferred to Teensy4.0 (max. 7500 steps). After loading the file, the CNC-program can be executed.

In manual mode of the CNC machine you can do following:
Inche the axis (X, Y, Z) forwards and backwards.
Four digital outputs (four relay outputs) for spindle, coolant, clamp and light can be forced.
The 0-10V PWM signal for the spindle speed can be forced.
The tool length can be automatically measured with a tool length sensor.
The state of the digital inputs are displayed (Reference sensors X, Y, Z, emergency stop and tool length sensor.

Four bytes, Hexadecimal, are used to transfer the actual positions of the axis from the Teensi to the Pi (0.0000 to 9999.9999 mm).

Used hardware with tasks

Raspberry Pi4

Task name	**Usage**
GUI	Graphic user interface
Mill	Data exchange GUI <-> Mill <-> Teensy

Teensy 4.0

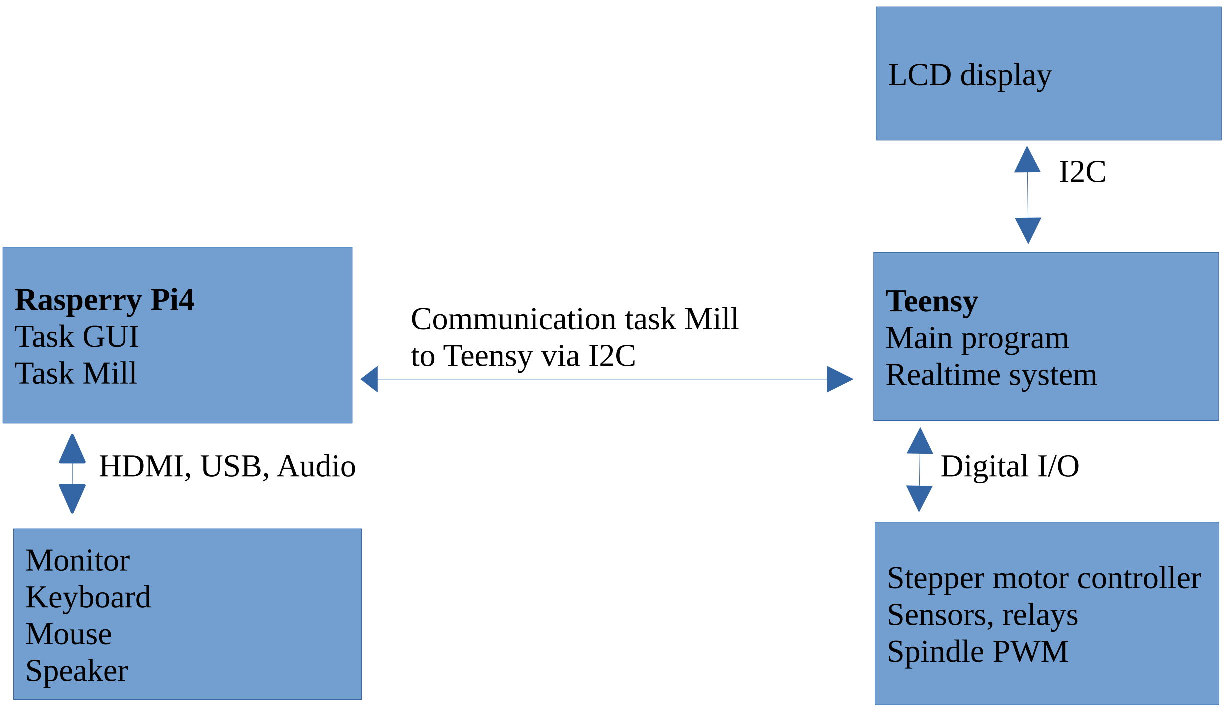
Task name	**Usage**
loop	Main program
handler	Timer interrupt. Realtime system to control the CNC machine

Used software

Raspberry Pi4
Spyder3 V3.3.3
Python V3.7

Teensy 4.0
Arduino 1.8.15
Teensy Loader 1.54

Principle structure



Softwarestructure

Raspberry Pi4, task GUI (execute event triggered)

PythonProgramGUIPortalfraese_V1_00.py
This is the main task.

Class APPGUI, initialize
Function poll100, zyclic call every 100ms
Function OnResizemainWindow, place the main frame
Function showFrame, places the visible frame with his objects
Function hideFrame, hide the specific frame
Function OpenFile, function for the OpenFileDialog, reads the filename
Function ButtonStartPressed, transfers the start command to Spider3 Mill
Function ButtonManualPressed, process of all the commands in frame manual
Function ButtonDiagnosticPressed, process of all the commands in frame diagnostic
Function SliderSpindleSpeedChange, function to transfer the manual spindle speed
Function Quit, quit program
Function Main, Starts multitask mill multiprocessing with data exchange to mill (shared memory), mainloop tkinter for GUI

Raspberry Pi4, task Mill (cyclic task)

PythonProgrammPortalfraese_V1_00.py

Function evaluate_line, reads a line from the G-Code file
Function read_file, opens the G-Code file and calls the function evaluate_line for each line
Function read_bit_motor, reads a byte and returns 8 bits
Function hexadecimalToDecimal, reads a hexadecimal-value and returns a decimal-value
Function decToHexToDec, converts a decimal value to 4 bytes decimal
Function main, multitask started from GUI, with loop forever (while True:)
    Read shared memory from GUI
    Read data from Teensy, I2C
    Case execution: Commands to Teensy, feedbacks from Teensy
    Write data to Teensy, I2C
    Write shared memory to GUI

Raspberry Pi4, programstructure Mill

Read data GUI -> Mill, Shared memory
Read data Teensy, I2C

CaseIdle	Idle
CaseTransferFilename	Transfer filename
CaseReadFile	Read file
CaseTransferFile	Transfer stepdata to teensy
CaseMotHandshakeCommandDone	Handshake command done
CaseMotOperateOn	Operate on
CaseMotOperateOff	Operate off, go back to idle
CaseMotInching	Inching
CaseMeasureToolLength	Measure tool length

Write data Teensy, I2C
Write data Mill -> GUI, Shared memory

Teensy4.0, programstructure

Function SendDataI2C, event triggered to send data to Raspberry Mill
Function ReciveDataI2C, event triggered to read data from Raspberry Mill
Function Step, toggl output step for X, Y anz Z axis
Function y=m*x+b, linear scaling function
Function SpeedMM_Min_ProgramScans, calculate speed from mm/min -> ProgramScans
Function Positioning, positioning sequence for axis X, Y and Z
Setup, initialize pin mode Teensy, starts timer interrupt, configures I2C slave for raspberry, initializes I2C master for LCD display
loop, transfers string to LCD display, toggels LED on Teensy board
handler, cyclic real time timer interrupt. executes all CNC commands

Teensy4.0 programstructure handler

Copy I2C recive data, to achive consistent data from I2C
Communication to Raspberry, fill StepData array
Read digital inputs
Handle immediate stop

```
switch (MotorAll.StepNo)
    case StepNoAction                    Load next command
        switch (ActualStepData.Code)
            case CodeG00/G01:               Initialize G00/G01
            case CodeG02/G03:               Initialize G02/G03
            case CodeInching:               Initialize inching
            case CodeMeasureToolLength: Initialize measure tool length
            case CodeG04:                   Initialize G04
            case CodeG52:                   Execute G52
            case CodeG54:                   Execute G54
            case CodeG74:                   Initialize G74
            case CodeG90:                   Execute G90
            case CodeG91:                   Execute G91
            case CodeM03:                   Execute M03
            case CodeM05:                   Execute M05
            case CodeM08:                   Execute M08
            case CodeM09:                   Execute M09
            case CodeM10:                   Execute M10
            case CodeM11:                   Execute M11
            case CodeM35:                   Execute M35
            case CodeM36:                   Execute M36
            case CodeM02/M30:               Execute M02/M30
    case StepPositioningMain:               Execute G74, calls function Positioning
    case StepLinearMovement:                Execute G00/G01
    case StepCircularMovement:              Execute G02/G03
    case StepInching:                       Execute inching
    case StepMeasureToolLength:             Execute measure tool length
    case StepDwellTime:                     Execute G04
    case StepHandshakeCommandDone:      Command done, goto StepNoAction
```

