Rotating Leds System

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1 Introduction

For the course ”Design of embedded systems” the students learn to program software on a real-time operating system Xenomai[1]. The students first have to do several exercises[2] where they stepwise learn to program a real-time program. In the last exercise everything learned must be proven in practice using a real world example.

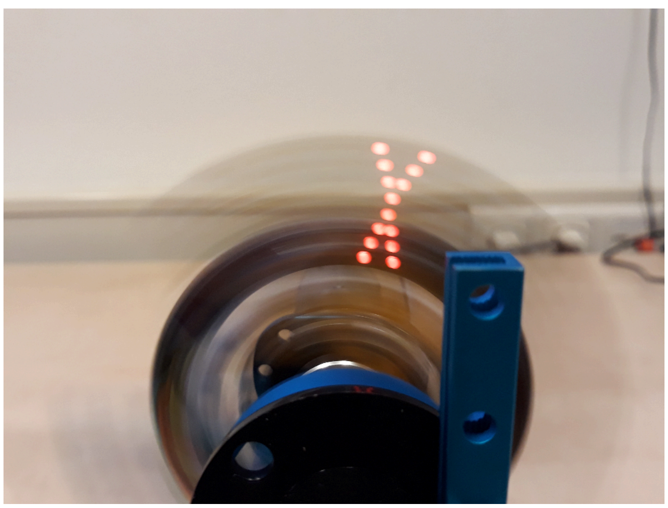


Figure 1: Rotating Leds System writing X

The real world example had the following requirements:

- a physical system which can be used as demo
- the system must be controlled by a Raspberry Pi running the realtime Xenomai OS
- the system must be controlled by the GPIO pins of the Raspberry Pi

- the control must have real-time timing aspects controlling some actuators using information from interrupts of sensors
- the system must give students experience with real-time programming in combination with hardware.
- the system must learn the students to read the hardware specs and use this to correctly control the hardware.

For this real world example we created the ”Rotating Leds System”, shown in figures 2 and 3 , which full fills all these requirements. This document describes all the details of the hardware of the ”Rotating Leds System”.

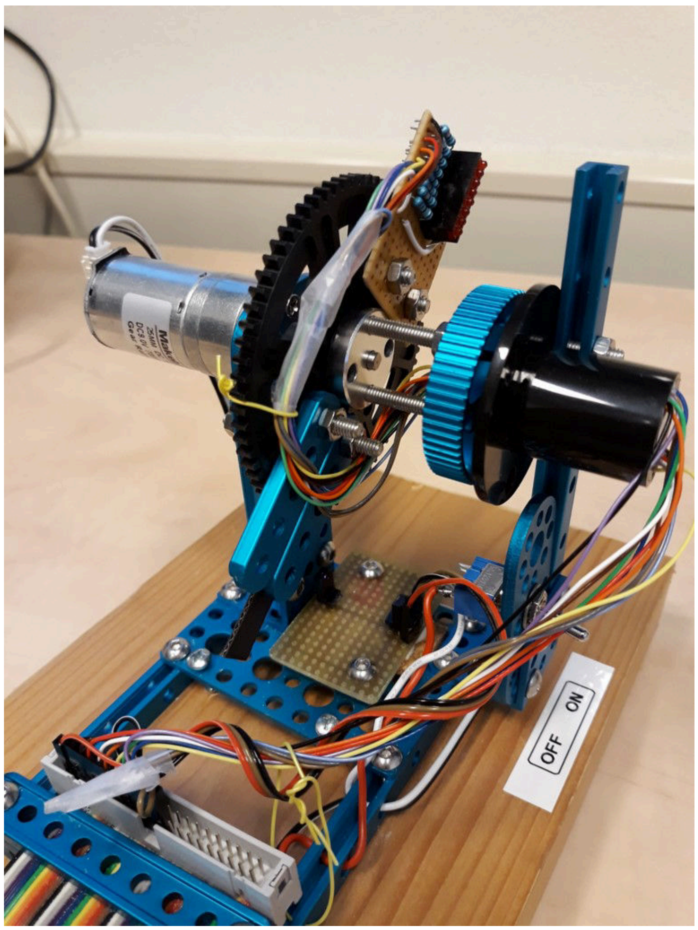


Figure 2: Rotating Leds System

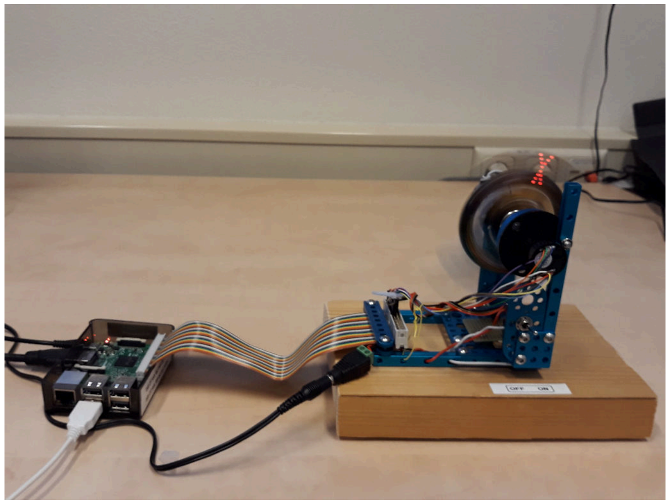


Figure 3: Raspberry Pi controlling the Rotating Leds System

2 Controlling the Rotating Leds System

The rotating leds system has a motor driving a wheel on which an array of leds is mounted. The wheel is turning that fast such that when turning the leds on and off at the right times you could write letters in the air. In figure 2 you can see the rotating leds system at rest with the 8 leds array almost at the top of the wheel. In figures 1 and 3 you see the wheel rotating and the leds controlled in such a way that the letter X is written. The challenge for the students is to write the real-time control program for the rotating leds system on the Rasperry Pi using the Xenomai API to achieve writing this letter X.

```
D0 = GPIO 2
D1 = GPIO 3
D2 = GPIO 4
D3 = GPIO 17
D4 = GPIO 27
D5 = GPIO 22
D6 = GPIO 10
D7 = GPIO 9
```

Figure 4: Leds D0-D7 connected to the Raspberry Pi's GPIO pins

The control system of the rotating leds system contains the following hardware:

- The LEDs are connected to eight GPIO ports on the Raspberry Pi as shown in the figure 2. Note that a high signal (1) means that the LED will be on; with a low signal (0) it will be off.

