3. Development of Hardware

3.1 *Motors and Gearboxes*

3.1.1 Motors

Two motors are used to drive the sprinkler head trajectory and sector angle. One of them (RS stock No.440-442) takes charge of trajectory and the other (No.332-082) of sector.

These are 4-phase hybrid motors and their main specifications are shown in Table.3-1. The further details can be referred to RS data sheet No.232-5745.

RS Stock No.	440-442	332-082
Step angle	1.8	1.8
Nominal phase parameters and rating: Voltage	5.1	5
Resistance at 20°C	5	5
Current (A)	1	1
Holding torque (mNm)	500	460

Table 3-1: Main features of motors

The configurations of the motors are shown in Fig.3-1.

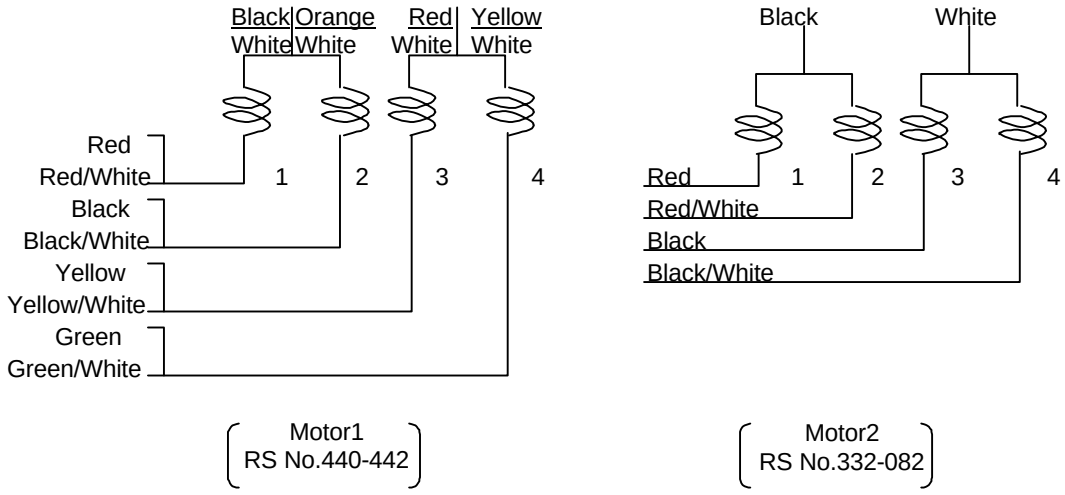

Fig.3-1: The configurations of motors.

Furthermore, Fig.3-3 in next section shows the electric circuit of the motor connections to the motor driver boards and the power supply.

3.1.2 Driver Board

Unipolar stepper motor drive board (RS stock No.332-098) was used. The technical specifications are written in Table.3-2.

a) Technical specifications

Size	standard Euro card 168 × 100 × 15	
Mating edge connector	standard 32-way DIN41612 socket	
Supply (board and motor)	15-30V	15V(Current setting)
Current consumption board only motor windings	 60 mA Max. 2A	
On-board auxiliary output	12V d.c. 50mA max regulated	
Switching logic control	Level '0' 0V Level '1' 12V	
Inputs 1. full/half step 2. direction 3. clock 4. preset	 0: half 1: full 0: anti-clockwise 1: clockwise 0: low pulse 1: high pulse	(Current setting) Level '0' fixed Level '0' fixed.

Table 3-2: Technical specifications of unipolar motor driver.

Fig. 3-2 tells the details of the connections.

