Blumann Etienne
Claudel Guillaume
Dechazal Olivier
Rimaur Fabien

January 2003

ECE8873 – Computing Techniques of Control Systems
Project 1

Measurement of position and speed of the Talrik II robot

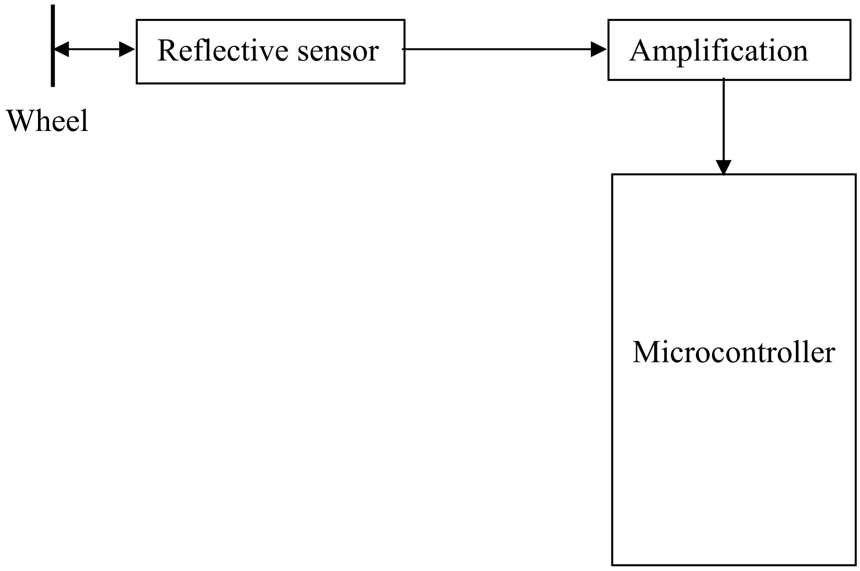
Index

INTRODUCTION

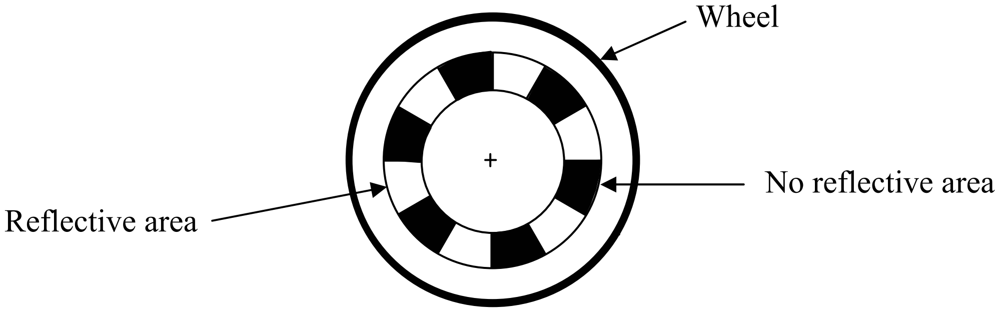
The goal of this project is to design an encoder to determine the position and the velocity of the TalrikII robot.
In this report, it will treat about electronic aspect, mechanical aspect and programming aspect.

1. Electronic aspect

1.1. Principle

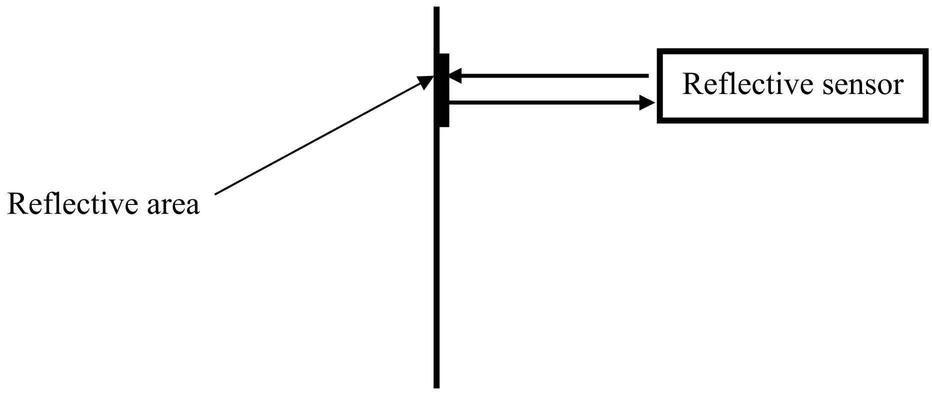


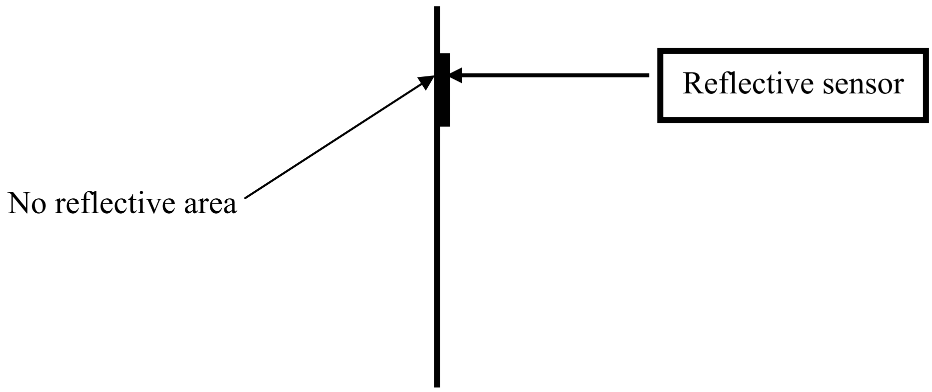
The reflective sensor is an infrared emitted system that functions on reflection of the infrared light on a sensitive surface.
Then reflective elements must be placed on wheels.