- There is an optical switch on the bottom; when the arm passes the optical switch it interrupts the LED light. This interruption causes the light sensor within the optical switch to go from a high signal (lots of light) to a low signal (no light) which is used as output of the optical switch. This output is connected to GPIO pin 23 of the Raspberry Pi. Because the light sensor is interrupted only for a small time, the sensor signal will be like:

```
-------------------.    .-------------------- HIGH(1) = 3.3 Volt
                   |____|
                          LOW(0) = 0 Volt
```

  This can be used to measure the time needed to pass the sensor since the Raspberry Pi can be programmed to give an interrupt when going from high to low and from low to high.

The passing time and the time of interrupt should be enough to calculate when to enable/disable leds in such a manner that we can write letters in the air with the rotating leds system.

3 System construction

3.1 Construction kit

The first well know construction kit is Meccano[4] using steel constructions parts using sizes based on inches, because it was a British invention. However during the years plastic construction kits, such as LEGO, became more popular because it was cheaper and easier to build with.

In recent years because of extrusion process of aluminium, it has become cheaper to make parts in aluminimum. Therefore modern metallic kits use aluminium instead of steel. Examples are Makerbeam, Makerblock and Gridbeam. However plastic is still much cheaper, so for toys plastic kits are most common. For building something with a real steady construction construction kits like Meccano are becoming less popular and replaced by these modern aluminium kits.

Personally I prefer Makeblock[3] because it uses:

- extruded aluminium instead of plastic/steel which is both light and strong
- both a repetitive hole pattern and a the t-slot style system for easy construction
- all kinds of electronic parts as actuators (eg. motors) and sensors

- the metric system

For the Rotating Leds System we used the Makeblock Construction kit to construct the system. To give you an idea of what kind of parts Makeblock comes with see figure 5 showing the parts of the Makeblock XY-Plotter Robot Kit.

Figure 5: Parts in the Makeblock XY-Plotter Robot Kit

3.2 Explaining the construction

The Rotating Leds System is mainly constructed of the following parts:

1. A rotating axis(fig 6 and 2)) driven by a 700rpm Makeblock motor(fig 7) on which a plastic gear wheel(fig 10)) is mounted on which the 8 leds array circuit is mounted(fig 12). The plastic gear wheel is mounted to the axis using a shaft hub(fig 11).
2. The wires from the rotating led circuit are connected to a slipring(fig 7) to allow a rotating connection to the rest of the system.
3. The slipring has a plastic axis which is difficult to mount to the steel axis of the motor. Also because the slipring is a plastic part its axis is not rotating as straight as a steel axis does. Therefore after some experimentation we come up with a loose connection between the motor axis and the slipring. On the slipring axis we slip the 4mm hole of a 62 tooth timing pully wheel(fig 9) . We use some tape in the connection to make the connection not to slip.The pully wheel is connected with two screw-able axis to the plastic wheel connected on the motor axis. This loose connection allows

the slipring to wiggle a bit which makes the rotation to happen with less friction. The slipring is connected with a single screw to a upright standing beam.

4. The motor is connected via an on/off switch to a separate power supply using a standard power connector shown in figure 26.

5. To the plastic wheel a strip is attached which when the wheel is rotating will block the infrared light in the optical switch circuit mounted at the bottom of the system. In figures 2 and 13. In figure 14 you can see how we mounted the optical switch circuit.

6. We didn't made a detailed construction drawing, however using the videos on the webpage `http://www.cs.ru.nl/lab/xenomai/` you can have pretty good look on the construction.