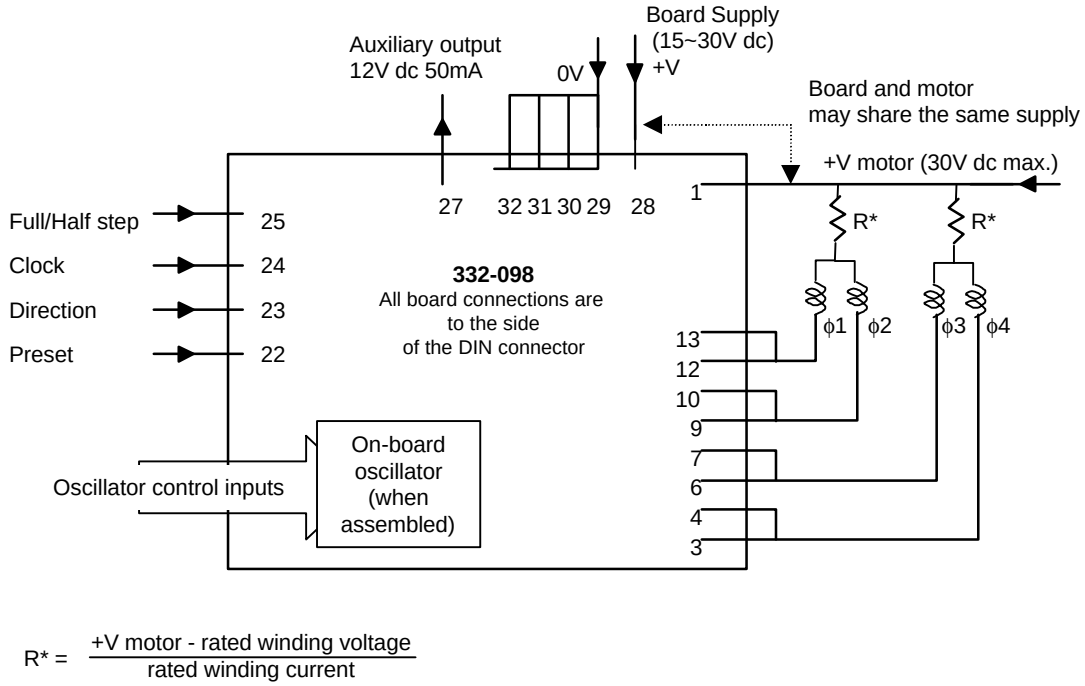

Fig.3-2: Unipolar stepper motor drive board connections.

If the power supply voltage is set to 24Vdc then R value for use with the RS motors are given in Table 3-3.

Motor	Rated current (A)	Rated winding voltage (V)	R (Ω)	Power dissipation through R (W)
332-082 440-442	1	5	19	19

Table 3-3: The adequate value of R

b) Electric connection to the peripheral devices

The wiring of motors, motor drivers, and main board is shown in Fig.3-3.

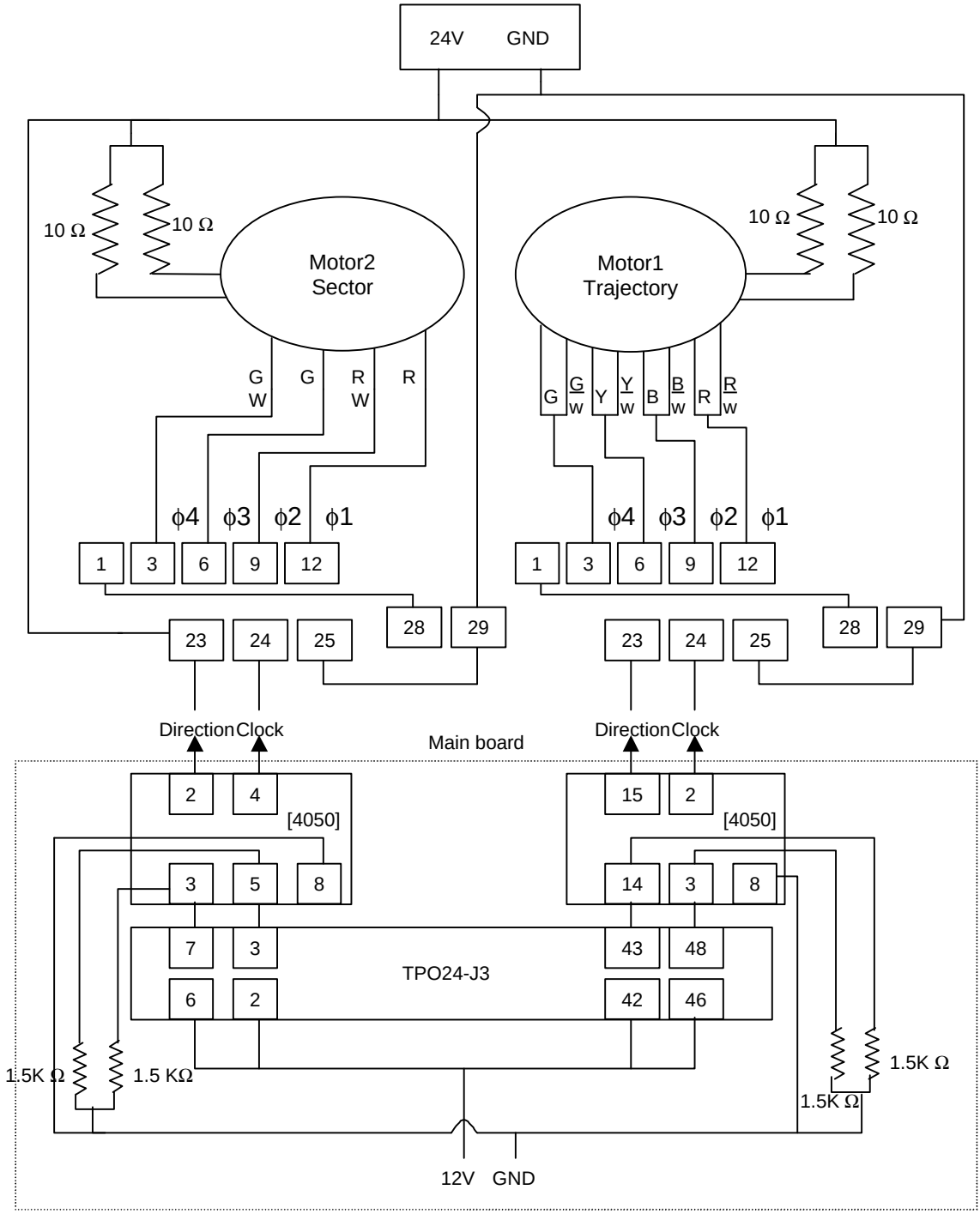

Fig.3-3: The electric circuit of motors, motor drivers, power supply.

c) Current settings

- Power supply : 15V
- Full/half step : Half (by connecting pin 25 to pin 29 (GND).)
- Preset : Not using

3.1.3 Gearbox

The motors have the smallest step angle of all the others that have been found so far. However, it is not accurate enough to drive the sprinkler head and near the limit of their holding torque.
to take into account of the speed, the smallest gearbox, Multipurpose Gearbox (4Nm)-Ratio 5:1 (RS stock No.718-852) was chosen. The features are shown in Table.3-4.