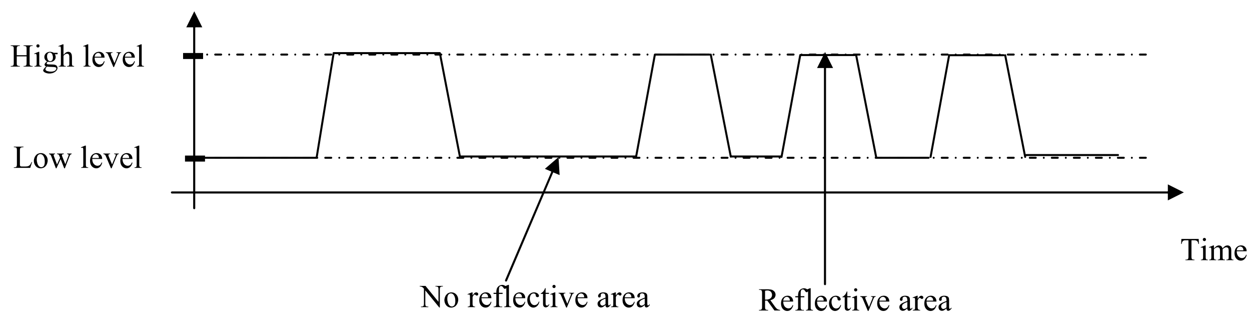
The reflective areas can be done with aluminum materials. The no reflective areas can be bone with black materials.

With this type of system and a reflective sensor, we can detect the presence or not of a reflective or not areas. Thus, in having the length of these areas we can know the angular speed of the wheel.





Then the output current will be in a high level if the area is reflective and in a low level if not. Thus trough a resistance we have the following voltage signal:



1.2. Components used and implementation

1.2.1 Reflective sensor

Two different sensors can be used.

- The reflective sensor HoneyWell HOA1180-003.
- And the HoneyWell HOA0708-001.

These input current drives are about 20mA. Then alimentation will be done with a 5V supply voltage and throw a 220Ω resistance.

For the HOA1180-003, the output current is about 2mA.
The thought a 470Ω resistance, the output voltage of this unit is about 0.94V.

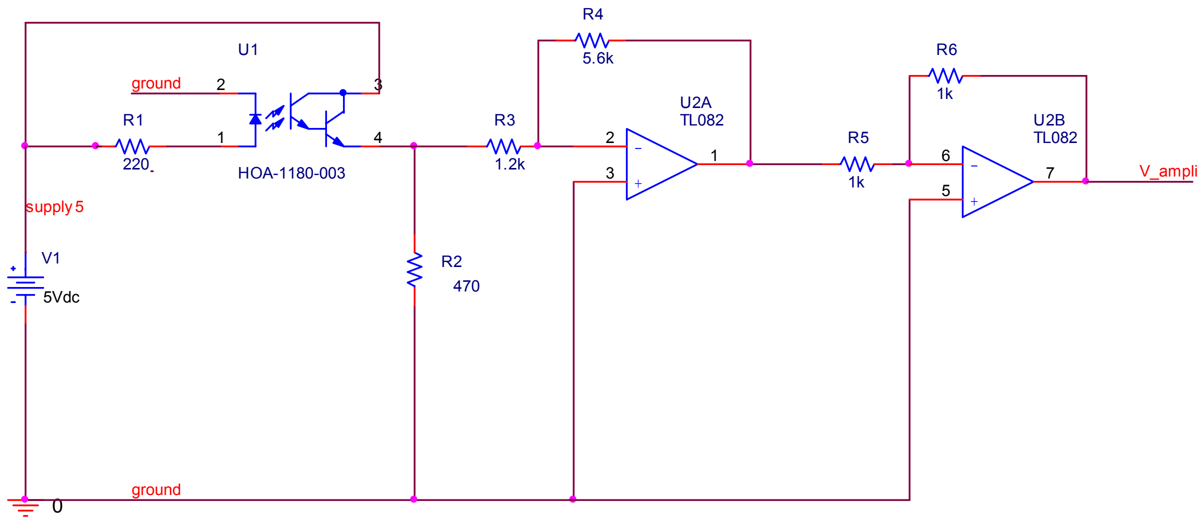
For the HOA0708-001, the output current is about 0.2mA.
The thought a 4.7kΩ resistance, the output voltage of this unit is about 0.94V.

1.2.2 Amplification

The microcontroller works in TTL voltage. Then, if the input voltage is smaller the 5V there is a lack of information.
Thus we must amplify the out signal of the optical unit. The gain is calculated for having a maximum 5V voltage.
Then $G = \frac{5}{0.94} = 5.3$. Amplification will have a gain close to 5.
Components used for this operation are operational amplifier TL082. This component is composed by two JFET operational amplifiers.
The first will be used for amplification about -4.6, and the second will be used for having a positive amplification. Thus its gain will be -1.

1.3. Design

This scheme was made with Orcad Spice, and use E12 series for resistances.



1.4. Price of electronics components

The choice of the sensor will depend on the mechanical aspect. In fact, the advantage of the HOA1180 is that it can works with a distance between sensor and reflective area of 12.7mm. The HOA0708 works with a maximum distance of 3.8mm.
Nevertheless, the HOA1180 is more expensive.

Constructor	Reference	Furnisher	Price
HoneyWell	HOA1180-003 or HOA0708-001	Radiospares	19,64 € 5,21€
ST MICROELECTRONICS	TL082-CN	Farnell	0,83€
NeOhm	CFR-1kΩ	Radiospares	2*0,34€
NeOhm	CFR-220Ω	Radiospares	0,34€
NeOhm	CFR-1.2kΩ	Radiospares	0,34€
NeOhm	CFR-470Ω or CRF-4.7kΩ	Radiospares	0,34€
NeOhm	CFR-5.6kΩ	Radiospares	0,34€

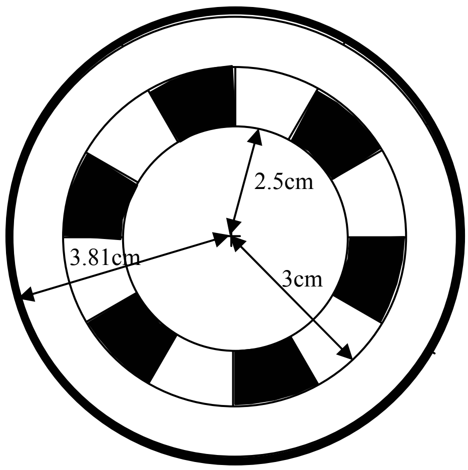
The total price is 22,51€ with the HOA1180 and 8,08€ with the HOA0708.

2. Mechanical aspect

2.1. Disk made

The radius of the wheel is given and equal to 3.81cm.
In this section we will make specifications about the reflective disk behind the wheel.