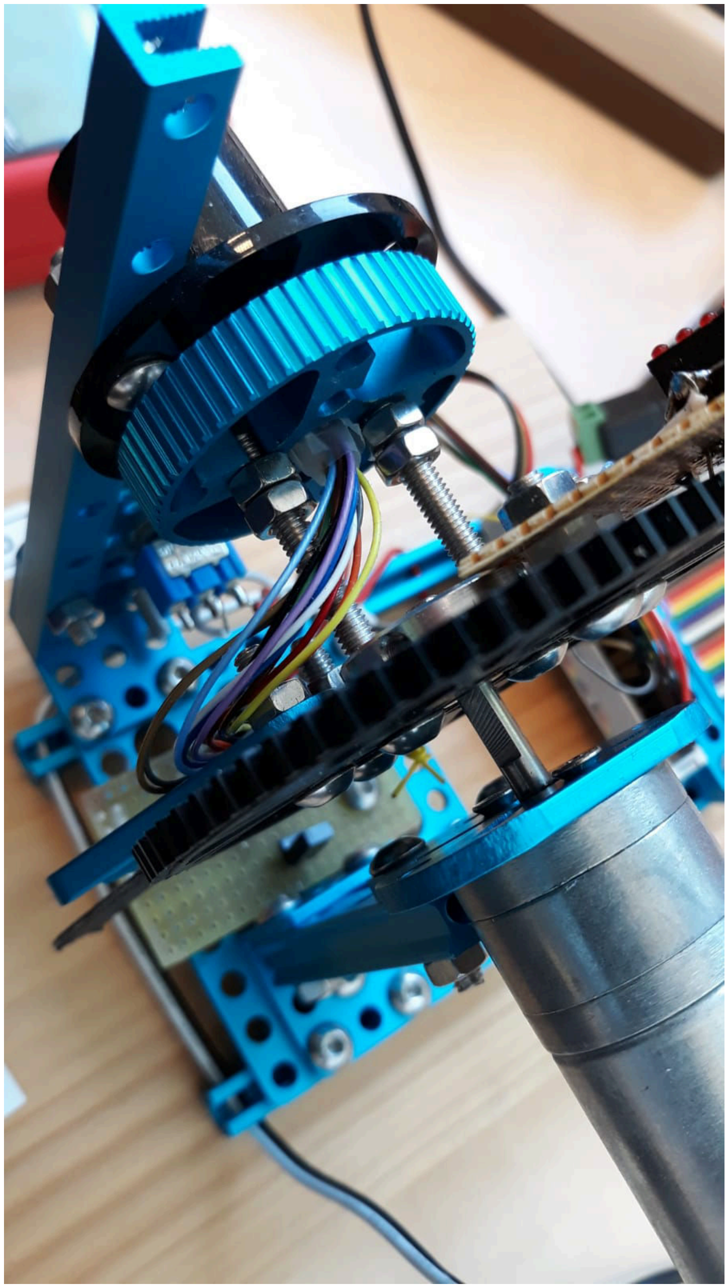


Figure 6: Top view of axis of Rotating Leds System

Figure 7: Makeblock 700rpm motor

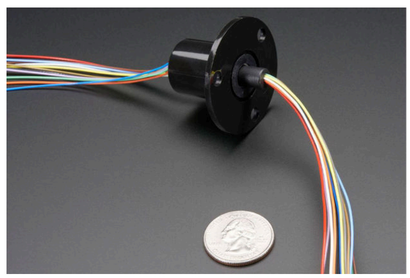


Figure 8: Slipring

Figure 9: Timing Pulley 62 tooth

Figure 10: Plastic gear 72 tooth

Figure 11: Shaft Hub

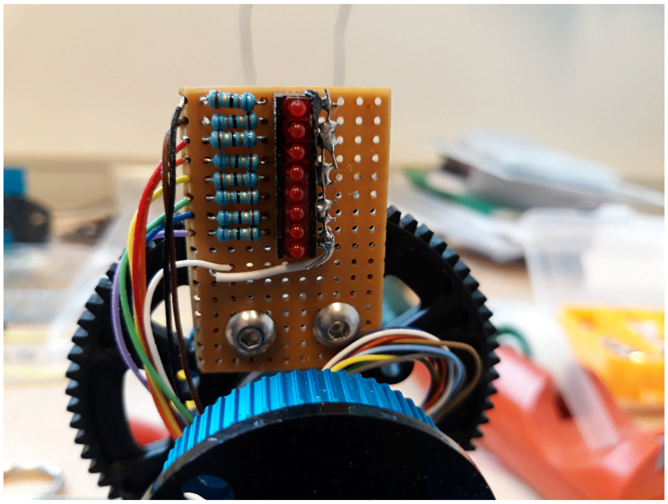


Figure 12: Leds Circuit board mounted on plastic gear wheel

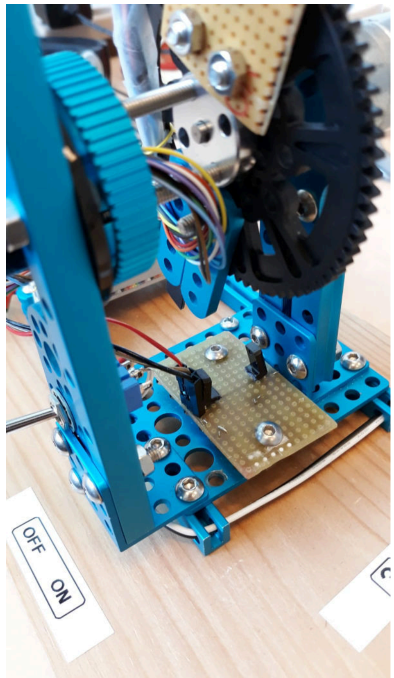


Figure 13: The Leds Circuit board.

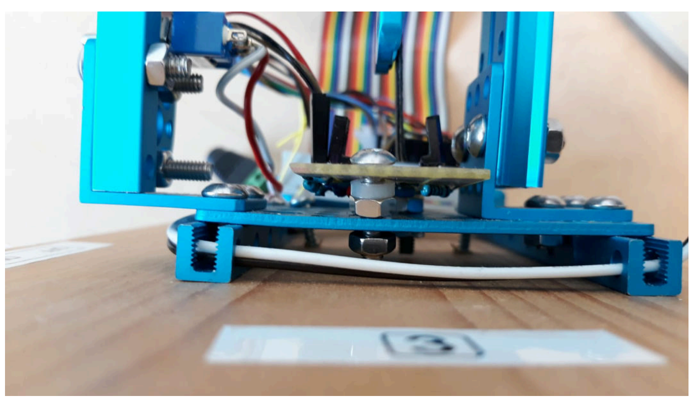


Figure 14: Side view of how the Leds Circuit board is mounted.

4 Circuits

In this section we describe the electronic circuits within the rotating leds system.

4.1 Leds Array Circuit

As led array we used the RTZ 2081 R from MENTOR shown in figure 15 and which we bought at Reichelt [5].