Gear ratio	Output speed using 250 rpm synchronous motor	Number of steps/rev	Rotate direction with respect to input	Max. output Torque
5:1	50rpm	1000	Opposite	1.5Nm

Table 3-4: The main features of the gearbox

3.2 *Field controller unit*

3.2.1 Introduction to the embedded computer

In this study, a PC/104 computer and two PC/104 I/O boards that are provided by DSP design were used. PC/104 cards are much smaller than ISA-bus cards found in PC's and stack together, which eliminates the need for a motherboard, backplane, and/or card cage. Power requirements and signal drive are reduced to meet the needs of an embedded system because PC/104 is essentially a PC with a different form factor, most of the program development tools used for a DOS PC can be used for a PC/104 system.
The three following sections show what features each part of the controller has and what their functions are for this sprinkler system.

3.2.2 TB486 PC/104 Tareget card PC compatible computer

The TB486 is a single board PC/104 compatible computer that can operate as a stand-alone module or can be used in a system consisting of a number of other PC/104 modules that runs ms DOS.

a) Features

- High integration processor: a 66MHz AMD Elan SC410 is fitted.
- PC/104 V2.3 16-bit bus interface for wide compatibility.
- Floppy and IDE disk controllers.
- Three RS232 serial ports – COM2 is user-configurable as RS-485.
- Up to 64M bytes of DRAM is supported.
- A 512 byte size serial EEPROM is provided to retain set-up parameter in the absence of an external battery.

b) Stand alone operation

- Power supply

+5V is required by using the power connector J4.

- Reset

By issuing a low going pulse on the /RESET line of J3.

c) Current settings

- Memory

A 4 M bytes DRAM is attached to the socket on this card.

- Clock

The CPU runs at 33MHz, which can be set higher up to 100MHz.

d) Current consumption

4 M bytes DRAM = 657 mA.
Mode 33MHz = 208 mA. (when Graphics and Ethernet are off.)
Serial ports = 4 mA.

Total Power Consumption = 869 (mA)

3.2.3 TP406 PC/104 Digital I/O Counter/Timer board

The TP406 provides a range of parallel I/O and counter/timer functions for use with PC/104 bus based systems.
The parallel I/O functions are provided by two uPD71055 chips which are equivalent to the Intel 8255 chips.
The counters/timers functions are provided by uPD71054 chips. These are equivalent to the Intel 8254 chip. The CLK, GATE, and OUT pins are all made available to the user. Further information should be referred to Technical reference manual of TP406 from DSP Design.

a) Features

- 40 lines of parallel I/O.
- 24mA current source/sink capability.
- Pull-up resister on most I/O pins.
- Six counter/timers channels with flexible connection options.
- I/O mapped – address jumper selectable.
- Option to interrupt processor.
- Single +5V power supply. Very low power operation possible.

b) Current settings

- Base Address – Jumper Area E5

Base Address is 0x210, which gives a binary number 00100001 (corresponding to A11 to A4).
So Jumper Area E5 is set as shown below:
[A1-B1 C1], [A2 B2-C2], [A3 B3-C3], [A4 B4-C4]
[A5 B5-C5], [A6-B6 C6], [A7 B7-C7], [A8 B8-C8]

c) Parallel I/O

Individual addresses are described in Table 3-5.

Offset	Chip	Register
0	71055 No.1	Port A Data register
1	71055 No.1	Port B Data register
2	71055 No.1	Port C Data register
3	71055 No.1	Command register
4	71055 No.2	Port A Data register
5	71055 No.2	Port B Data register
6	71055 No.2	Port C Data register
7	71055 No.2	Command register

Table 3-5: TP406 address map for parallel I/O

Three micro switches are connected to this parallel port with such a pin assignment as shown in Table 3-6.

PIN	Signal	Usage	PIN	Signal	Usage
1	0V		2	0V	
3	PA0	NC	4	PA1	Motor position micro switch 1
5	PA2	NC	6	PA2	Motor position micro switch 2
7	PA4	NC	8	PA	NC
9	PA6	NC	10	PA	NC
11	0v	NC	12	PE3	NC
13	PB0	NC	14	PB1	Wheel micro switch
15	PB2	NC	16	PB3	NC
17	PB4	NC	18	PB5	NC
19	PB6	NC	20	PB7	NC
21	0v	NC	22	PE2	NC
23	PC0	NC	24	PC1	NC
25	PC2	NC	26	PC3	NC
27	PC4	NC	28	PC5	NC
29	PC6	NC	30	PC7	NC
31	0v	NC	32	PE1	NC
33	PD0	NC	34	PD1	NC
35	PD2	NC	36	PD3	NC
37	PD4	NC	38	PD5	NC
39	PD6	NC	40	PD7	NC
41	0v	NC	42	PD0	NC
43	PE4	NC	44	PE7	NC
45	PE5	NC	46	PE6	NC
47	-12V	NC	48	+12V	NC
49	+5V	NC	50	+5V	NC

Table 3-6: Pin assignments of Digital I/O on TP406.