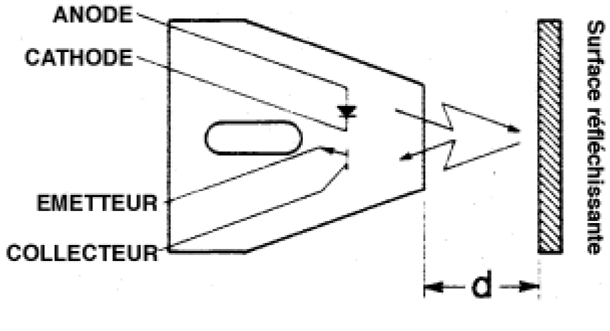
A restrain is that this disk must be easy to build. Thus dimensions should be human.



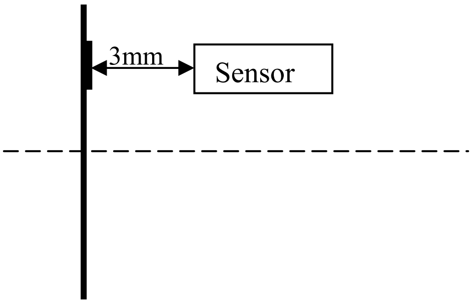
With this disposition, the state change of the sensor will be done every 30° in other word every $30° * 2.75 = 1.43cm$.
Then maximum precision will be 1.43cm.

2.2. Position of elements (HOA0708)

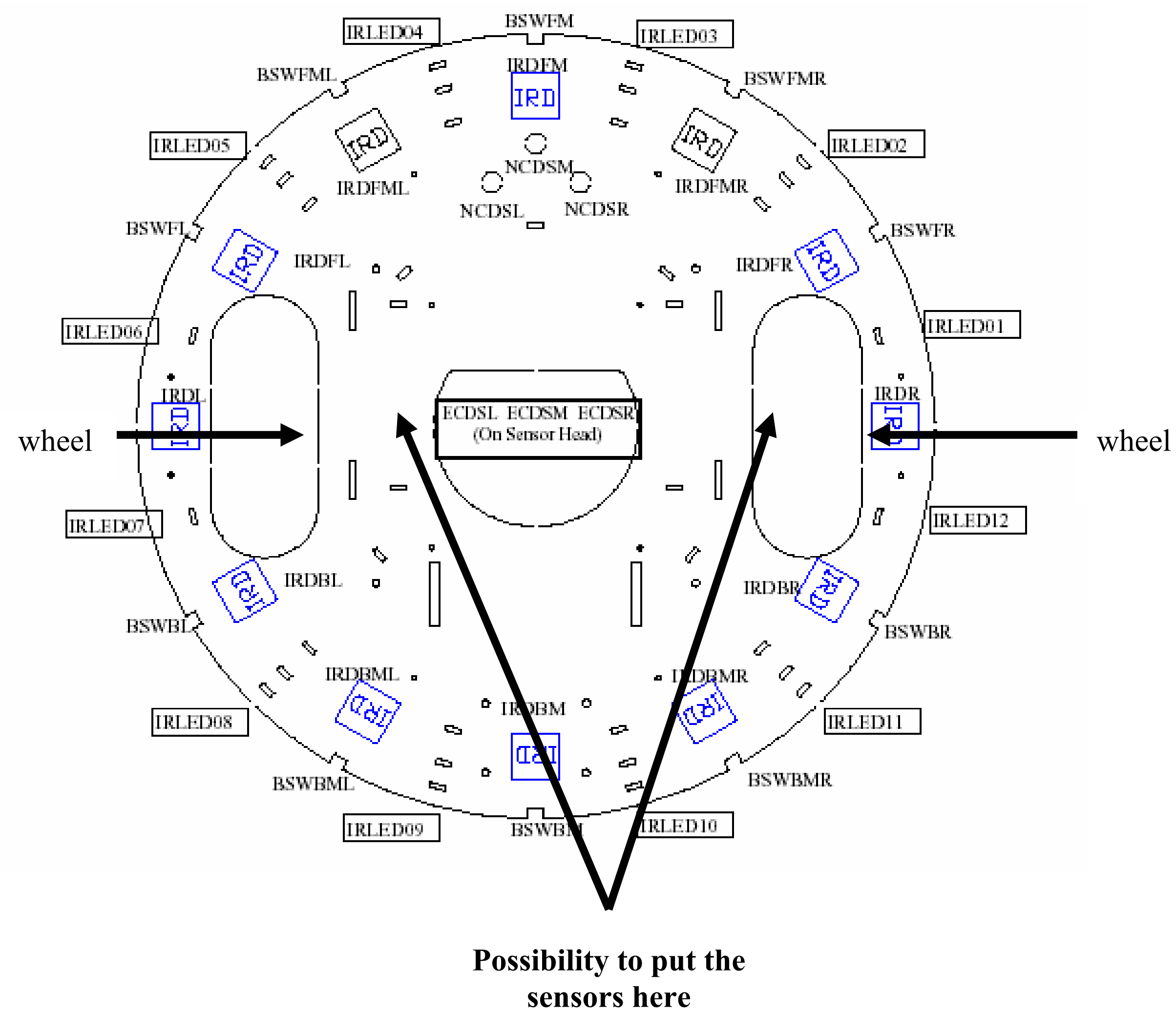
2.2.1 The sensor
As we said the maximum distance from the disk to the sensor is about 3.80mm.