Figure 15: Led array RTZ 2081 R from MENTOR

The website at Reichelt[5] gives the following specifications:

```
MEN RTZ 2081R
LED array, 8-way strip from MENTOR
Diameter 2 mm, horizontal.

Typical: 2.25 V/20 mA
Print grid 2.54/5.08 m
Colour: red

Operating voltage : 2,0  3,0 V
Normal current:  20 mA
```

Using this information we can calculate the value of the resistor which we need to place in series with this led to have it safely running:

```
Typical Voltage of led diode: 2.25V
Typical Current of led diode: 20mA

Vcc: 3.3V
Remaining Voltage : 3.3-2.25= 1.05
```

```
So dissipation of remaining 1.05V on resistor
with a 20mA current gives a resistance of:

      R=V/I = 1.05/0,02 = 53 Ohm
```

We didn't had any 53 Ohm resistors so we take a slightly larger one of 68 Ohm giving us the following electronic scheme for each led in the array shown in figure 16:

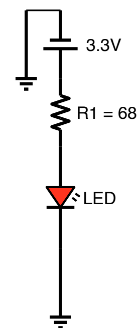


Figure 16: Led electronic scheme

The lower pins of the led array shown in figure 15 can be easily bend downwards so that we can put them through 8 holes of a stripboard. The upper pins we can easily soldered together and then connected to the ground voltage. This is shown in figure 17 where the black wire connects the pins to the white wire of the slipring which is connected to a ground pin on the Raspberry Pi.

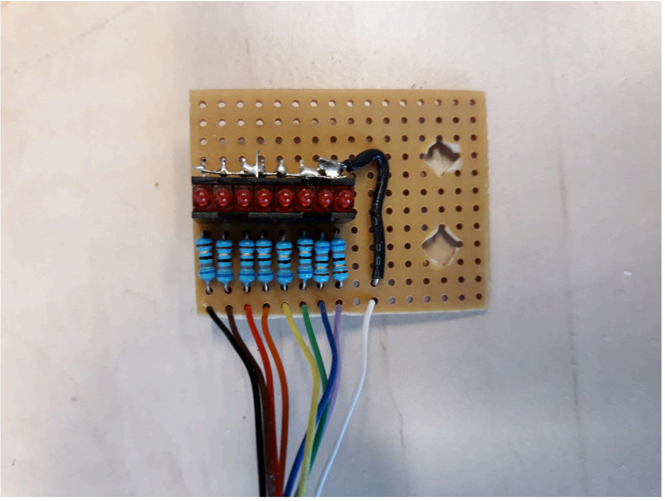


Figure 17: Leds circuit board

In figures 17 and 18 you can see the the different color lines from the slipring connected to a 68 Ohm resistor which is connected to a led. The two 4mm holes are used for mounting the circuit board on the wheel in the rotating leds system.

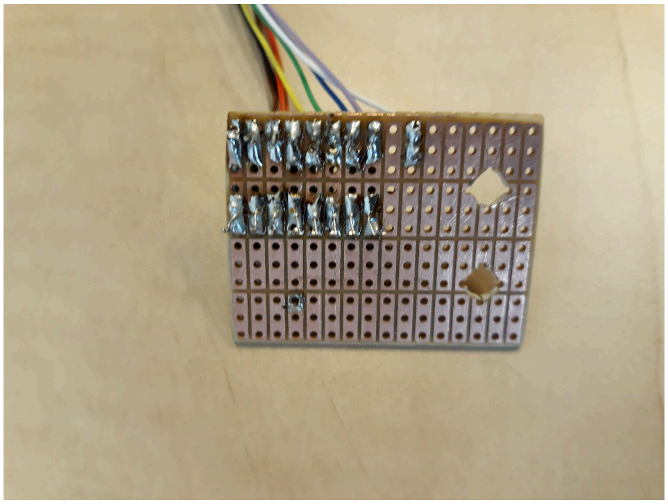


Figure 18: Leds mounted

4.2 Optical Switch circuit

As optical switch we used the OPB625 sensor[6] sold by Farnell.

Figure 19: Optical Switch OPB625

The website at Farnell[6] says:

> The OPB625 is a Photologic Slotted Optical Switch with 10K pull-up (buffered or inverted) output. This printed circuit board mounting switch consists of an 890nm, infrared light emitting diode (LED) and a monolithic integrated circuit that incorporates a photodiode, a linear amplifier and a Schmitt trigger on a single silicon chip. Device is also TTI/LSTTL compatible and can drive up to 10 TTL loads. Suitable for mechanical switch replacement, speed indication (tachometer), mechanical limit indication and edge sensing.

The OPB625 is an optical switch, which is build from a diode outputting infrared light, and a photological sensor which is sensitive for this infrared light.

The switch is triggered when the light beam from the diode cannot reach the photologic sensor because it is blocked by some strip in the slot between the diode and the photologic sensor. The datasheet for the OPB625 optical switch contains the electronic scheme shown in figure 20 :

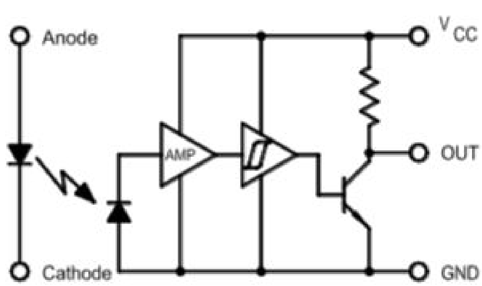


Figure 20: Optical Switch OPB625 electronic scheme

The optical switch has an a 10K pull-up which keeps the output Voltage high at Vcc when the switch is not triggered. So the output is Vcc when the switch is not triggered and is 0V when triggered.

From the datasheet we find:

1. For the Output Photologic sensor in the optical switch the Operating DC Supply Voltage(VCC) must be in the range 4.5-16V.
2. Input Diode has a Maximal Forward DC Current of 50 mA. The typical Forward Voltage of the diode is 1.6 V at I=10mA.