- Current Setting

[Buffer command word] = 0x0F.

[Port A, Port B, Port C, Port D, Port E] = [IN, IN, OUT, OUT, OUT]

So,

[Command word] = 0x00.

- Operation

When the micro switch is on, input signal turns to be 1.

A test program of the parallel I/O is given as TP406.c in the attached CD.

d) Counters/Timers

26-ways Counter/Timer connector is J5 whose register assignments are shown in Table 3-7. Further, the next table gives the current connection to peripheral devices.

Assignment	Offset	Chip	Register
Timer for reading data	8	71054 No.1	Counter 0 register
Anemometer(Wind speed)	C	71054 No.2	Counter 0 register
Wind vane(Wind Direction)	D	71054 No.2	Counter 1 register
Pressure Transducer	E	71054 No.2	Counter 2 register
Set control word in chip No.1	B	71054 No.1	Control word register
Set control word in chip No.2	F	71054 No.2	Control word register

Table 3-7: Register assignment of Counters/Timers on TP406.

- Current settings

[Jumper Area E1]

This jumper area allows a buffered version of the PC/104 clock signals (called BCLK) to drive the CLK inputs of the uPD71054 counter/timer chip No.1.

Set [A1-B1], [A2-B2], [A3-B3] for the function as a timer in programs.

[Jumper Area E4] - No shorts.

[Operating Mode]

Chip No.1 : Mode 4

Chip No.2 : Mode 0

[Pin assignment]

PIN	SIGNAL	USAGE	PIN	SIGNAL	USAGE	CHIP/ CHANNEL
1	GND		2	CLK0	Timer for reading data	No.1 Chan.0
3	GATE0		4	OUT0		
5	GND		6	CLK1		No.1 Chan.1
7	GATE1		8	OUT1		
9	GND		10	CLK2		No.1 Chan.0
11	GATE2		12	OUT2		
13	GND		14	CLK0		No.2 Chan.0
15	GATE0	5V	16	OUT0	Wind speed	
17	GND		18	CLK1		No.2 Chan.1
19	GATE1	5V	20	OUT1	Wind Vane	
21	GND		22	CLK2		No.2 Chan.2
23	GATE2	5V	24	OUT2	Pressure	
25	BCLK		26	Vcc	Input to GATE	

Table 3-8: Pin assignments of Counters/Timers on TPO24.

3.2.4 TPO24 PC/104 OPT-Isolated Digital I/O board

The TPO24 provides 12 lines each of opto-isolated digital inputs and outputs for use with PC/104 bus based systems. TPO24 is intended to provide a level of opto-isolations in low voltage systems.

The parallel I/O functions are provided by a uPD71055 chip which is equivalent to the Intel 8255 chip. 12 of the pins of the uPD71055 are buffered and drive the opto-isolated outputs, and other 12 pins receive inputs from the opto-isolated inputs.

a) Features

- 12 lines of opto-isolated outputs.
- 160mA current source/sink capability on each output.
- 12 lines of opto-isolated inputs.
- All inputs and outputs are isolated from each other.
- I/O mapped – address jumper selectable.
- Single +5V power supply. Very low power operation possible.

[Register assignment]

OFFSET	REGISTER
0	Port A Data register
1	Port B Data register
2	Port C Data register
3	Command register

Table 3-9: Offset addresses of registers on TPO24.

b) Current settings

- Base Address – Jumper Area E1

Base Address is 0x220, which gives a binary number 01001000 (corresponding to A9 to A2).

So Jumper Area E1 is set as shown below:

[A1 B1-C1], [A2 B2-C2], [A3 B3-C3], [A4-B4 C4]

[A5 B5-C5], [A6 B6-C6], [A7-B7 C7], [A8-B8 C8]

- Operating Mode, Control Word

'Mode0' is set.

Port A, higher half of Port C are set as output and the other ports as input.

Since,

[Control Word] = 0x03

[Pin assignment]

PIN	SIGNAL	USAGE	PIN	SIGNAL	USAGE
1	PPA0		2	PPA0	12V
3	PA0	Motor1 clock signal	4	PA0	
5	PPA1		6	PPA1	12V
7	PA1	Motor1 rotate direction	8	PA1	
9	PPA2		10	PPA2	
11	PA2		12	PA2	
13	PPA3		14	PPA3	
15	PA3		16	PA3	
17	PPA4		18	PPA4	
19	PA4		20	PA4	
21	PPA5		22	PPA5	12V
23	PA5	Chemigation pump	24	PA5	
25	PPA6		26	PPA6	12V
27	PA6	Solenoid valve	28	PA6	
29	PPA7		30	PPA7	
31	PA7		32	PA7	
33	PPC4		34	PPC4	
35	PC4		36	PC4	
37	PPC5		38	PPC5	
39	PC5		40	PC5	
41	PPC6		42	PPC6	12V
43	PC6	Motor2 clock signal	44	PC6	
45	PPC7		46	PPC7	12V
47	PC7	Motor2 rotate direction	48	PC7	
49	N/C		50	N/C	

Table 3-10: Pin assignment of Digital I/O on TPO24.

c) Current consumption

[Max. Power Consumption] = 55 mA
when all output Opto-isolators on.