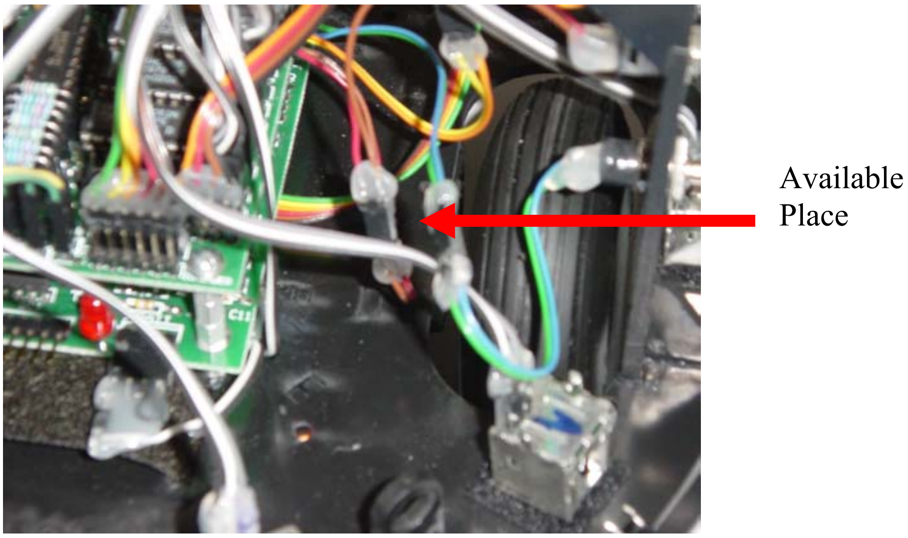
Then disposition of elements could be the following:



After observing the robot we can place the sensors like this

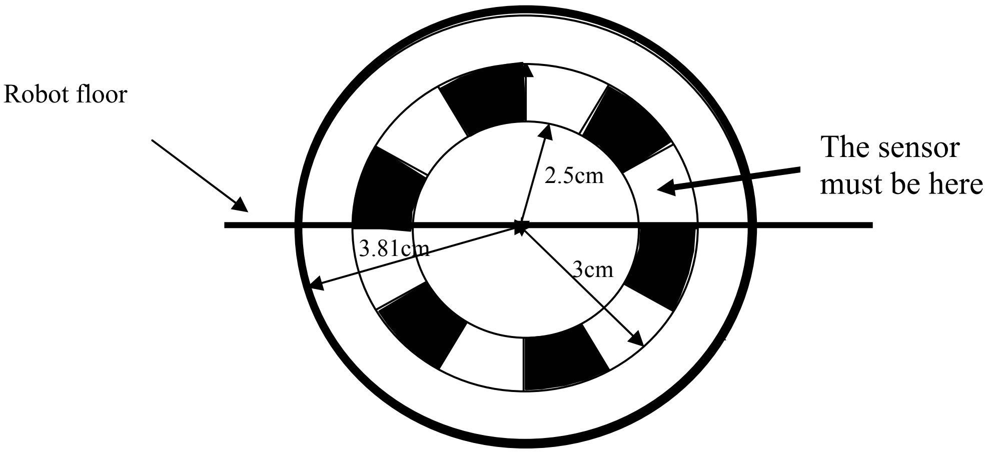


We can see that there are enough places beside the wheels on the robot:

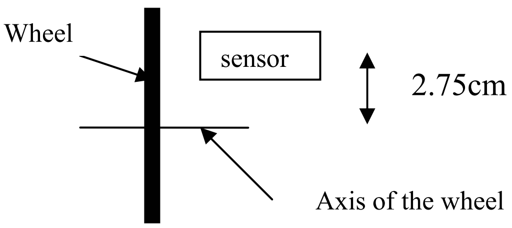


We have to put the sensor so that it is able to see the black and white parts of the disk.

<u>Side view</u>



<u>Above view</u>



Now the sensor has to be installed: You can use glue to fix it on the robot, otherwise you can screw it using a bolt.

2.3. Connection of the circuit

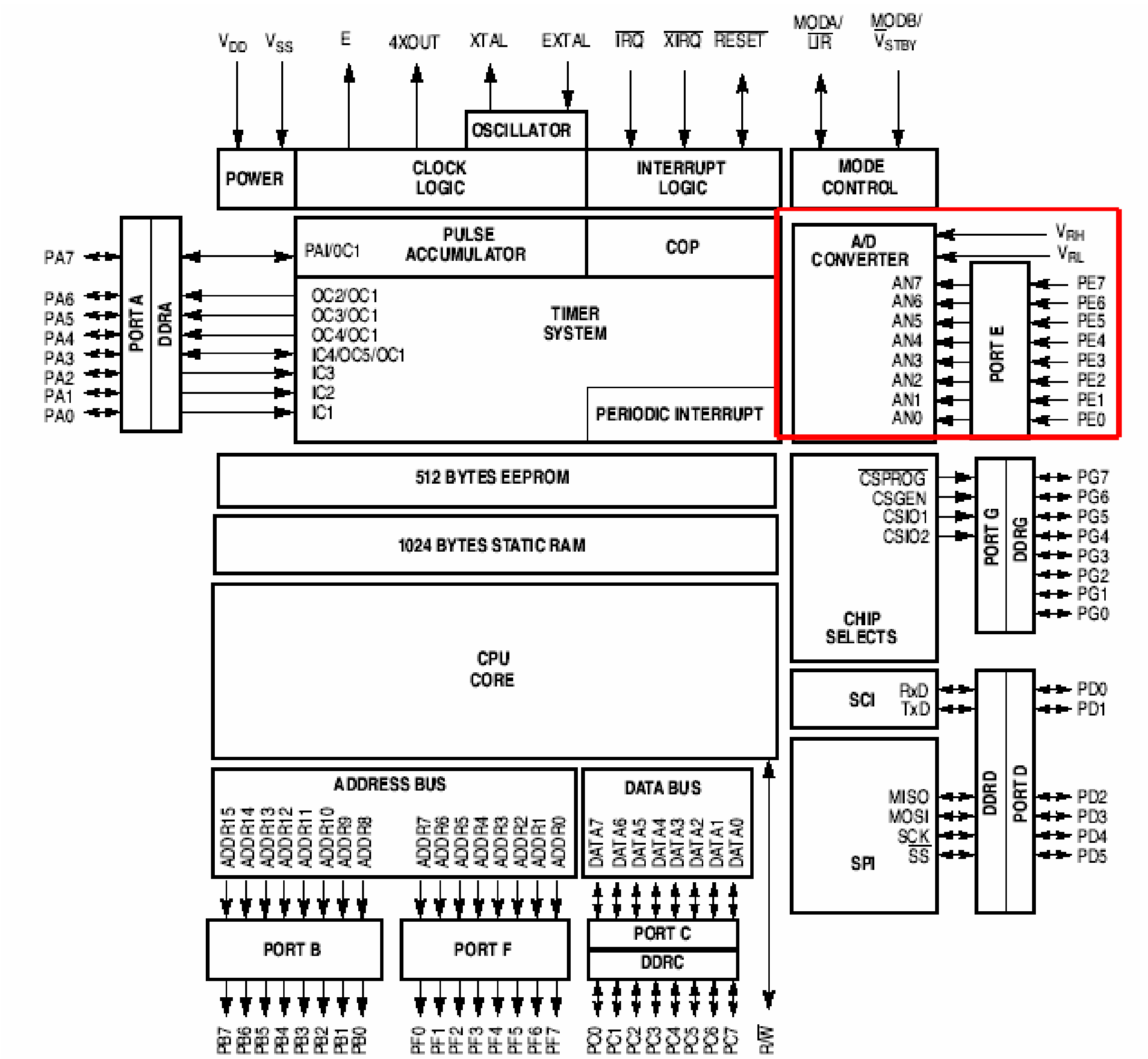
Now we have to find where to connect the different parts of the circuit on the robot.