Transfer digital outputs (spindle, coolant, clamp, light) and status to Mill
Switch enable, transfer output enable
Transfer digital outputs motor X, Y and Z
Transfer digital output PWM spindle speed
Copy I2C send data, to achive consistent data to I2C

Used libarys

Spyder3
time
datetime
tkinter for GUI
multiprocessing for communication GUI <-> Mill
smbus for I2C communication Mill <-> Teensy

Arduino
https://github.com/Richard-Gemmell/teensy4_i2c
i2c_driver.h
i2c_driver_wire.h

https://www.arduinolibraries.info/libraries/liquid-crystal-i2-c
LiquidCrystal_I2C.h
Required changes in LiquidCrystal:
In file: LiquidCrystal_I2C.H --> #include <Wire.h> replaced to #include <i2c_driver_wire.h>
LiquidCrystal_I2C.CPP --> #include <Wire.h> replaced to #include <i2c_driver_wire.h>

LiquidCrystal_I2C.H

```
//YWROBOT
#ifndef LiquidCrystal_I2C_h
#define LiquidCrystal_I2C_h

#include <inttypes.h>
#include "Print.h"
//#include <Wire.h> // 2020-12.02, because of Teensy I2C
#include <i2c_driver_wire.h>
```

LiquidCrystal_I2C.CPP

```
#endif
//#include "Wire.h" // 2020-12.02, because of Teensy I2C
#include "i2c_driver_wire.h"
```

Data shared memory Pi4 tasks GUI <-> Mill

GUI <--> Mill, Shared memory, overfiew
ComGUIArrayInt = multiprocessing.Array('i', range(32))
ComGUIArrayIntStringActualStep = multiprocessing.Array('i', range(100))
ComGUIArrayIntStringActualFile = multiprocessing.Array('i', range(256))

ComGUIArrayInt
ComGUIArrayInt[0] GUI -> Mill Command. 1=read file, 2=start program. Mill -> GUI 0 = command read
ComGUIArrayInt[1] GUI -> Mill ManualCommands. Bit 0 = Manual command Spindle on
Bit 1 = Manual command Coolant on
Bit 2 = Manual command Clamp on
Bit 3 = Manual command Light on
Bit 4 = Manual command X+
Bit 5 = Manual command X-
Bit 6 = Manual command Y+
Bit 7 = Manual command Y-
Bit 8 = Manual command Z+
Bit 9 = Manual command Z-
Bit 10 = ClearDiagnosticCounterI2C
Bit 11 = Manual mode selected
Bit 12 = Measure tool length
ComGUIArrayInt[2] GUI -> Mill Spindle speed in manual mode
ComGUIArrayInt[3]
ComGUIArrayInt[4]
ComGUIArrayInt[5]
ComGUIArrayInt[6]
ComGUIArrayInt[7]
ComGUIArrayInt[8] Mill -> GUI Actual line number in file
ComGUIArrayInt[9] Mill -> GUI State. 0=Idle, 1=Program active
ComGUIArrayInt[10] Mill -> GUI Digital states. Bit 0 = Reference sensor X
Bit 1 = Reference sensor Y
Bit 2 = Reference sensor Z
Bit 3 = Emergency stop button
Bit 4 = Spindle on
Bit 5 = Coolant on
Bit 6 = Clamp on
Bit 7 = Light on
Bit 8 = Tool length sensor
Bit 9 = Measure tool length done
ComGUIArrayInt[11] Mill -> GUI Diagnostic I2C Recive good
ComGUIArrayInt[12] Mill -> GUI Diagnostic I2C Recive checksum error
ComGUIArrayInt[13] Mill -> GUI Diagnostic I2C Recive hardware error
ComGUIArrayInt[14] Mill -> GUI Diagnostic I2C Send good
ComGUIArrayInt[15] Mill -> GUI Diagnostic I2C Send hardware error
ComGUIArrayInt[16] Mill -> GUI actual position X HighHigh
ComGUIArrayInt[17] Mill -> GUI actual position X High
ComGUIArrayInt[18] Mill -> GUI actual position X Low

ComGUIArrayInt[19] Mill -> GUI actual position X LowLow
ComGUIArrayInt[20] Mill -> GUI actual position Y HighHigh
ComGUIArrayInt[21] Mill -> GUI actual position Y High
ComGUIArrayInt[22] Mill -> GUI actual position Y Low
ComGUIArrayInt[23] Mill -> GUI actual position Y LowLow
ComGUIArrayInt[24] Mill -> GUI actual position Z HighHigh
ComGUIArrayInt[25] Mill -> GUI actual position Z High
ComGUIArrayInt[26] Mill -> GUI actual position Z Low
ComGUIArrayInt[27] Mill -> GUI actual position Z LowLow
ComGUIArrayInt[28] Mill -> GUI actual position Reserve
ComGUIArrayInt[29] Mill -> GUI actual position Reserve
ComGUIArrayInt[30] Mill -> GUI actual position Reserve
ComGUIArrayInt[31] Mill -> GUI actual position Reserve

ComGUIArrayIntStringActualStep Mill -> GUI
Value 0 = Stringlen
Value 1..99 = Stringdata

ComGUIArrayIntStringActualFile GUI -> Mill
Value 0 = Stringlen
Value 1..255 = Stringdata

Data Raspberry → Teensy, I2C

I2C Master --> Slave, Struct I2C recive, max. 32 Byte possible
Raspberry → Teensy, Byte 0..27, 28 Byte
Byte 0
  Bit 0 = Operate (0 - Stepper disabled 1 - Stepper enabled)
  Bit 1 = Reserve 1
  Bit 2 = Reserve 2
  Bit 3 = Reserve 3
  Bit 4 = Reserve 4
  Bit 5 = Reserve 5
  Bit 6 = Reserve 6
  Bit 7 = Reserve 7
Byte 1
  Bit 0 = ActivateCommand
  Bit 1 = Reserve 1
  Bit 2 = Reserve 2
  Bit 3 = Reserve 3
  Bit 4 = Reserve 4
  Bit 5 = Reserve 5
  Bit 6 = Reserve 6
  Bit 7 = Reserve 7
Byte 2
  Bit 0 = Manual command Spindle on
  Bit 1 = Manual command Coolant on
  Bit 2 = Manual command Clamp on
  Bit 3 = Manual command Light on
  Bit 4 = Manual command X+
  Bit 5 = Manual command X-
  Bit 6 = Manual command Y+
  Bit 7 = Manual command Y-
Byte 3
  Bit 0 = Manual command Z+
  Bit 1 = Manual command Z-
  Bit 2 = Clear diagnostic counter I2C
  Bit 3 = Measure tool length
  Bit 4 = Reserve 4
  Bit 5 = Reserve 5
  Bit 6 = Reserve 6
  Bit 7 = Reserve 7
Byte 4, 5 Spindle speed in manual mode
Byte 6 G Code / M Code
Byte 7, 8, 9, 10 Value 0 (with four decimal places)
Byte 11, 12, 13, 14 Value 1 (with four decimal places)
Byte 15, 16, 17, 18 Value 2 (with four decimal places)
Byte 19, 20, 21, 22 Value 3 (with four decimal places)
Byte 23, 24, 25, 26 Value 4 (with four decimal places)
Byte 27 Checksum (XOR Byte 0..26)