You can test I/O port by test24op.c and the board called TEST BOARD-OPT24.

3.3 *Sensors*

3.3.1 Wind vane

To know the wind direction applied for the control models , a precision potentiometer wind vane with corrosion resistance case provided by Vector Instruments Inc. was used. The main specifications of the wind vane is described as Table 3-11.

[Performance]	
Maximum wind speed	over 75 m/s (150 Kts, 170 mpf).
Threshold	0.6 m/s
Response	Distance constant: 2.3 m
	Damping ratio: 0.2
Range	360 mechanical angle, full circle continuous rotation allowed.
[Electrical]	
Wiper current	20mA max.
Supply voltage	20V max.
Electrical variation angle Resolution	356.5° ± 1.5° (3.5° deadband). ±0.2°

Table 3-11: Main specifications of Wind Vane.

The output is analog. So, a FVC654 was used to convert the analog voltage into frequency to be able to be fed into a counter channel.

The electric circuit to connect the wind vane to the computer is designed as Fig.3-4, and Fig.3-5.

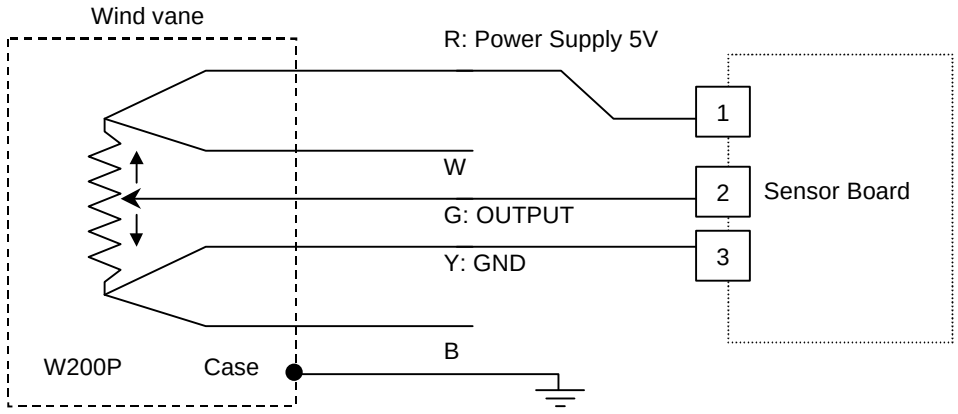

Fig.3-4: The connection of the wind vane between the sensor and the sensor board.

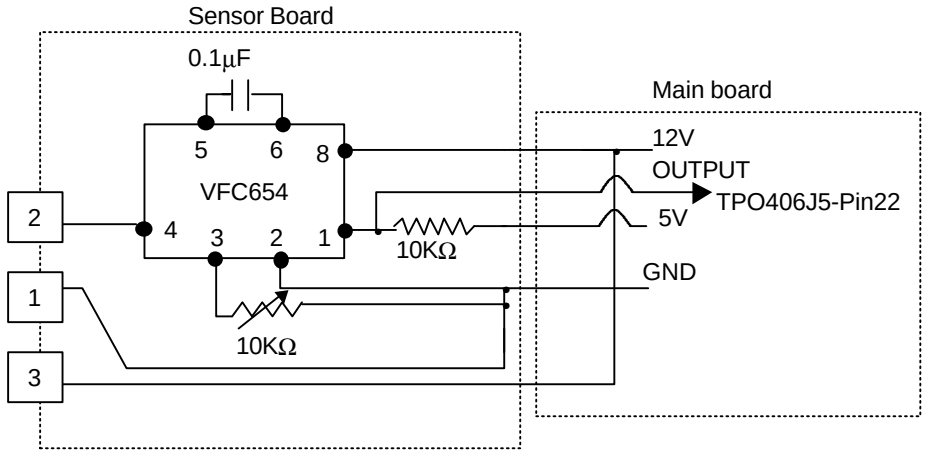

Fig.3-5: The connection of the wind vane between the sensor board and the main board.

The equation to show the real value is sought as below.

The output frequency of FVC654 is 500 at 358.25 degrees and the potentiometer is linear.

Since,

$$[Wind\ Direction] = 360 - (356.5 \times Frequency / 500 + 1.75) \quad (3.1)$$

3.3.2 Anemometer

To decide the orientation of the sprinkler nozzle, wind speed should be known. PULSE OUTPUT AMEMOMETER A101M provided by Vector Instruments Inc. was used. The main specifications are described as the following Table 3-12.

Performance]	
Non-linearity	0.7% (10-55m/s speed range).
Distance constant	5m (R30 rotor).
Calibration	10Hz per m/s 2%
Resolution	10cm
[Electrical]	
Operating conditions: LED:	
Forward current	10mA min.
Opto-Schmitt photo sensor IC: Supply Voltage, Vcc Output voltage, Vo Schmitt hysteresis Total Current (LED + IC) Cable	 4.5V min., 16V max. 0.4V max, output 'low' Vcc, output 'high' 30% max., 10% min. 18mA typ., 30mA max. 6core, 7/0.2mm, 3 meters long.