2.3.1 The ground

As it is said on page 8 of the MRC11 user's manual, the pin 1 on the controller MRC11 is connected to the ground. Thus it could be used as a common ground for the circuitry shown before

2.3.2 Getting in the microcontroller

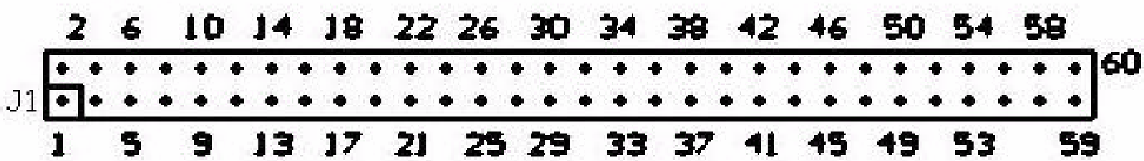
As it is described earlier, the signal in output of the speed measurer has to be sent in the microcontroller in order to be processed. After that, the signal goes to the computer which will give us the speed and position information we need.
The MOTOROLA 68HC11 processor which is on the MRC11 microcontroller of the robot already possess an analog to digital converter so that it is not needed to buy one.
Here is the block diagram of the processor:



As we can see, the analog to digital converter inputs are the PE0 to PE7 ports and we have to send 2 voltages Vrh (high level) and Vrl (low level, we can choose it equal to the ground). The corresponding ports on the MRC11 microcontroller are given on page 8 and 9 of the MRC11 user's manual:

-PE0 to PE7 corresponds to pin 43 to 50,

-Vrl and Vrh correspond respectively to pin 51 and 52.



Thus we can connect pin 51 to pin 1(gnd).

3. Algorithm for determining the position and velocity from the encoder measurements

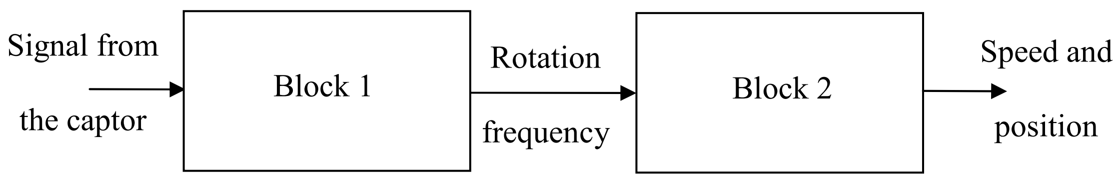
So as to simplify the problem, we will consider firstly a system with only one wheel. In the second part, we will have an interest for two-wheel systems. Finally, we will comment on the calculus of the position and the velocity of the robot.

3.1. A one-wheel system

As this system has only one wheel, it needs only one reflective sensor. Thus, the system is easier to study. Anyway, we notice there are several methods to determine the position and velocity of the robot.

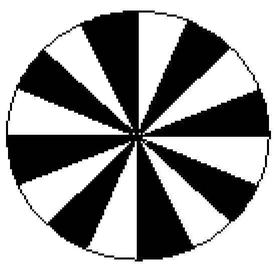
3.1.1 Different methods to determine the position and velocity of a one-wheel system

The system to determine the position and the velocity of the robot is not very complicated: we can divide it in two parts. The first one gives the frequency of rotation of the wheel (and so the speed of the robot). The second one calculates the position of the robot.



Simple schema of the algorithm

As the signal from the captor is continuous, the blocks have to work with a continuous data flow. Therefore, both part of this system have to treat quickly the data: faster than the rotation frequency of marks.



Here, the rotation frequency of marks is the rotation frequency of the wheel multiplied by the number of black marks.

Reflective wheel

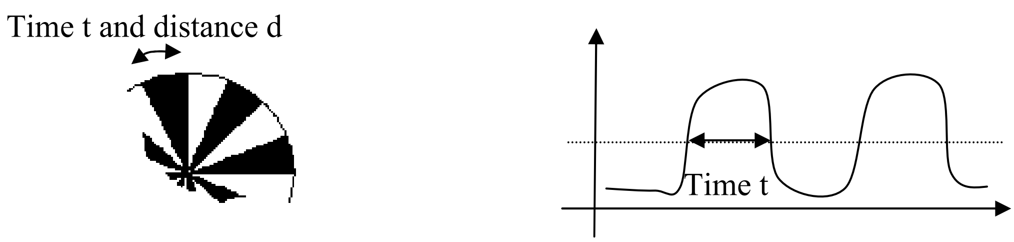
One solution, to make the system quicker, is to execute the two parts with different chips. For example, the block 1 can be on the robot and the second block on the computer with a wireless connexion (900 MHz).
Another solution is to make two processes which are executed on the same chip. Thus, there is no need of any wireless connexions. But, as all the calculi are worked out by the same microcontroller, the chip has to be strong enough to maintain “the real-time”.
The last solution is to execute the two blocks one after the others on the same chip and so, not to have two processes. This idea is the most simple (to understand and to program) but needs more calculi power.

So each solution has its advantages and its disadvantages; but for our problem, one of them is better than the others.

3.1.2 Choice of the algorithm

We have chosen the third solution. Indeed, it seems to be the best one because of several reasons:

- A radio connexion is not required: we do not need to manage the transmission.
- Even if the calculi are quite big, we do not saturate the microcontroller because there is not a big data flow (the maximal speed of the robot is 12 inches per second).