Data Teensy → Raspberry, I2C

Slave --> I2C Master, Struct I2C send, max. 32 Byte possible
Teensy → Raspberry, Byte 0..22, 23 Byte
Byte 0
  Bit 0 = OperateOn
  Bit 1 = Reserve 1
  Bit 2 = Reserve 2
  Bit 3 = Reserve 3
  Bit 4 = Reserve 4
  Bit 5 = Reserve 5
  Bit 6 = Reserve 6
  Bit 7 = Reserve 7
Byte 1
  Bit 0 = CommandDone
  Bit 1 = ReadyForCommand
  Bit 2 = ProgramDone
  Bit 3 = Reserve 3
  Bit 4 = Reserve 4
  Bit 5 = Reserve 5
  Bit 6 = Reserve 6
  Bit 7 = Reserve 7
Byte 2
  Bit 0 = Reference sensor X
  Bit 1 = Reference sensor Y
  Bit 2 = Reference sensor Z
  Bit 3 = Emergency stop button
  Bit 4 = Spindle on
  Bit 5 = Coolant on
  Bit 6 = Clamp on
  Bit 7 = Light on
Byte 3
  Bit 0 = Tool length sensor
  Bit 1 = Measure tool length done
  Bit 2 = Reserve 2
  Bit 3 = Reserve 3
  Bit 4 = Reserve 4
  Bit 5 = Reserve 5
  Bit 6 = Reserve 6
  Bit 7 = Reserve 7
Byte 4, 5, 6, 7 Actual position motor 0 (with four decimal places)
Byte 8, 9, 10, 11 Actual position motor 1 (with four decimal places)
Byte 12, 13, 14, 15 Actual position motor 2 (with four decimal places)
Byte 16, 17, 18, 19 Actual position motor 3 (with four decimal places)
Byte 20, 21 ActualStepProgram
Byte 22 Checksum (XOR Byte 0..21)

Input / Output assignment Teensy 4.0

Pin	Used for
13	LED buildin
14	Ref. 1 Y-Axis (Input)
15	Ref. 2 Z-Axis (Input)
16	SCL1 Raspberry
17	SDA1 Raspberry
18	SDA0 Liquid Christal
19	SCL0 Liquid Christal
20	Ref. 0 X-Axis (Input)
21	Emergency stop (Input Pullup)
22	PWM Spindle Speed (Output)
23	Tool length sensor (Input Pullup)
3.3V	Output 250mA
GND 0V	Power supply 0V
Vin 5V	Power supply 5V
12	Enable 0 (Output)
11	Step 0 (Output)
10	Dir 0 (Output)
9	Enable 1 (Output)
8	Step 1 (Output)
7	Dir 1 (Output)
6	Enable 2 (Output)
5	Step 2 (Output)
4	Dir 2 (Output)
3	Spindle on (Output)
2	Coolant on (Output)
1	Clamp on (Output)
0	Light on (Output)
GND 0V	(Not connected)

Input Emergency stop and tool length sensor
These input are switches, therefore use Input_Pullup.
If the buttons are not pressed, the switches are closed (normally closed, NC), the voltage at the input pin = 0.0V, the input is logically false.
If the buttons are pressed, the switches are open, the voltage at the input pin = 3.3V, the input is logically true.

Inputs reference sensors axis X, Y and Z
NPN – inductive sensor
Input to Teensy via SFH 618A-3 VIS optocoupler
Sensor outputcable to 24V via 4.7K resistor and to input optocoupler.
Output optocoupler via 665R resistor to 3.3V and to input Teensy.

I2C busconfiguration and wiring

Raspberry I2C master to Teensy:
Used bus 3

Edit config.txt
sudo nano /boot/config.txt

Available I2C buses: 1, 3, 4, 5, 6, 7
Don't use bus 0 and 2

Bus 1 = Pin 3 (GPIO2) SDA1
Pin 5 (GPIO3) SCL1
Bus 1 with internal pull up resistors, 3.3V

Bus 3 = Pin 11 (GPIO17) SDA
Pin 13 (GPIO27) SCL
Bus 3 without internal pull up resistors, 3.3V
dtoverlay=i2c-gpio,bus=3,i2c_gpio_delay_us=2,i2c_gpio_sda=17,i2c_gpio_scl=27

Bus 4 = Pin 16 (GPIO23) SDA
Pin 18 (GPIO24) SCL
Bus 4 without internal pull up resistors, 3.3V
dtoverlay=i2c-gpio,bus=4,i2c_gpio_delay_us=2,i2c_gpio_sda=23,i2c_gpio_scl=24

config.txt
Uncomment some or all of these to enable the optional hardware interfaces
dtparam=i2c_arm=on
dtparam=i2c1=on
#dtparam=i2s=on
#dtparam=spi=on

dtoverlay=i2c-gpio,bus=3,i2c_gpio_delay_us=2,i2c_gpio_sda=17,i2c_gpio_scl=27
dtoverlay=i2c-gpio,bus=4,i2c_gpio_delay_us=2,i2c_gpio_sda=23,i2c_gpio_scl=24

Teensy, I2C slave to Raspberry:
Teensy slave address 8
Teensy Pin 16 SCL1 Raspberry SCL GPIO 27, Pin 13
Teensy Pin 17 SDA1 Raspberry SDA GPIO 17, Pin 11
Pull up resistors 2K2 Ohm

Teensy, I2C master to LCD display LiquidChristal:
Liquid Christal slave address 39
Teensy Pin 18 SDA0
Teensy Pin 19 SCL0

Teensy, settings mill

Timer interrupt in us

```
#define TimeInterrupt 15.5625
```

Hardware mechanic

```
const double StepsPerTurn = 400.0;
const double SpindlePitch = 3.0; // 3.0 mm
const double MM_Step = 0.0075; // mm per step
const double ToolLengthSensor = 32.2; // Switching point of tool length sensor in mm
```

Speeds axis X,Y,Z

```
const double SpeedG00 = 2400.0; // Speed rapid movement in mm/min, 2400.0mm/min = 40mm/s
const double SpeedG74 = 1200.0; // Speed reference run in mm/min, 1200.0mm/min = 20mm/s
const double SpeedInching = 150.0; // Speed inching in mm/min, 150.0mm/min = 2.5mm/s
const double SpeedMeasureToolLength = 300.0; // Speed measure tool length in mm/min, 300.0mm/min = 5mm/s
const double SpeedMeasureToolLengthUpToReferenceSensor = 450.0; // Speed measure tool length in mm/min, 450.0mm/min = 7.5mm/s
```