The operating voltage is also the maximal output voltage of the output from the photologic sensor. However the GPIO pins of the Raspberry Pi can at maximum receive 3.3V as input. So it would be better if we could also use the 3.3V of the Raspberry Pi to power the sensor instead. Although it was below what the specifications said, we tested it, and it seems to work alright

When we want to put the optical switch to use in electronic scheme we can directly connect the Vcc power and GND from the Raspberry Pi to the Vcc and GND of the photologic sensor, and the OUT of the photologic sensor to a GPIO input of the Raspberry Pi. However the diode cannot be connected directly to the Vcc and GND from the Raspberry Pi because its typical Voltage drop is around 1.6 Volt, and connecting it to 3.3 Volt would burn it out immediately. So we have to put it in series with an Resistor which dissipates the remaining voltages:

```
Typical Voltage of diode: 1.6V
Typical Current of diode: 10mA (max 50mA)

Vcc: 3.3V
Remaining Voltage : 3.3-1.6= 1.7


So dissipation of remaining 1.7V on resistor
with a 10mA current gives a resistance of:

   R=V/I = 1.7/0,01 = 170 Ohm
```

We didn't had a 170 Ohm resistor but instead took a 230 Ohm resistor which also works fine with a 8mA current. The electronic scheme of the infrared led is shown in figure 21:

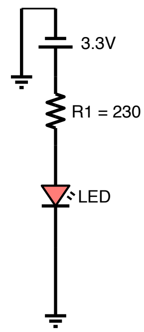


Figure 21: The Led electronic scheme for the optical switch

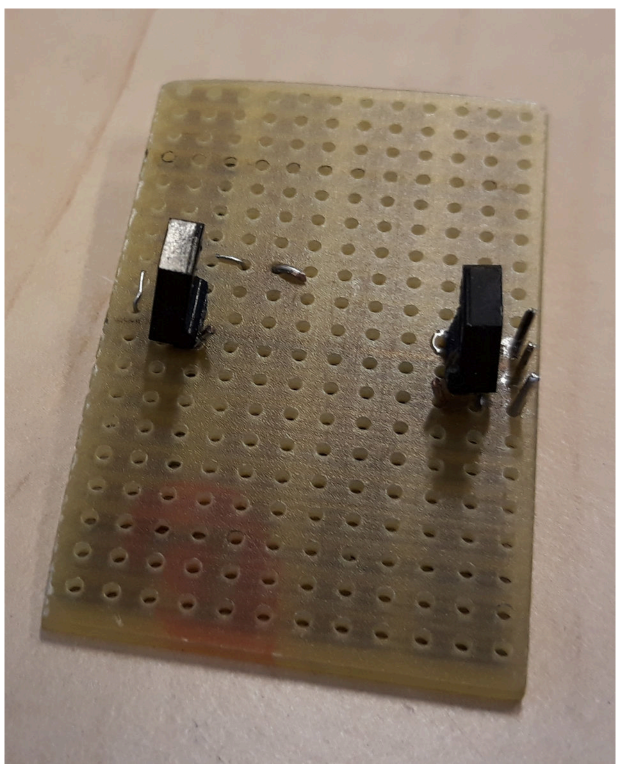


Figure 22: Top view of Optical Switch circuit

In figures 22 we see that we made the split between the diode and photologic sensor bigger. The reason is to give more space to the rotating strip.

In figures 22 and 23 you can see that we added a 3 pins male Dupont connector to make this circuit easily connectable.

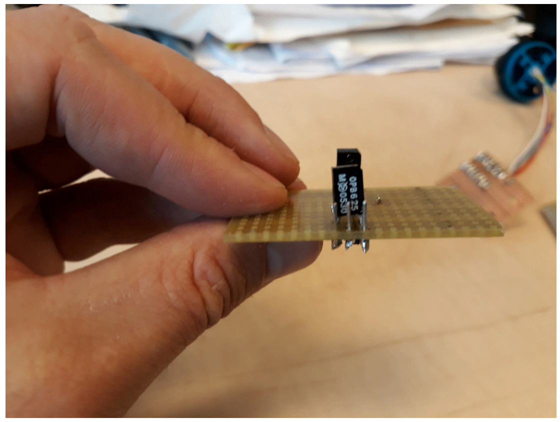


Figure 23: Side view of Optical Switch circuit

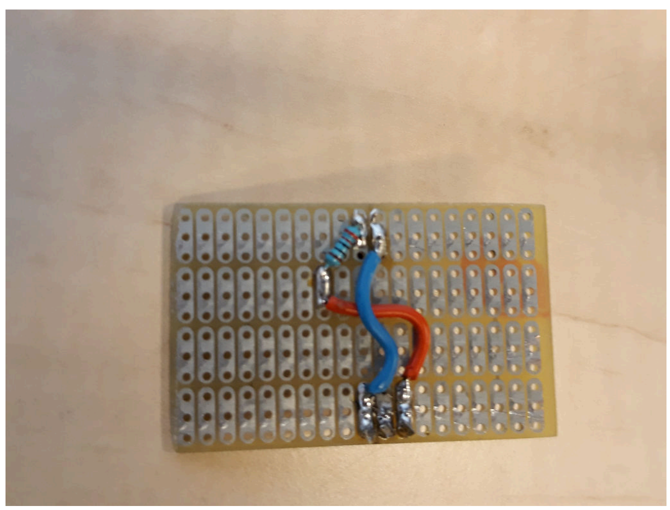


Figure 24: Back view of Optical Switch circuit

In figure 24 we see with the blue line the GND of the diode and the photologic sensor connected, and we see with the red line the Vcc connected to the photologic sensor also driving the in series connected diode and 210 Ohm resistor.

4.2.1 Improvements

Two problems appeared:

1. continuously low signal on sensor caused by external sunlight
2. spurious interrupts

The first problem could be easily solved by lowering the roller blinds in the room. An alternative solution is to add a small roof on the optical sensor so that only light from the diode will reach the sensor, but not light from any other external source.

The source of the second problem was not entirely clear. Several causes could cause the problem:

1. just enough external sunlight could trigger a low signal, but there is not enough sunlight to keep it continuously low
2. the power to the sensor is not stable enough, so when having a dip in the power we get a low trigger in the sensor
3. according to the specifications the sensor needs a 5 Volt power source. But Because the same voltage is given as high output signal I tested it if it worked also right with 3.3 Volt because a GPIO input signal may be maximal 3.3 Volt. After testing I conclude it worked fine. However maybe it is not fine, causing the spurious interrupts.