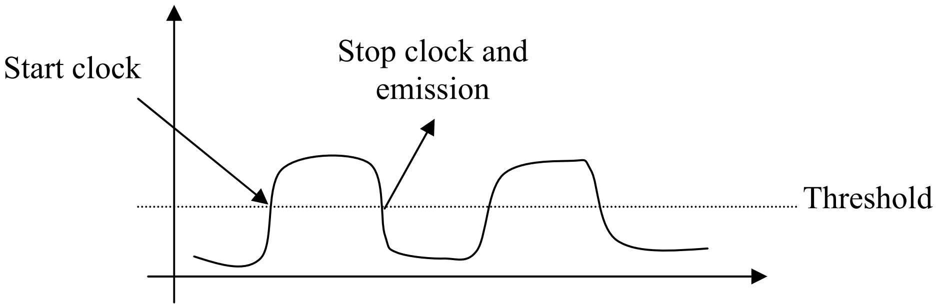
Relation between rotation frequency and signal frequency

In the schema above, d determines the distance covered by the robot during t seconds.

3.1.3 The chosen algorithm in detail

To well understand the system, we will develop the second block later. Here, we keep an interest on the first block that has to determine the period of time where a mark (black or white one) is in front of the sensor.
We can resume it in few lines:

- First, converting the signal from the reflective sensor to digital with the analogue to digital encoder embedded in the microcontroller.
- Then, storing data in a variable: port PE0 and call function to A/D conversion.
- Detecting if the signal is under the threshold: determine if the sensor is in front of a black or a white mark.
- Determining if the emission must be in a rising front or a descending front. Example:



Program clock start and stop

- Waiting for an exceeding of the threshold (sense 2).
- Reset clock.
- In an infinite loop:
    - Waiting for an exceeding of the threshold (sense 1).
    - Stopping the clock and storing it.
    - Reset clock
    - Call calcul_pos function with the registered clock and the sense of rotation.
    - Waiting for an exceeding of the threshold (sense 2).
    - Stopping the clock and storing it.
    - Reset clock
    - Call calcul_pos function with the registered clock and the sense of rotation.

Thus, the maximum of accuracy is obtained because this algorithm detects the half period of the signal: it makes a difference between the white and black marks.

3.2. A two-wheel system

But, Talrik II has two wheels and two different motors. So, the system is more complex. We will comment here these differences and the final algorithm.

3.2.1 The differences between a one-wheel and a two-wheels system

The main idea of the algorithm does not change: the determination of the frequency of the signal is still done on the robot and then another function calculates the position and velocity of the machine.

But, as the robot has two wheels, this algorithm must have an interest in the different cases can occurs at the start:

- The right and left sensors detect white marks.
- The right and left sensors detect black marks.
- The right sensor detects a white mark and the other a black one.
- The right sensor detects a black mark and the other a white one.

And the system must manage the possibility a wheel can turn whereas the other is immobile. And so, a side can not be specified, regarding the other. The algorithm must be totally symmetric.

3.2.2 The chosen algorithm

The final algorithm to determine the rotation frequency is written in C because downloading C on the robot is easy. The functions have been created to be executed very fast (only logical operations):

```
//** #include <libscrtk.h>              // library taken from mekatronix web site
                                       // that includes functions regarding conversion
                                       // and the clock.

bool test(int a) {                     // This function tests if le signal a is under
        int threshold=128;             // the threshold. Middle of the scale [0-255]:8 bits
        return (a<threshold);
};

int choiceofcase(int a, int b) {                             // This function gets the case where
        if ( test(a) && test(b) ) {return cas=0;};           // the system is.
        if ((!test(a)) && test(b)) {return cas=1;};
        if ( test(a) && (!test(b))) {return cas=2;};
        if ((!test(a)) && (!test(b))) {return cas=3;};
};
```

```
bool cond(int a, int b, int c) {                              // This function returns if the
        switch  (c) {                                         // system has changed.
                case 0: return ( test(a) && test(b)) ;break;
                case 1: return ( (!test(a)) && test(b)) ;break;
                case 2: return ( test(a) && (!test(b))) ;break;
                case 3: return ((!test(a)) && (!test(b))) ;break;
                default: return true;
        };
};


// This function makes the differences between changes of cases: starting, stopping clock..

void changecase(int casprev, int cas, bool slop[2], int time[4]) {
        //Variables
        int result[4];                          // array that contains all information the
                                                // computer needs.
        bool rot_a=0;                   // sense of rotation for a;
        bool rot_b=0;                   // sense of rotation for b;

        //** Acquisition: store the sense of rotation in rot_a and rot_b;
        //** the pin PC7 for rot_a;
        //** the pin PC6 for rot_b;


        // Changes of the signal a: left wheel.
        if (((casprev==0) && (cas==1)) || ((casprev==1) && (cas==0)) || ((casprev==2)
  && (cas==3)) || ((casprev==3) && (cas==2))) {
                        if (slop[0]) {
                                //**  time[0]=clock;
                        }
                        else {
                                //**  time [1]=clock;
                                result[0]=time[1]-time[0];
                                //** Acquisition: store the sense of rotation in rot_a;
                                //** Acquisition: pin PC7 in rot_a;
                                //** result[1]= rot_a;
                                result[2]=0;
                                result[3]=0;
                                calcul_pos(result[0], result[1], result[2], result[3]);
                        }
        };
        // Changes of the signal b.
        if (((casprev==0) && (cas==2)) || ((casprev==1) && (cas==3) ) ||  ((casprev==2)
  && (cas==0)) || ((casprev==3) && (cas==1))) {
                        if (slop[1]) {
                                //** time[2]=clock;
                        }
                        else {
                                //** time [3]=clock;
                                result[2]=time[3]-time[2];
                                //** Acquisition: store the sense of rotation in rot_b;
                                //**Acquisition: pin PC6 in rot_b;
                                //**result[3]= rot_b;
```