Speed calculation spreadsheet

1	Fill in green fields only							
2								
3	Input speed must be min. 2, because one cycle output on and one cycle output off							
4		Timer Interrupt in us	15,5625					
5							Spindle pitch	3
6		Steps per turn motor	400	Deg per step	0,9		mm/Step	0,0075
7								
8								
9								
10	Speed prog. scan	ms per step	ms/turn	Turns/min	Turns/s	Step frequency / Hz	mm/s	mm/min
11	2	0,031125	12,45	4819,3	80,32	32128,51	240,96	14457,83
12	3	0,0466875	18,675	3212,9	53,55	21419,01	160,64	9638,55
13	4	0,06225	24,9	2409,6	40,16	16064,26	120,48	7228,92
14	5	0,0778125	31,125	1927,7	32,13	12851,41	96,39	5783,13
15	6	0,093375	37,35	1606,4	26,77	10709,50	80,32	4819,28
16	7	0,1089375	43,575	1376,9	22,95	9179,58	68,85	4130,81
17	8	0,1245	49,8	1204,8	20,08	8032,13	60,24	3614,46
18	9	0,1400625	56,025	1071,0	17,85	7139,67	53,55	3212,85
19	10	0,155625	62,25	963,9	16,06	6425,70	48,19	2891,57
20	11	0,1711875	68,475	876,2	14,60	5841,55	43,81	2628,70
21	12	0,18675	74,7	803,2	13,39	5354,75	40,16	2409,64
22	13	0,2023125	80,925	741,4	12,36	4942,85	37,07	2224,28
23	14	0,217875	87,15	688,5	11,47	4589,79	34,42	2065,40
24	15	0,2334375	93,375	642,6	10,71	4283,80	32,13	1927,71
25	16	0,249	99,6	602,4	10,04	4016,06	30,12	1807,23
26	17	0,2645625	105,825	567,0	9,45	3779,83	28,35	1700,92
27	18	0,280125	112,05	535,5	8,92	3569,83	26,77	1606,43
28	19	0,2956875	118,275	507,3	8,45	3381,95	25,36	1521,88
29	20	0,31125	124,5	481,9	8,03	3212,85	24,10	1445,78
30	21	0,3268125	130,725	459,0	7,65	3059,86	22,95	1376,94
31	22	0,342375	136,95	438,1	7,30	2920,77	21,91	1314,35
32	23	0,3579375	143,175	419,1	6,98	2793,78	20,95	1257,20
33	24	0,3735	149,4	401,6	6,69	2677,38	20,08	1204,82
34	25	0,3890625	155,625	385,5	6,43	2570,28	19,28	1156,63
35	26	0,404625	161,85	370,7	6,18	2471,42	18,54	1112,14
36	27	0,4201875	168,075	357,0	5,95	2379,89	17,85	1070,95
37	28	0,43575	174,3	344,2	5,74	2294,89	17,21	1032,70
38	29	0,4513125	180,525	332,4	5,54	2215,76	16,62	997,09
39	30	0,466875	186,75	321,3	5,35	2141,90	16,06	963,86
40	31	0,4824375	192,975	310,9	5,18	2072,81	15,55	932,76
41	32	0,498	199,2	301,2	5,02	2008,03	15,06	903,61
42	33	0,5135625	205,425	292,1	4,87	1947,18	14,60	876,23
43	34	0,529125	211,65	283,5	4,72	1889,91	14,17	850,46
44	35	0,5446875	217,875	275,4	4,59	1835,92	13,77	826,16
45	36	0,56025	224,1	267,7	4,46	1784,92	13,39	803,21
46	37	0,5758125	230,325	260,5	4,34	1736,68	13,03	781,50
47	38	0,591375	236,55	253,6	4,23	1690,97	12,68	760,94
48	39	0,6069375	242,775	247,1	4,12	1647,62	12,36	741,43
49	40	0,6225	249	241,0	4,02	1606,43	12,05	722,89
50	41	0,6380625	255,225	235,1	3,92	1567,24	11,75	705,26
51	42	0,653625	261,45	229,5	3,82	1529,93	11,47	688,47
52	43	0,6691875	267,675	224,2	3,74	1494,35	11,21	672,46
53	44	0,68475	273,9	219,1	3,65	1460,39	10,95	657,17
54	45	0,7003125	280,125	214,2	3,57	1427,93	10,71	642,57
55	46	0,715875	286,35	209,5	3,49	1396,89	10,48	628,60
56	47	0,7314375	292,575	205,1	3,42	1367,17	10,25	615,23
57	48	0,747	298,8	200,8	3,35	1338,69	10,04	602,41
58	49	0,7625625	305,025	196,7	3,28	1311,37	9,84	590,12
59	50	0,778125	311,25	192,8	3,21	1285,14	9,64	578,31
60	51	0,7936875	317,475	189,0	3,15	1259,94	9,45	566,97
61	52	0,80925	323,7	185,4	3,09	1235,71	9,27	556,07
62	53	0,8248125	329,925	181,9	3,03	1212,40	9,09	545,58
63	54	0,840375	336,15	178,5	2,97	1189,94	8,92	535,48
64	55	0,8559375	342,375	175,2	2,92	1168,31	8,76	525,74
65	56	0,8715	348,6	172,1	2,87	1147,45	8,61	516,35
66	57	0,8870625	354,825	169,1	2,82	1127,32	8,45	507,29
67	58	0,902625	361,05	166,2	2,77	1107,88	8,31	498,55
68	59	0,9181875	367,275	163,4	2,72	1089,10	8,17	490,10
69	60	0,93375	373,5	160,6	2,68	1070,95	8,03	481,93

Explanation spreadsheet speed calculation

Speed prog. scan 2 means, that the step output is one cycle high and one cycle low.
Speed prog. scan 10 means, that the step output is one cycle high and nine cycle low.

The higher the number of steps per turn, the lower the max. achived speed.
The higher the number of steps per turn, the lower the torpue.
The smaller the number of steps per turn, the finer the gradations in mm/s.
The lower the TimeInterrupt, the higher the max. achived speed
The higher the power supply of the stepper motor controller, the higher the achived speed.

ms per step = TimerInterrupt us / 1000 * Speed prog. scan
ms per turn = ms per step * Steps per turn motor
Turns per min = (1 / ms per turn) * 60000
Turns per s = 1000 / ms per turn
Step frequency Hz = 1 / ms per step * 1000
mm/s = 1000 / ms per turn * Spindle pitch
mm/min = mm/s * 60

Speed calculation, function „SpeedMM_Min_ProgramScans“

inline unsigned long SpeedMM_Min_ProgramScans(double MM_Min)
Input: double mm/min, output programscans

```
// ##### Function calculate speed from mm/min -> ProgramScans
// e.g.
// 2400mm/min :60 = 40mm/s
// 40mm/s :3 = 13,3 Turns/s (SpindlePitch 3,0mm)
// 13,3 Turns/s = 13,3 Turns/1000ms = 1000ms/13,3 Turns = 75 ms/Turn
// 75ms/Turn / 400 = 0,1875 ms/Step (Steps per turn motor = 400)
// 0,1875 ms/Step * 1000 = 187,5 us/Step
// 187,5 us/Step : 15,5625 = 12,048 ProgramScans
```

→ 2400mm/min = 12,048 program scans (Spindle pitch 3mm, timer interrupt 15,5625us)

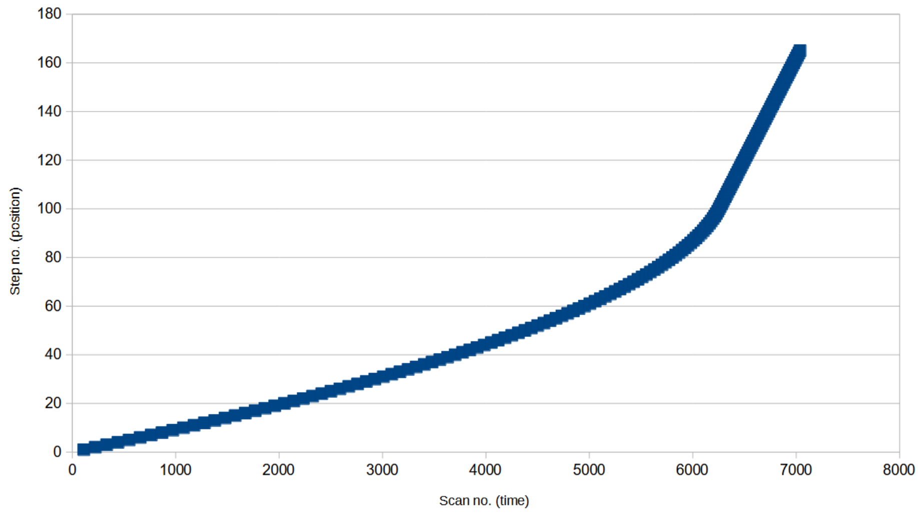
Amount of steps start - stopramp calculation, function „Y = m*x+b“

Unit speeds in mm/min

```
// Actual Speed >=200 and <= 2000, Steps Ramp = 0..100
// Actual Speed < 200, Steps Ramp = 0
// Actual Speed > 2000, Steps Ramp = 100
// Y = m*x+b
#define YMXB_MinInput 200.0
#define YMXB_MaxInput 2000.0
#define YMXB_MinResult 0.0
#define YMXB_MaxResult 100.0
```

Function start – stopramp spreadsheet

	A	B	C	D
1	Fill in green fields only			
2				
3	Timer interrupt in us	15,5625		
4	Speed mm/min	2400	#define YMXB_MinInput	200
5			#define YMXB_MaxInput	2000
6			#define YMXB_MinResult	0
7			#define YMXB_MaxResult	100
8				
9			Spindle pitch	3
10				
11	Y = m*x+b	122,2222222		
12	Steps ramp	100		
13	Speed prog. Scan	12,04819277		
14				
15	Scan no. Time	Step no. Position		
16	112,048192771084	1		
17	223,096385542168	2		
18	333,144578313252	3		
19	442,192771084336	4		
20	550,24096385542	5		
21	657,289156626504	6		
22	763,337349397588	7		
23	868,385542168672	8		
24	972,433734939756	9		
25	1075,48192771084	10		
26	1177,53012048192	11		
27	1278,57831325301	12		
28	1378,62650602409	13		
29	1477,67469879518	14		
30	1575,72289156626	15		
31	1672,77108433734	16		
32	1768,81927710843	17		
33	1863,86746987951	18		
34	1957,9156626506	19		
35	2050,96385542168	20		
36	2143,01204819276	21		
37	2234,06024096385	22		
38	2324,10843373493	23		
39	2413,15662650601	24		
40	2501,2048192771	25		
41	2588,25301204818	26		
42	2674,30120481927	27		
43	2759,34939759035	28		
44	2843,39759036143	29		
45	2926,44578313252	30		
46	3008,4939759036	31		
47	3089,54216867469	32		
48	3169,59036144577	33		
49	3248,63855421685	34		
50	3326,68674698794	35		