Reason 1 seems to be also solved by lowering the rolling blinds, or adding a roof on the optical sensor.

Reason 2 seems unlikely because the Raspberry Pi has a power regulator chip, however if you don't have an adequate power supply it can happen. The Raspberry Pi will both let the red power LED blink and show a lightning bolt in the top right corner of the screen if the power drops below 4.65V. But we bought the official Raspberry Pi power supplies and these should be fine. But to be sure a solution could be to put a capacitor at the power line to the sensor to prevent any major power drops to the sensor.

Reason 3 seems to most likely cause, because we went outside the specifications. So instead of using the 3.3V Vcc from the Raspberry Pi, we can use the 5V Vcc from the Raspberry Pi to power the sensor. But we then need to reduce the output Voltage of the photologic sensor with an extra resistor. If we look at figure

we see the photologic sensor's output pin is connect with a 10k Ohm resistor to the Vcc (pull up). Thus if we put an 15k Ohm resistor between the photologic sensor's output pin and the GND we effectively create a Voltage divider on the output when the output signal is high(Vcc):

```
Vcc = 5.0V
```

```
R_pullup = 10k
R_new    = 15k

I = V/R = 5/(10.000+15.000) = 0,2 mA
Vout is the Voltage drop over R_new :

Vout= I * R = 0,2 * 15 = 3 Volt
```

To the output voltage is 3 Volt when the output is high, and 0 Volt when the output is low. The voltage divider circuit is shown in figure 25:

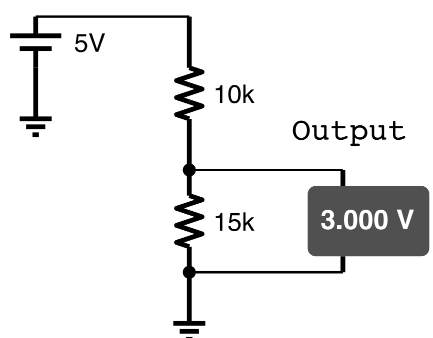


Figure 25: voltage divider scheme

And finally powering the 210 Ohm resistor in series in with the diode with 5V means:

```
Typical Voltage of diode: 1.6V
Typical Current of diode: 10mA (max 50mA)

Vcc: 5.0V
Remaining Voltage : 5.0-1.6= 3.4


So dissipation of remaining 3.4V on resistor
with a 10mA current gives a resistance of:

      R=V/I = 3.4/0,01 = 340 Ohm

However we used a 210 Ohm resistance which
gives a current of:
```

```
I=V/R=3.4/210=0,016 A (16mA)
```

A current of 16 mA is ok, because it is still far below the maximum of 50mA

5 Test the circuits

The circuits can be tested in two ways, where the motor is switched off. Download two scripts from the Xenomai lab site[2] at the Documentation page, under section "Rotating LEDs System": `led_loop.bash` and `light_sensor_interrupt.bash`:

1. Test the LEDs by using the script `led_loop.bash`. Execute it by `bash led_loop.sh`. This should turn each led on once, from top to bottom.
2. Similarly, test the light sensor using script `light_sensor_interrupt.bash`. Manually turn the wheel to trigger the light sensor.

6 Connections

We wanted the different circuit boards in the system and the Raspberry Pi itself to be easy attachable and removable from the system.

6.1 Dupont type Jump wires

Often jump wires are used to connect electronic circuits to the Raspberry Pi GPIO pins. Jump wire is a collection name for all kind of wires which allows you to connect electronic components without the need to soldering. They come with all different type of connectors.

The connector type the rasperry pi gpio pins use is an IDC connector. IDC[9] stands for Insulation-displacement connector is an electrical connector designed to be connected to the conductor(s) of an insulated cable by a connection process which forces a selectively sharpened blade or blades through the insulation, bypassing the need to strip the the conductors of insulation before connecting.

The Jumper Wire cables used for the Raspberry Pi are called Dupont wires[7]. This name is derived from the manufacturer Dupont which made these type of cables and wires. A dupont wire can come as individual line or they can come in a group of them in a cable. In the latter case the connector of the cable, called a Dupont connector[8], can come in a male or female version where the distance between the pins is 0.1 inch or 2.54mm.

All current Raspberry Pi boards have a 40-pin GPIO header, which is basicly a 40 pins male IDC Connector where the distance between the pins is 0.1 inch or 2.54mm. A 40 pins female Dupont connector fits on the Raspberry Pi.

So to connect the the different circuit boards in the system and the Raspberry Pi we use Dupont type of Jump wires. Because the Dupont type IDC connectors give a good connection, and using a Dupont Crimp Tool[12] we can easily add Dupont connectors to the wires from a component making the component then easily attachable and removable[10]. You can easily buy a Dupont crimping tool[12] and a plastic box[11] containing a set of Dupont Type Pins and Sockets Set.

6.2 Overview of connectors

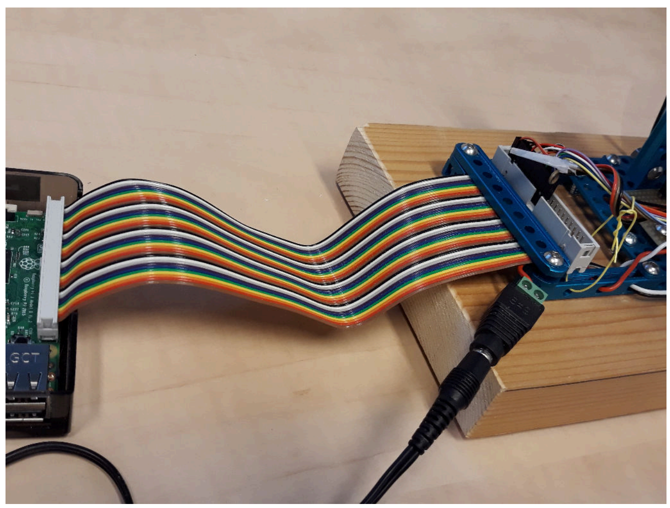


Figure 26: A 40 pins female-male Dupont wire connecting Raspberry Pi to Rotating Leds Systems. Also the 9V power connector for the 700rpm motor is shown.