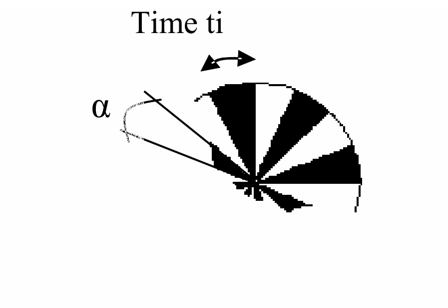
```
                        result[0]=0;
                        result[1]=0;
                        calcul_pos(result[0], result[1], result[2], result[3]);
                }
        };
        // Changes of signals a and b.
        if (((casprev==0) && (cas==3)) || ((casprev==1) && (cas==2)) || ((casprev==2)
 && (cas==1)) || ((casprev==3) && (cas==0))){
                if (slop[0]) {
                        //** time[0]=clock;
                }


                else {
                        //**  time [1]=clock;
                        result[0]=time[1]-time[0];
                        //** Acquisition: store the sense of rotation in rot_a;
                        //**Acquisition: pin PC7 in rot_a;
                        //**result[3]= rot_a;

                }
                if (slop[1]) {
                        //** time[2]=clock;
                }
                else {
                        //** time [3]=clock;
                        result[2]=time[3]-time[2];
                        //** Acquisition: store the sense of rotation in rot_b;
                        //**Acquisition: pin PC6 in rot_b;
                        //**result[3]= rot_b;
                }
                if (!(slop[0])) {
                        if (!(slop[1]))  {calcul_pos(result[0], result[1], result[2],
                       result[3]);}
                        else{
                                result[2]=0;
                                result[3]=0;
                                calcul_pos(result[0], result[1], result[2], result[3]);

                        };
                }
                else {
                        if (!slop[1])) {
                                result[0]=0;
                                result[1]=0;
                                calcul_pos(result[0], result[1], result[2], result[3]);

                        };
                };
        };
};

void main() {

// definition
```

```
		int a=0;			// signal :left wheel
		int b=0;			// signal :right wheel
		int cas=0;			// state of the system
		int casprev=0;			// previous state of the system
		bool condition=false;		// represents if the state has changed
		bool slope[2];			// first front of the signal: true=rising front…
		int timer[4];			// starting and stopping clock of each signal

// initialization
		// functions
		//** init _analog();		// init function for A/D conversion
		//** init _clocktk();		// init function for the clock

		//** Acquisition: store the data in a and b:
		//** The PE0 pin for signal 1.
		//** The PE1 pin for signal 2.
		//** function for A/D conversion of signal 1 and store it in a.
		//** function for A/D conversion of signal 2 and store it in b.

		// definition of the slope
		if (test(a)) {slope[0]=true;}
		else {slope[0]=false;};
		if (test(b)) {slope[1]=true;}
		else {slope[1]=false;};

// initialization of timer
		timer[0]=0;
		timer[1]=0;
		timer[2]=0;
		timer[3]=0;

// choice of the case
		cas=choiceofcase(a,b);

// main loop
		while (true) {

			condition=cond(a,b,cas);

			while (condition) {
				//** Acquisition: store the data in a and b:
				//** The PE0 pin for signal 1.
				//** The PE1 pin for signal 2.
				//** function for A/D conversion of signal 1 and store it in a.
				//** function for A/D conversion of signal 2 and store it in b.
				// condition
				condition=cond(a,b,cas);
			};

			casprev=cas;
			cas=choiceofcase(a,b);
			changecase(a,b,slope,timer);

		}
}
```

4. Algorithm to determine the position and the velocity of the robot

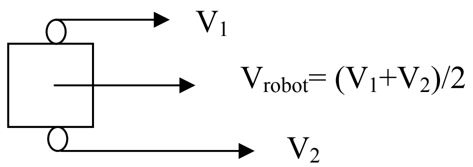
4.1. Speed

Once known the time t_i taken by each wheel i to turn of a single section we can easily calculate the speed of rotation θ_i : $\theta_i = \alpha / t_i$



Then we can calculate the rectilinear speed of the robot for each wheel i:

$V_1=R*\theta_1$ with R the radius of the wheel
$V_2=R*\theta_2$

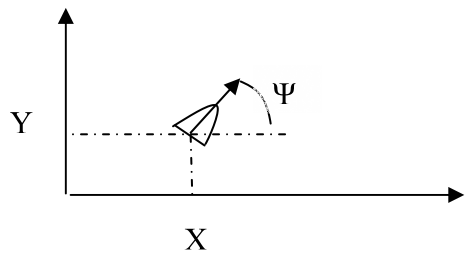


4.2. Position

To represent the position of the robot we use three parameters:

- 2 coordinates (X,Y) to represent the robot in the plan
- 1 angle to give its direction in comparison with the axe X

The scheme beneath represents the coordinates of the robot:



We can differentiate two cases for computing the position of the robot:

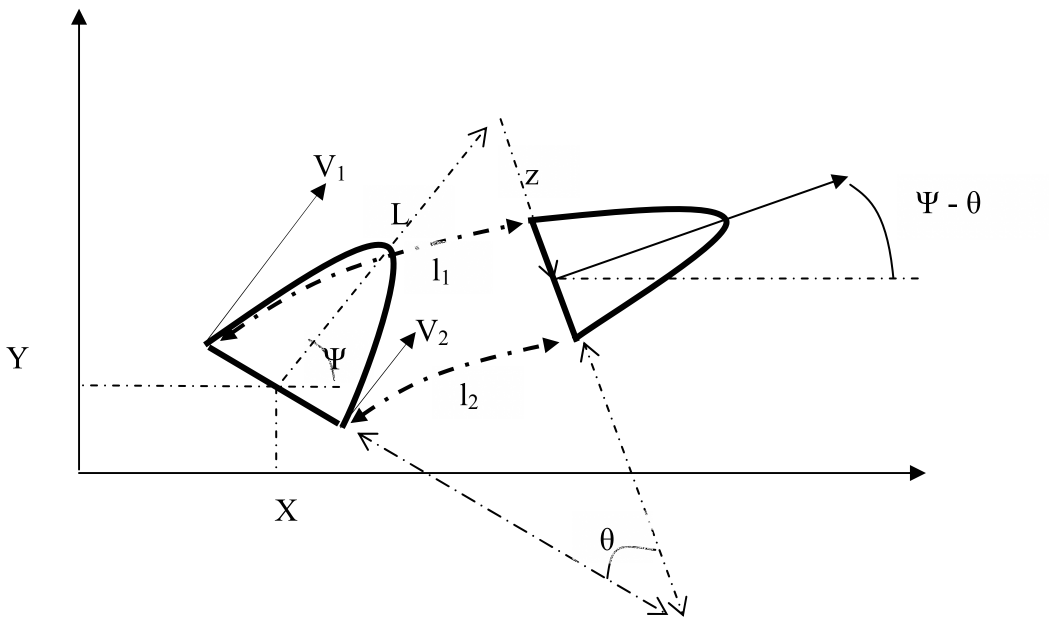
4.2.1 The two wheels turn at the same speed (V1=V2)