Explanation spreadsheet function start - stopramp

Speed from G-Code file 2400 (2400 mm/min or 60mm/min)
Calculation steps ramp: 100
Calculation speed prog. Scan 12
Timer interrupt = 15,5625 us

Movement:
First step after 112 (100+12) prog. Scans (112 * 15,5625 us = 1743 us or 1.7ms)
Second step after 223 (112 + 111) prog. Scans (223 * 15,5625 us = 3470 us or 3.4ms)
Third step after 333 (223 + 110) prog. Scans (333 * 15,5625 us = 5182 us or 5.1ms)
Fourt step after 442 (333 + 109) prog. Scans (442 * 15,5625 us = 6878 us or 6.8ms)
...
100th step after 6254 (6241 + 13) prog. Scans (6254 * 15,5625 us = 97,327ms)
101th step after 6266 (6254 + 12) prog. Scans (6266 * 15,5625 us = 97,514ms) at linear speed
102th step after 6278 (6266 + 12) prog. Scans (6278 * 15,5625 us = 97,701ms)
...

Calculation linear movement

There is a virtual time master (step no.). When a step has to be executed, for example after each 12th prog. Scan, there is a decision, which axis has to made a step.
The axis with the longest distance is making at every decision a step.
The other axis are making it’s steps when the difference between the required position and the actual position is >= mm/step (0,0075mm).

Example:
Axis Y has got the longest distance with 533,333 steps

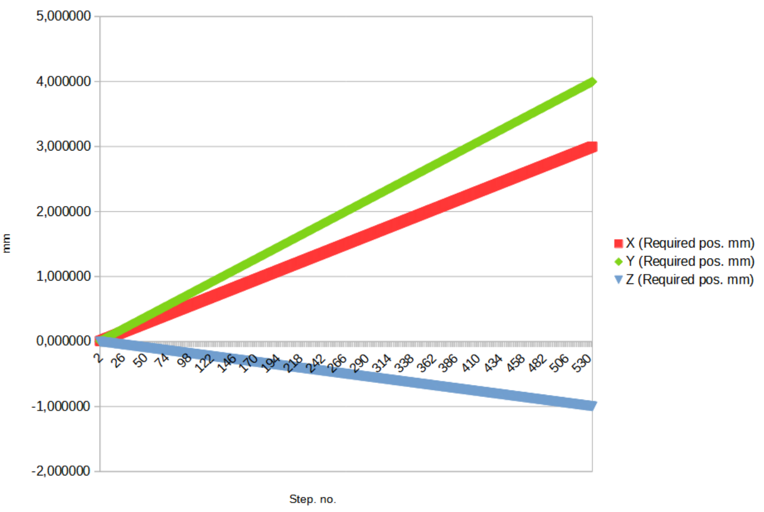
Distance X: 3,0mm
Amount steps X: 400 → 3.0/0,0075
Distance per step: 3,0 / 533,3 = 0,005625

Distance Y: 4,0mm
Amount steps Y: 533,333 → 4,0/0,0075
Distance per step: 4,0 / 533,333 = 0,0075

Distance Z: -1mm
Amount steps Z: 133,333 → 1,0/0,0075
Distance per step: 1,0 / 533,333 = -0,001875

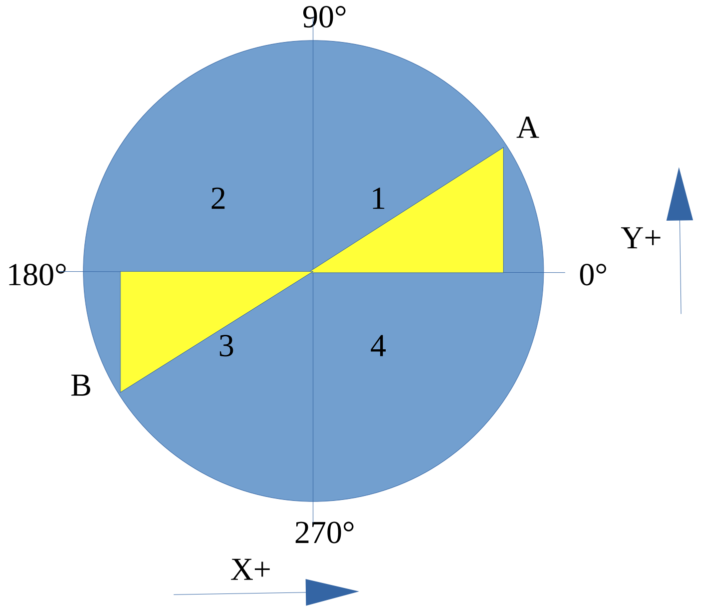
Linear movement spreadsheet

Step no.	X (Required pos. mm)	Y (Required pos. mm)	Z (Required pos. mm)
1	0,005625	0,007500	-0,001875
2	0,011250	0,015000	-0,003750
3	0,016875	0,022500	-0,005625
4	0,022500	0,030000	-0,007500
5	0,028125	0,037500	-0,009375
6	0,033750	0,045000	-0,011250
7	0,039375	0,052500	-0,013125
8	0,045000	0,060000	-0,015000
9	0,050625	0,067500	-0,016875
10	0,056250	0,075000	-0,018750
11	0,061875	0,082500	-0,020625
12	0,067500	0,090000	-0,022500
13	0,073125	0,097500	-0,024375
14	0,078750	0,105000	-0,026250
15	0,084375	0,112500	-0,028125
16	0,090000	0,120000	-0,030000
17	0,095625	0,127500	-0,031875
18	0,101250	0,135000	-0,033750
19	0,106875	0,142500	-0,035625
20	0,112500	0,150000	-0,037500
21	0,118125	0,157500	-0,039375
22	0,123750	0,165000	-0,041250
23	0,129375	0,172500	-0,043125
24	0,135000	0,180000	-0,045000
25	0,140625	0,187500	-0,046875
26	0,146250	0,195000	-0,048750
27	0,151875	0,202500	-0,050625
28	0,157500	0,210000	-0,052500
29	0,163125	0,217500	-0,054375
30	0,168750	0,225000	-0,056250
31	0,174375	0,232500	-0,058125
32	0,180000	0,240000	-0,060000
33	0,185625	0,247500	-0,061875
34	0,191250	0,255000	-0,063750
35	0,196875	0,262500	-0,065625
36	0,202500	0,270000	-0,067500
37	0,208125	0,277500	-0,069375
38	0,213750	0,285000	-0,071250
39	0,219375	0,292500	-0,073125
40	0,225000	0,300000	-0,075000



Calculation circular movement

There is a virtual time master (step no.). When a step has to be executed, for example after each 12th prog. Scan, there is a decision, which axis has to made a step.