We use for the whole system the following connections:

- A 40 pins female-male Dupont wire to connect the Raspberry Pi the rotating leds system shown in figure 26. We can then easily connect the pi to the system. All circuit boards within the system can then be connected within the system to the male pins of this Dupont wire.
- In figures 22 and 23 you can see that we added a 3 pins male Dupont connector to the optical switch circuit ot make this circuit easily connectable. It contains a 3 pins male Dupont connector to connect the Vcc,GND and

output signal of the optical switch to 3 pins of the 40 pins male Dupont connector.(see previous item)

- A 5 and 6 pins female connector, shown in figure 27 to connect together the 8 output lines for the leds and the GND wire. As you can see in figure 28 these connectors are connected to the outer wires of the slipring. The inner wires of the slipring are soldered to the circuit board for the leds. We didn't use Dupont connectors here, because this circuit board is rotating with 700rpm, so with soldering it is better fixed. And also soldering takes less space and therefore making the circuit board smaller.

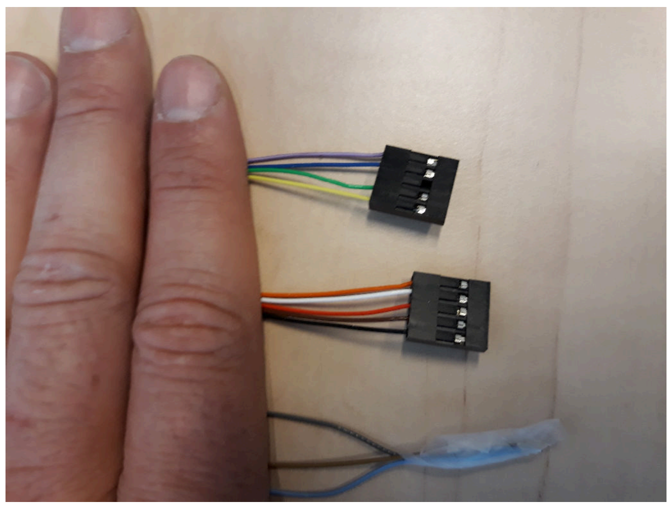


Figure 27: Connectors from the Leds Array Circuit board to the Raspberry Pi

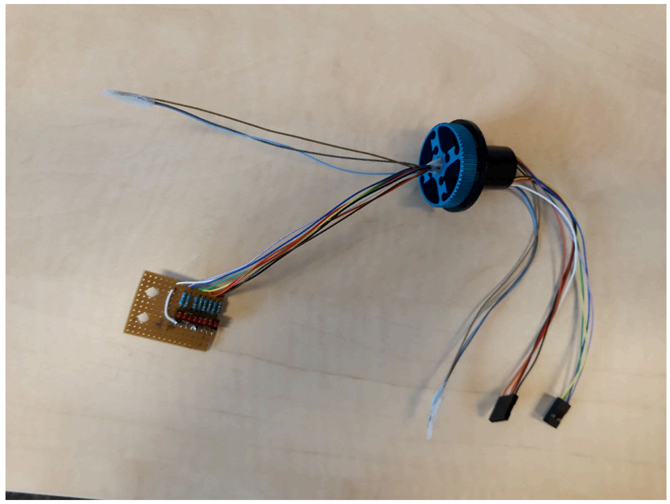


Figure 28: Dupont connectors attached to slipring's outer wires; inner wires connected to led-array circuit board. Some wires are unused.

6.3 Overview of GPIO pin connections to internal wires of Rotating Leds System

6.3.1 Leds Array Circuit

gpio	phys.pin	led number	color of wire
2	3	D0	black
3	5	D1	brown
4	7	D2	red
17	11	D3	orange
27	13	D4	yellow
22	15	D5	green
10	19	D6	blue
9	21	D7	violet
ground	34		white

We use the resistor color coding for our led number to color mapping. From the D2 to the D8 resistor the resistor coding matches the rainbow color coding used for the 40 pins Dupont wire.

6.3.2 Optical Switch Circuit

The circuit pins are label right,middle and left where we use the perspective of standing right in front of the rotating leds system as in figure 2.

For the original circuit using the 3.3 volt power supply.

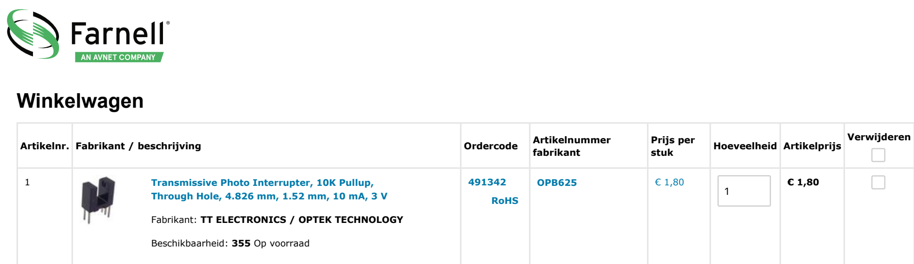
gpio	phys.pin	circuit pin	color of wire	
Vcc(3.3V)	1	left	red	
23	14	middle	brown	output signal
ground	16	right	black	

For the improved circuit using the 5 volt power supply.

gpio	phys.pin	circuit pin	color of wire	
Vcc(5V)	2	left	red	
23	14	middle	brown	output signal
ground	16	right	black	

7 Parts

Below we specify all the parts you need to build the rotating leds system. In this listing we didn't include wires, a soldering iron, a block of wood and wood screws. We assume you already have them.