Table 3-12: Main specifications of the anemometer.

Then, the electric circuit to connect wind vane to the computer is designed as Fig.3-6.

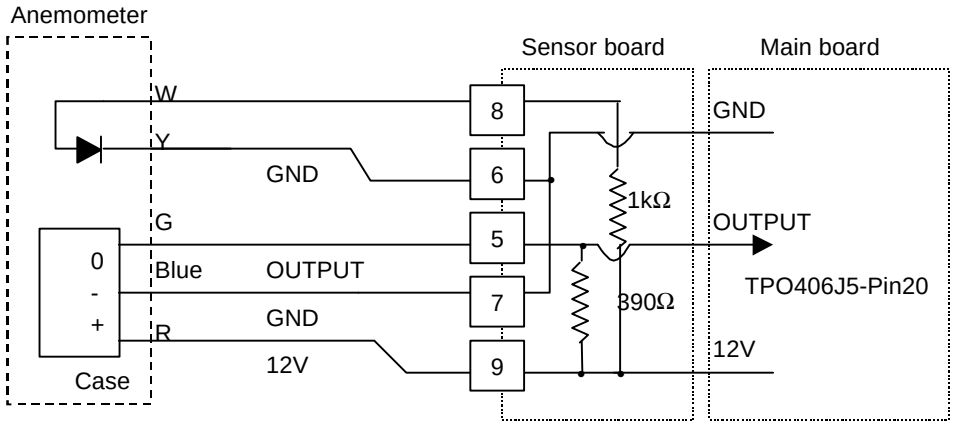

Fig.3-6: The connection between the anemometer and the main board.

The equation to describe the real value is shown as below.

From the above data sheet,

$$[\text{Wind Speed (m/s)}] = 0.1 \times [\text{Output Frequency}] \quad (3.2)$$

3.3.3 Pressure Transducer

A pressure transducer, MODEL SA 100PSIA from Data Instruments Inc., was installed in order to know the characteristics of the water distribution. The detail features are described as the following table.

[Range]	0-13.8 bar, 0-100psi

[Electrical]	
Span	5±0.1 Vdc at 77°F (25°C)
Excitation Voltage	9 to 20 Vdc
Null Offset	1.0±0.20 Vdc at 77°F (25°C)
Output Current	15mA

Table 3-13: the features of the pressure transducer, MODEL DA 100PSIA.

Electric circuit:

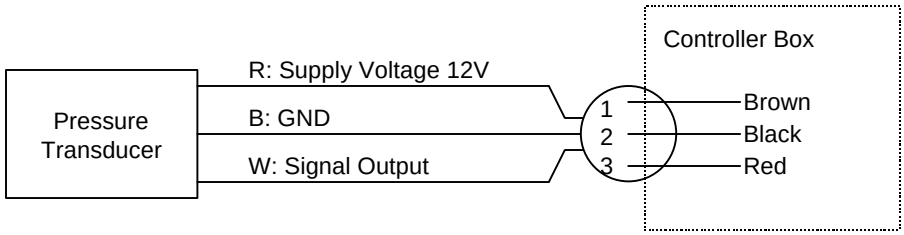

Fig.3-7: The connection between the pressure transducer and the controller box.

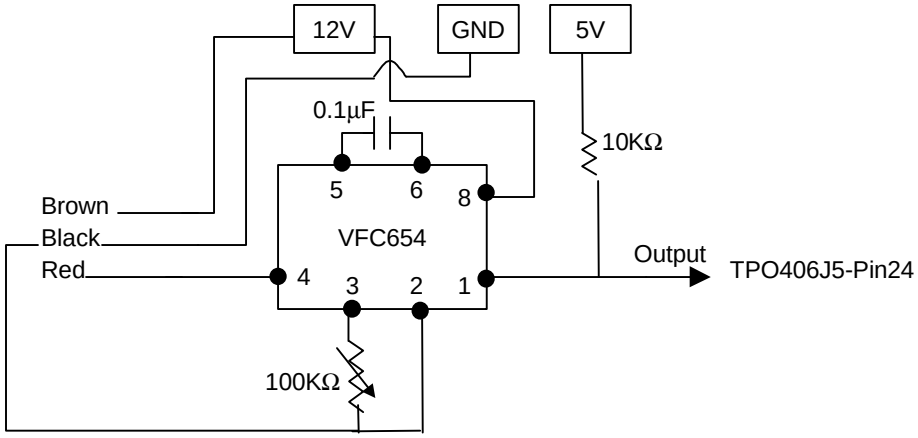

Fig.3-8: The electric connection in the controller box.

The equation to give the real value is found as below.

Using a pressure meter, the relationship of frequency output to input pressure is found as shown in Fig.3-9.