Example:
Zero point is in the middle of the circle (X0 Y0), radius 50,0mm, G03 counterclockwise

Quadrant no. 1	Quadrant no. 2	Quadrant no. 3	Quadrant no. 4
X+ Y+	X- Y+	X- Y-	X+ Y-

Calculate coordinates for G-commands:

Startpoint A:
X = cos30° * 50,0mm = 43,301mm
Y = sin30° * 50,0mm = 25,0mm

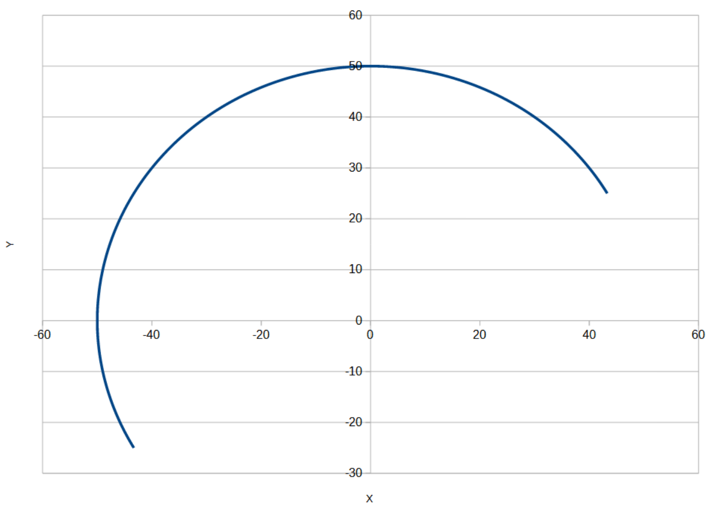
Endpoint B:
X = cos30° 50,0mm = -43,301mm
Y = sin30° *50,0mm = -25,0mm

G90
G01 X43,301 Y25,0
G03 X-43,301 Y-25,0 I-43,301 J-25,0 (I = center of the circle X, J = center of the circle Y)

Calculations in program:
Radius = $\sqrt{((| I)^2 + (| J)^2)}$ = $\sqrt{((| -43,301)^2 + (| -25)^2)}$ = 50,0
Center circle X = Startposition X + I = 43,301 + (-43,301) = 0,0
Center circle Y = Startposition Y + J = 25,0 +(-25,0) = 0,0
Quadrant startpos = 1 because I < 0,0 and J <= 0,0
Quadrant endpos = 3 because X < CenterCircleX and Y <= CenterCircleY
Startangle in quadrant 1 = asin((| J / Radius) = asin(| -25,0 / 50,0) = 30,0°
Endangle in quadrant 3 = asin (| (CenterCircleY - (Y)) / Radius) + 180,0° = asin (| (0 - (-25)) / 50,0) + 180,0°= 210,0°
Distance angle = endangle – startangle = 210,0° - 30,0° = 180,0°
Angle (distance) per step = asin(mm per step / Radius) = asin(0,0075 / 50,0) = 0,0085°
RequiredPosX = cos(ActualAngle) * Radius + CenterCircleX = e.g. cos(60,0°) * 50,0 + 0,0 = 25,0
RequiredPosY = sin(ActualAngle) * Radius + CenterCircleY = e.g. sin(60,0°) * 50,0 + 0,0 = 43,301

Circular movement spreadsheet

	A	B	C	D	E	F
1	G03					
2	Start X	Start Y	End X	End Y	I (CenterCircle X)	J (CenterCircle Y)
3	43,301	25	-43,301	-25	-43,301	-25
4						
5	**Radius**					
6	**49,9998**	r^2 = i^2 + J^2				
7						
8	**Center of the circle**					
9	0	X	Start X + CenterCircle X			
10	0	Y	Start Y + CenterCircle Y			
11						
12	**Quadrant startpos**					
13	Quadrant 1	1				
14	Quadrant 4	0				
15						
16	**Quadrant endpos**					
17	Quadrant 1	0				
18	Quadrant 2	0				
19	Quadrant 3	1				
20	Quadrant 4	0				
21						
22	Angel startpoint in Quadrant					
23	30,0001610491016	Quadrant I	SIN(J / Radius)			
24	59,9998576748706	Quadrant IV	SIN(I / Radius)			
25						
26	Angel endpoint in Quadrant					
27	30,0001610491016	Quadrant I + III	SIN((CenterCircleY – EndY) / Radius)			
28	59,9998576748706	Quadrant II + IV	SIN((CenterCircleX – EndX) / Radius)			
29						
30	Startangle		Quadrant I → +0 deg			
31	30		Quadrant II → +90 deg			
32			Quadrant III → +180 deg			
33	Endangle		Quadrant IV → +270 deg			
34	210					
35						
36	Angel (deg)	Radian	X (mm)	Y (mm)		
37	30	0,52359866667	43,3010702707414	24,9998782878701		
38	30,0085	0,52374701962	43,2973609884245	25,0063018544938		
39	30,017	0,52389537258	43,2936507531933	25,0127248707638		
40	30,0255	0,52404372553	43,2899395651295	25,0191473365387		
41	30,034	0,52419207849	43,2862274243148	25,0255692516773		
42	30,0425	0,52434043144	43,2825143308309	25,0319906160381		
43	30,051	0,5244887844	43,2788002847594	25,0384114294799		
44	30,0595	0,52463713736	43,2750852861822	25,0448316918613		
45	30,068	0,52478549031	43,2713693351809	25,0512514030411		
46	30,0765	0,52493384327	43,2676524318374	25,0576705628778		
47	30,085	0,52508219622	43,2639345762335	25,0640891712304		
48	30,0935	0,52523054918	43,260215768451	25,0705072279574		
49	30,102	0,52537890213	43,2564960085717	25,0769247329178		
50	30,1105	0,52552725509	43,2527752966775	25,0833416859701		
51	30,119	0,52567560804	43,2490536328503	25,0897580869732		
52	30,1275	0,525823961	43,2453310171721	25,0961739357858		
53	30,136	0,52597231396	43,2416074497246	25,1025892322669		
54	30,1445	0,52612066691	43,23788293059	25,109003976275		
55	30,153	0,52626901987	43,2341574598501	25,1154181676692		
56	30,1615	0,52641737282	43,2304310375869	25,1218318063082		
57	30,17	0,52656572578	43,2267036638826	25,1282448920509		
58	30,1785	0,52671407873	43,222975338819	25,1346574247561		
59	30,187	0,52686243169	43,2192460624782	25,1410694042827		
60	30,1955	0,52701078464	43,2155158349424	25,1474808304896		
61	30,204	0,5271591376	43,2117846562936	25,1538917032356		
62	30,2125	0,52730749056	43,208052526614	25,1603020223797		
63	30,221	0,52745584351	43,2043194459856	25,1667117877808		
64	30,2295	0,52760419647	43,2005854144907	25,1731209992979		
65	30,238	0,52775254942	43,1968504322114	25,1795296567898		
66	30,2465	0,52790090238	43,19311449923	25,1859377601155		
67	30,255	0,52804925533	43,1893776156285	25,192345309134		
68	30,2635	0,52819760829	43,1856397814894	25,1987523037042		
69	30,272	0,52834596124	43,1819009968948	25,2051587436853		
70	30,2805	0,5284943142	43,1781612619271	25,2115646289361		
71	30,289	0,52864266716	43,1744205766685	25,2179699593156		



Abort movement

Abort inching

In manual mode, inching of the axis can be aborted due to pressing the inching off button or toggle the active axis by pressing the button of the active axis again. Inching will also be stopped, when the hardware emergency stop button is pressed.