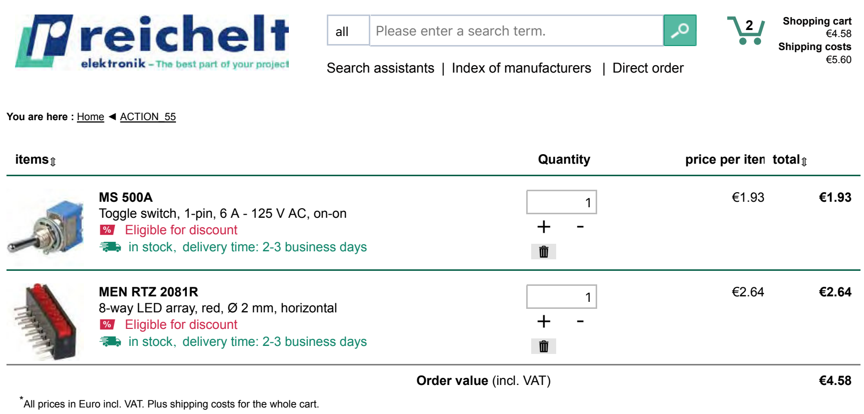


Farnell
AN AVNET COMPANY

Winkelwagen

Artikelnr.	Fabrikant / beschrijving	Ordercode	Artikelnummer fabrikant	Prijs per stuk	Hoeveelheid	Artikelprijs	Verwijderen
1	Transmissive Photo Interrupter, 10K Pullup, Through Hole, 4.826 mm, 1.52 mm, 10 mA, 3 V Fabrikant: TT ELECTRONICS / OPTEK TECHNOLOGY Beschikbaarheid: 355 Op voorraad	491342 RoHS	OPB625	€ 1,80	1	€ 1,80	

Figure 29: Parts ordered at `https://nl.farnell.com/`



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items	Quantity	price per item	total
MS 500A Toggle switch, 1-pin, 6 A - 125 V AC, on-on Eligible for discount in stock, delivery time: 2-3 business days	1	€1.93	€1.93
MEN RTZ 2081R 8-way LED array, red, Ø 2 mm, horizontal Eligible for discount in stock, delivery time: 2-3 business days	1	€2.64	€2.64
	Order value (incl. VAT)		€4.58

*All prices in Euro incl. VAT. Plus shipping costs for the whole cart.

Figure 30: Parts ordered at `https://www.reichelt.nl/`

KIWI electronics

Product Name	Model	Quantity	Unit Price	Total
DC Motor - 25mm - 9V/700RPM	MB-80032	1	€ 15.95	€ 15.95
Slip Ring with Flange - 22mm diameter, 12 wires, max 240V @ 2A	KW-2355	1	€ 21.95	€ 21.95
Timing Pulley - 62T - Blue - 4-pack	MB-83008	1	€ 9.15	€ 9.15
DC Motor Bracket B - 25mm - 2-pack	MB-61802	1	€ 5.75	€ 5.75
Plastic Gear 72T (Pair)	MB-83454	1	€ 1.95	€ 1.95
Plate 7x9 B - Blue - 2-pack	MB-61210	1	€ 4.60	€ 4.60
Hardware Robot Pack - Stainless Steel Screws	MB-95017	1	€ 27.95	€ 27.95
Small Fourway Socket Wrench	MB-70020	1	€ 2.95	€ 2.95
Beam 0412-044 - Blue - 4-Pack	MB-60703	1	€ 3.10	€ 3.10
Crimping plier - 0.08-0.5mm - 20-28 AWG	KW-1985	1	€ 19.95	€ 19.95
Dupont Type Pins & Sockets Set - 310 pieces	KW-1938	1	€ 9.95	€ 9.95
Bracket 3x3 - Blue - 4-pack	MB-61500	1	€ 7.95	€ 7.95
Plate O1 - Blue - 2-pack Not in stock. ***	MB-61220	1	€ 3.45	€ 3.45
Beam 0412-076 - Blue - 4-Pack	MB-60707	1	€ 4.15	€ 4.15
Slide Beam 0824-064 - Blue - Pair	MB-60014	1	€ 5.25	€ 5.25
Beam 0808-120 - Blue - 4-pack	MB-60528	1	€ 10.50	€ 10.50
40 pins Rainbow GPIO cable extender male/female - 20cm	KW-1857	1	€ 5.95	€ 5.95
Terminal block to 2.1mm DC barrel jack - Female	C-DC21FT	1	€ 2.50	€ 2.50
Power Adapter 9V/2.5A - 22W - 2.1mm DC plug	HNP24-090L6	1	€ 13.95	€ 13.95
Prototyping Board - 12x18cm - 2.54mm pitch	KW-1921	1	€ 5.95	€ 5.95
Shaft Hub - 4mm - 2-pack	MB-84740	1	€ 4.50	€ 4.50

Sub-Total (Ex. VAT):	€ 154.88
VAT (21%):	€ 32.52
Total:	**€ 187.40**

Figure 31: Parts ordered at `http://kiwi-electronics.nl/`

References

[1] https://xenomai.org/ and https://en.wikipedia.org/wiki/Xenomai

[2] http://www.cs.ru.nl/lab/xenomai/

[3] https://www.makeblock.com/ and https://en.wikipedia.org/wiki/Makeblock

[4] https://en.wikipedia.org/wiki/Meccano

[5] https://www.reichelt.nl/8-voudige-led-array-rood-2mm-liggend-men-rtz-2081r-p6283

[6] https://nl.farnell.com/tt-electronics-optek-technology/opb625/photo-interrupter-transmissive/dp/491342

[7] https://en.wikipedia.org/wiki/DuPont_wire

[8] https://en.wikipedia.org/wiki/DuPont_connector

[9] https://en.wikipedia.org/wiki/Insulation-displacement_connector

[10] https://www.instructables.com/id/Fitting-Dupont-Connectors/

[11] https://www.kiwi-electronics.nl/dupont-type-pins-sockets-set-310-pieces

[12] https://www.kiwi-electronics.nl/krimptang-0-08-0-5mm-20-28awg