The robot has a rectilinear movement. During the time T, it has move of the folowing way :

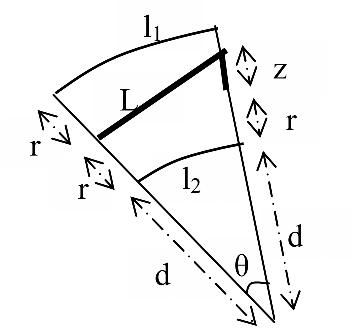
$X_{new} = X_{old} + (V_1 * T) * \cos(\Psi)$
$Y_{new} = Y_{old} + (V_1 * T) * \sin(\Psi)$
$\Psi_{new} = \Psi_{old}$

4.2.2 The two wheels do not turn at the same speed, the robot has a rotation movement

The figure beneath represents the movement of the robot from the point (X, Y) and the different parameters that we consider to calculate the next position.



For a brief period T, we can approximate that $l_1 = V_1 * T$ and $l_2 = V_2 * T$. The first figure can be simplified in the figure below:



2*r is the length from one wheel of the robot to the other. Geometrically we can deduce all the following lengths:

$\theta = (l_1-l_2)/ (2*r)$
$d = 2*r*l_2/(l_1-l_2)$
$L= (r + d) \tan(\theta)$
$Z= L/\sin(\theta) - r - d$

Once known the lengths of L and Z, it is easy to calculate the new position parameters of the robot. By projection we get :

$X_{new} = X_{old} + L*\cos(\Psi) - Z*\sin(\theta - \Psi)$
$Y_{new} = Y_{old} + L*\sin(\Psi) - Z*\cos(\theta - \Psi)$
$\Psi_{new} = \Psi_{old} - \theta$

Remarks:

- The lengths can have negative values in the case of a backward movement of the robot for example and one of the two speeds can be nil without changing the equations.

- It is clear that if at a time the coordinates (X, Y) are wrong, the following positions would be also wrong. In fact errors are spread all along the calculations of the positions that is why the position of the robot is only reliable for a certain period of time.

4.3. Program written in C

The function calcul_pos(int t1, int sens1, int t2, int sens2) is called as soon as the sensor has detected the cross of a section of the disc of one of the wheel. It is also called if after 500 ms none of the sensor has detected a movement. It corresponds at a stop in the movement of the robot. The variable t1 corresponds at the time taken by the left wheel of the robot to turn of a single section, t2 is the same for the right wheel. The variable sens1 has the value '0' when the movement of rotation of the left wheel is forward and '1' when the movement of rotation is backward.

```
//definition of constants
# define R=7.24                 // radius of a wheel of the robot in cm
# define r =9.48                // half-length from a wheel of the robot to the other one in cm
# define nb_sections=12         // number of sections on the wheel
//variables global nb_t1, nb_t2, total1, total2, phi, X, Y

void calcul_pos(int t1, int sens1, int t2, int sens2 )
{
//definition of variables
int V1=0,V2=0,teta,d,l,l1,l2,z,stop=0;
if ( (t1+t2)==0 )               // stop condition : if the sensor does not get data after 500ms,
                                // t1=t2=0
        {
        stop=1;
        }
else
        {
        if (sens1==1)
                {
                t1=-t1;
                }
        if (sens2==1)
                {
                t2=-t2;
                }
        if (t1 !=0)
                {
                nb_t1 ++;
                total1=total1+t1;
                }
        if (t2 !=0)
                {
                nb_t2 ++;
                total2=total2+t2;
                }
        }
```

```
if (nb_t1+nb_t2 >2 || stop)        //data are updated every 3 measures to have a mean value
                                    //except if the stop condition happens
        {
        l1=2*Π*R*nb_t1/ (nb_sections);
        v1= l1/total1;
        l2=2*Π*R*nb_t2/ (nb_section);
        v2=l2*total2;
                }
        //computing of intermediate variables
        if (v1-v2 !=0)              //see above the explanations for geometric calculations
                {
                teta=(l1-l2)/(2*r);
                d=2*r*l2/(l1-l2);
                l=(r+d)*tan(teta);
                z=l/sin(teta)-r-d;
                //computing of position and speed variables
                X=X+l*cos(phi)-z*sin(teta-phi);
                Y=Y+l*sin(phi)-z*cos(teta-phi);
                phi=phi-teta;
                Vrobot=(v1+v2)/2;       //value in cm/ms
                }
        else
                {
                X=X+l1*cos(phi) ;       // value in cm
                Y=Y+l2*sin(phi) ;       // value in cm
                phi=phi ;               // value in radian
                }
        //initialisation of the global variables
        nb_t1=0;
        nb_t2=0;
        total1=0;
        total2=0;
        }
}
```

4.4. Conclusion

- We thought that it was interesting to make a mean value of the speed of each wheel to reduce the risk of calculating a wrong position. Indeed since we calculate a position thanks to the previous one, a wrong position would provoke an error for all the following ones.
- It is difficult to evaluate the time taken by the embedded computer to perform the programs. In case it would be quick enough we could increase the number of measures taken by our sensor and by the way the precision and if it is too slow we could decrease the number of measures.
- We do not know well the library including in the computer. For example we are not sure that the computer is able to calculate sinus or tangent of an angle directly. If not so, we would have to make approximations like $\sin(\theta) \approx \theta$.

5. Bibliography

[1] HoneyWell HOA0708/0709 Reflective Sensor Datasheet
[2] HoneyWell HOA1180 Reflective Sensor Datasheet
[3] ST GENERAL PURPOSE DUAL JFET OP-AMPS Datasheet
[4] NEOHM GENERAL PURPOSE CARBON RESISTANCE Datasheet
[5] www.farnell.com
[6] www.radiospares.fr
[7] Mekatronix manual on www.mekatronix.com
Talrik IITM Assembly Manual
Talrik IITM User's Manual
MRC11 Microcontroller
MSCC11 Single-Chip Controller