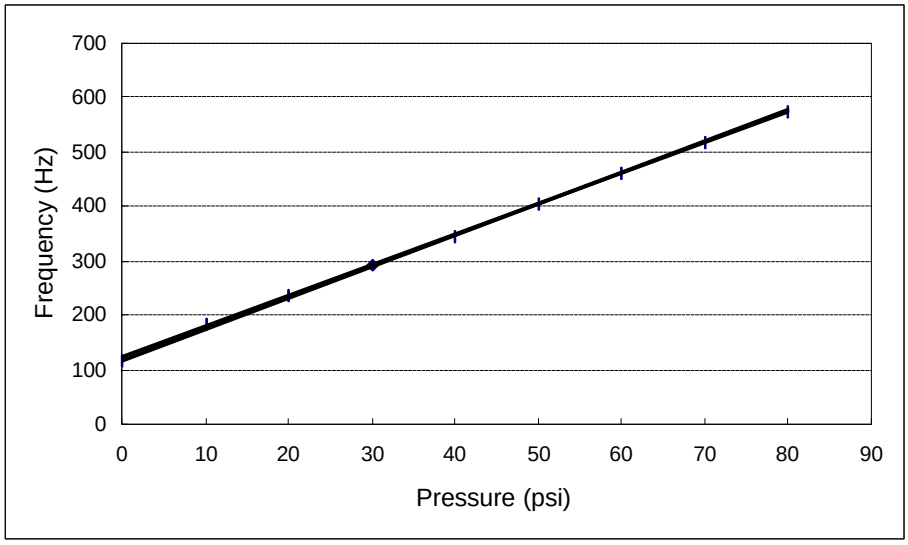

Fig.3-9: The calibration of the output frequency to the output voltage from the pressure transducer.

Since, the equation to show the actual pressure value is

$$Pressure\ (psi) = (Frequency - 117) / 5.7373 \quad (3.3)$$

3.3.4 Motor position micro-switches

Stepping motors are controlled accurately by digital signals and by feedforward control. However, to know the initial position and to consider a possibility that slipping might occur, it needs to confirm the positions of motors sometimes. Single sealed miniature micro switches V3S Series, from Burgess, were used. As shown in Fig.3-10, there is a pin which is set to press the micro-switches at the definite point, 90° from the travelling direction for the sector angle, 27° from the ground for the trajectory angle. The mechanism of this micro-switch is totally enclosed to IP67.

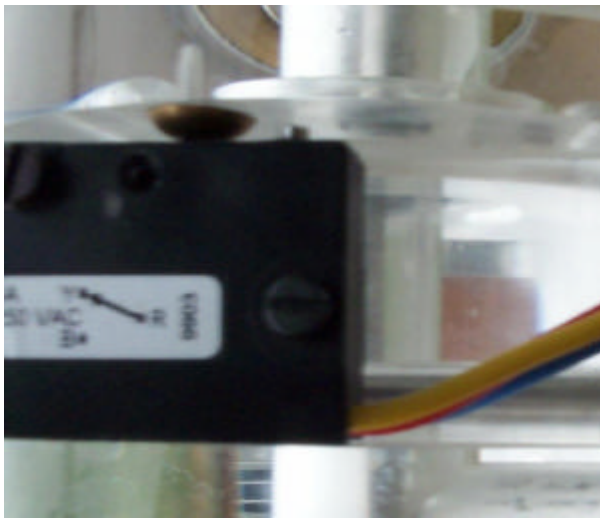

Fig.3-10: Motor rotate position micro switch.

3.3.5 Cut-off Valve

When wind becomes strong, water should not be distributed efficiently. Therefore, the water supply is stopped with dependent on the calculation results of the control model for the trajectory angle. If the resulted angle is below 9 degrees, the valve will be closed. This solenoid valve provided by SIRAI is normally opened as shown in Fig.3-11 and rated by 12V, 0.5A. The electric circuit for it is described in Fig. 3-12.

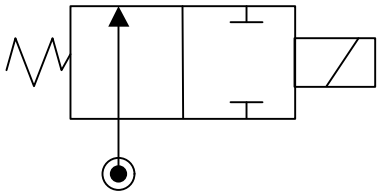

Fig.3-11: The system of the solenoid valve.

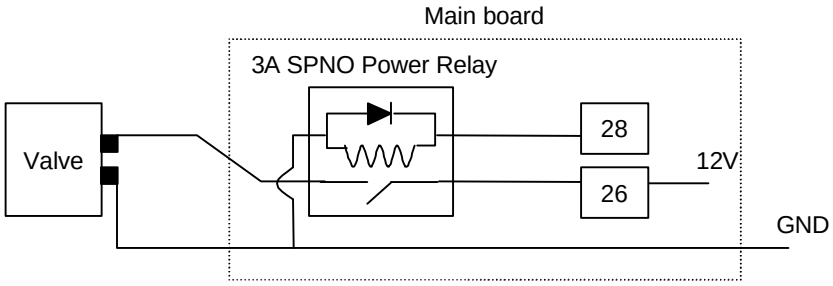

Fig.3-12: The connection between the valve and the Main board.

3.3.6 Chemigation pump

It will be economical and environmentally gentle that a chemigation system is added to the prototype irrigation system because it can eliminate another equipment for chemicals and the chemicals are distributed precisely. A diaphragm pump rated by 12 V, 0.55A is used to inject chemicals into the main flow. However, the back pressure of the main flow is bigger than that of the pump. A suitable pump is recommended in Section 7.2.