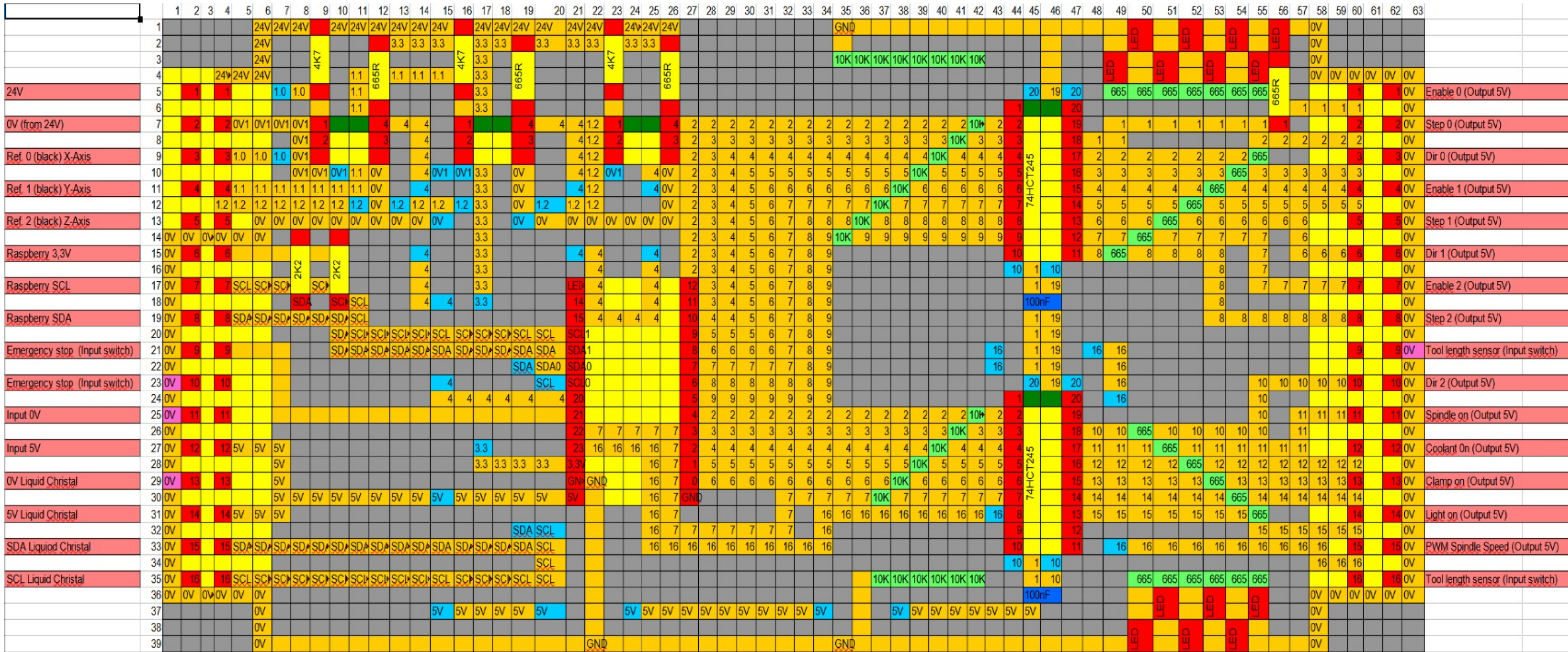
Abort measure tool length

In manual mode, measure toolo length can be aborted due to pressing the measure tool lengt off button via the GUI or pressing the hardware emergency stop button.

Abort automatic mode

If the automatic mode is active, the start button changes to abort button. By pressing the abort button, the automatic mode will be aborted.
After aborting the automatic mode, the abort button changes back to start. After aborting, the automatic mode can be continued by pressing the start button.
If a movement is active during pressing the abort button, the movement goes to stopramp and then the movement will be stopped. When the movement is stopped, the spindle will be switched off.
If a movement is already in stopramp when the abort button is pressed, the stopramp will be executed and then the movement will be stopped. When the movement is stopped, the spindle will be switched off.
After aborting, the movement always continues with the startramp.

Layout circuit board Teensy 4.0



SFH 618A-3 VIS Optocoupler

Pin 1 Sensor Ref and 4K7 to +24V
Pin 2 0V (from 24V)
Pin 3 0V (from 5V)
Pin 4 665R to 3.3V and Input Teensy

Teensy

13 LED buildin (not connected)	12 Enable 0 (Output)
14 Ref. 1 Y-Axis (Input)	11 Step 0 (Output)
15 Ref. 2 Z-Axis Input)	10 Dir 0 (Output)
16 SCL1 Raspberry	9 Enable 1 (Output)
17 SDA1 Raspberry	8 Step 1 (Output)
18 SDA0 Liquid Christal	7 Dir 1 (Output)
19 SCL0 Liquid Christal	6 Enable 2 (Output)
20 Ref. 0 X-Axis (Input)	5 Step 2 (Output)
21 Emergency stop (Input Pullup)	4 Dir 2 (Output)
22 PWM Spindle Speed (Output)	3 Spindle on (Output)
23 Tool length sensor (Input Pullup)	2 Coolant 0n (Output)
3.3V Output 250mA	1 Clamp on (Output)
0V Power supply	0 Light on (Output)
5V Power supply	0V (Not connected)

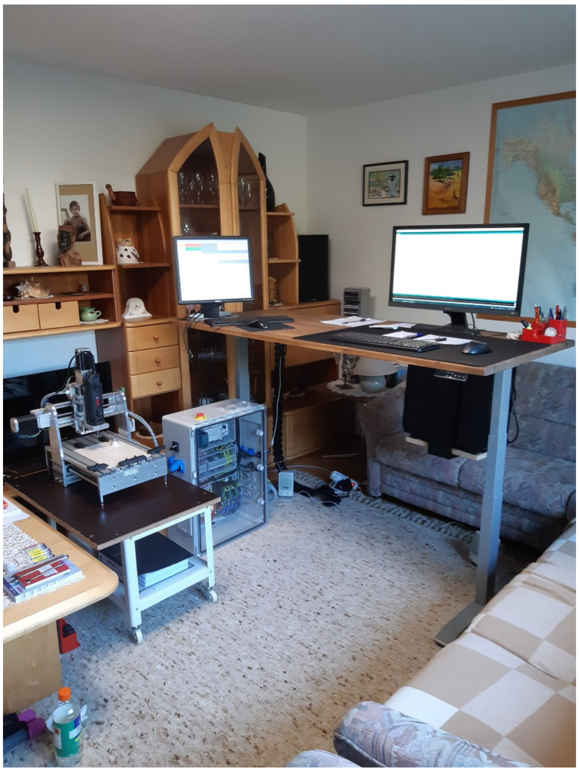
74HCT245 top

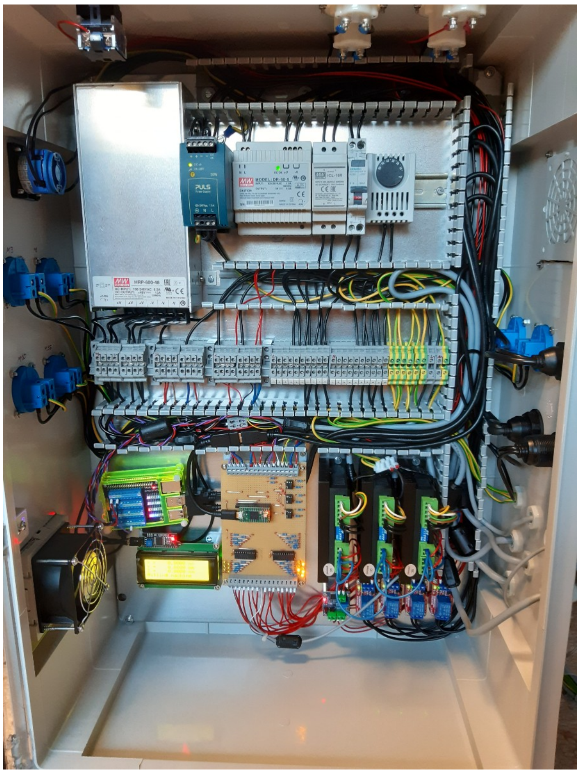
Pin 1+20 to +5V
Pin 10+19 to 0V
2 → 18 Enable 0
3 → 17 Step 0
4 → 16 Dir 0
5 → 15 Enable 1
6 → 14 Step 1
7 → 13 Dir 1
8 → 12 Enable 2
9 → 11 Step 2

74HCT245 bottom

Pin 1+20 to +5V
Pin 10+19 to 0V
2 → 18 Dir 2
3 → 17 Spindle on
4 → 16 Coolant 0n
5 → 15 Clamp on
6 → 14 Light on
7 → 13 PWM Spindle Speed
8 → 12 Spare
9 → 11 Spare

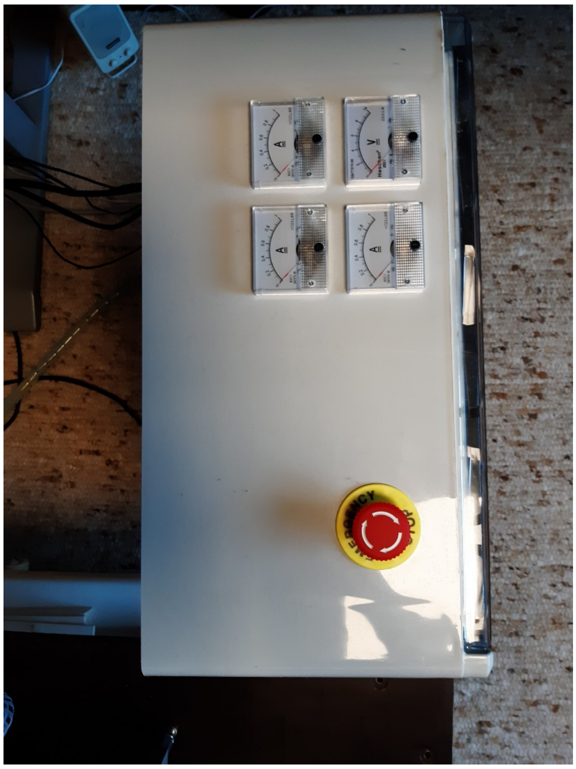
Pictures

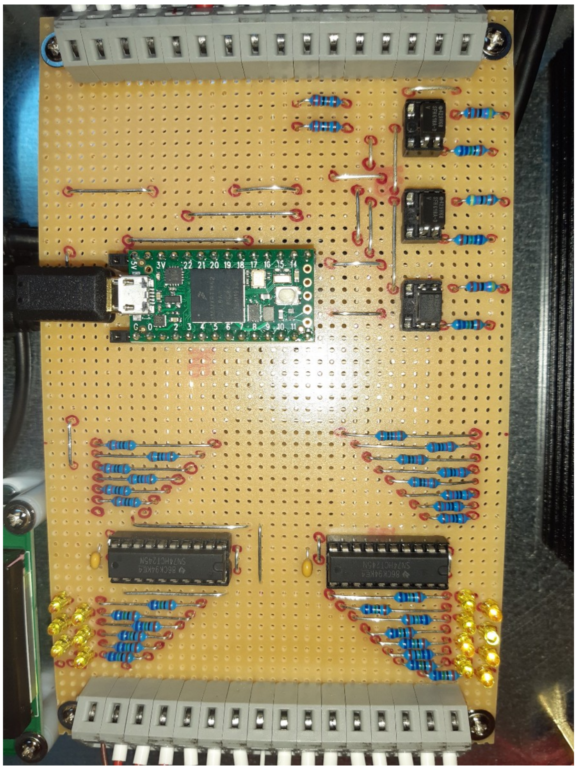




Top: Power supplies 48V, 24V, 5V
Bottom: Pi4, LCD, circuit board, motor controls
PWM 0-10V, four output relays

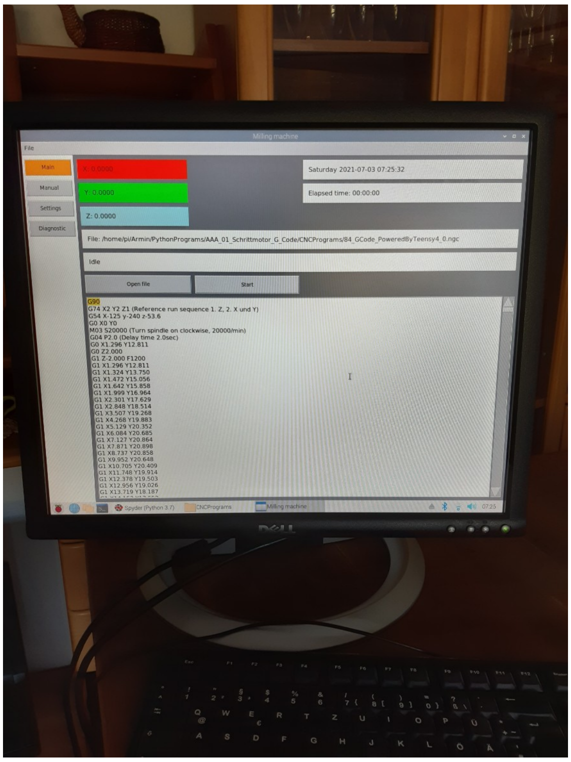
USB programming port Teensy
Connections for PI4 (USB memory, audio, keyboard, HDMI, mouse)

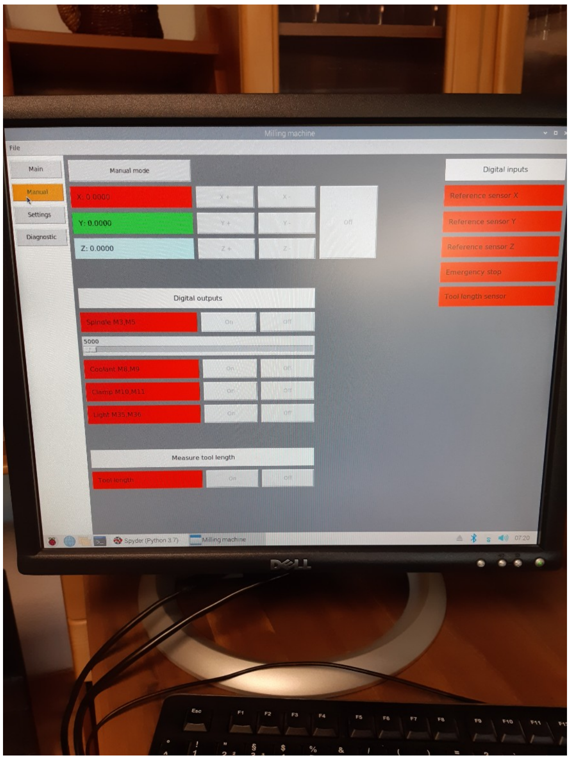


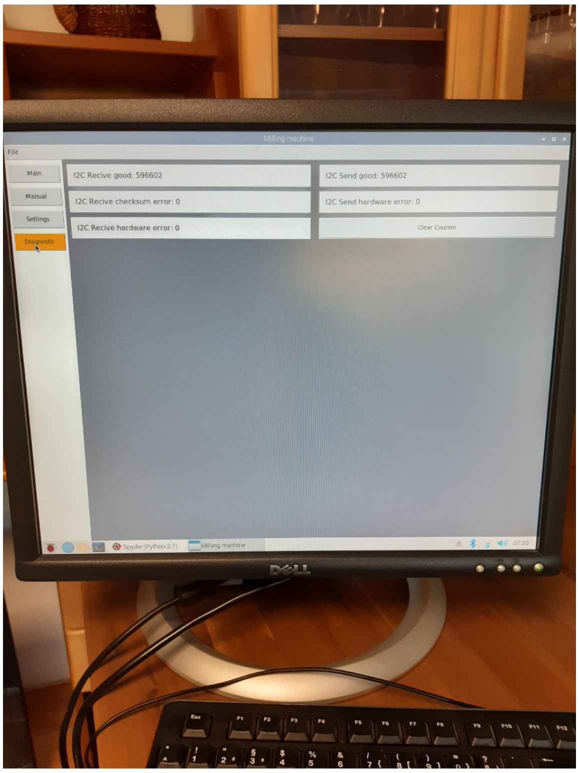


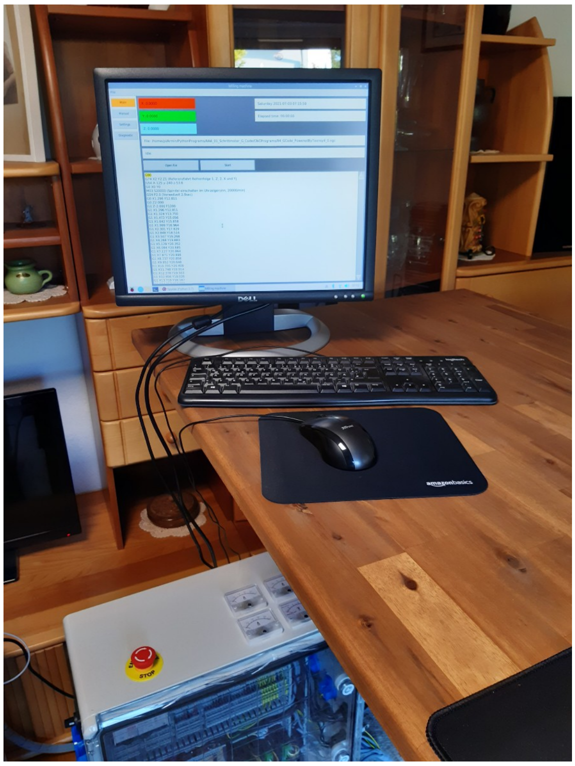
Circuit board with Teensy 4.0

LCD display and Raspberry Pi4, both connectet to Teensy via I2C









GUI on Raspberry Pi4