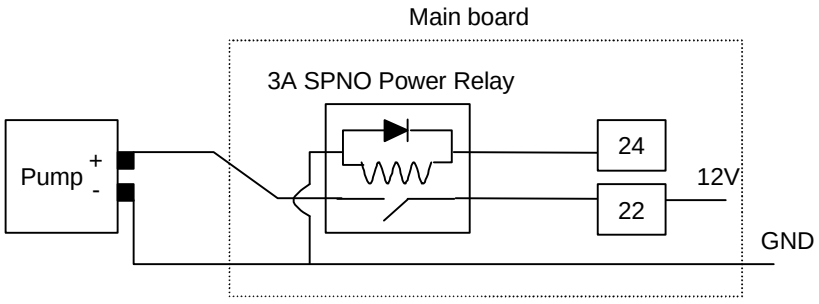

Fig.3-13: The connection between the pump and the Main board.

3.3.7 Environmental protection

There are two boxes, control box and motor driver box as a field unit controller. The boxes are rated IP66.

a) Control box

It includes a main board, a sensor board, PC/104 cards, and a PC connector board.

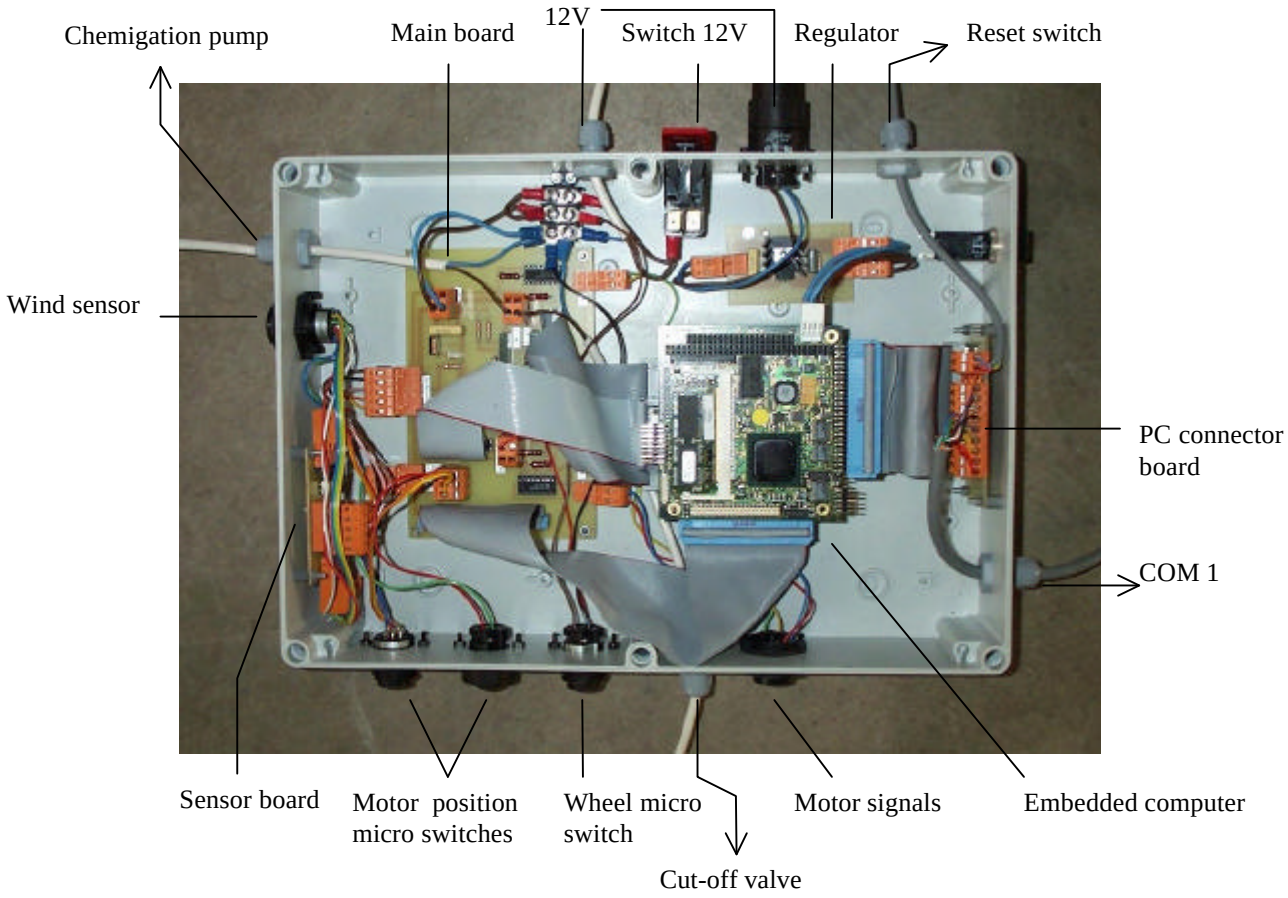

Fig.3-15: Control box

<Main board>

Function:

- Regulate 12V to 5V.
- A connection between the sensor board and J5 (counters/timers) on TP406.
- A connection and buffer between the driver boards in the motor driver box and J3 on TPO24.

- Two relays for the sprinkler valve and the pump which are driven by the signals from J3 on TPO24.
- A connection between micro switches and J3 (parallel I/O) on TP406.

Electric circuit:

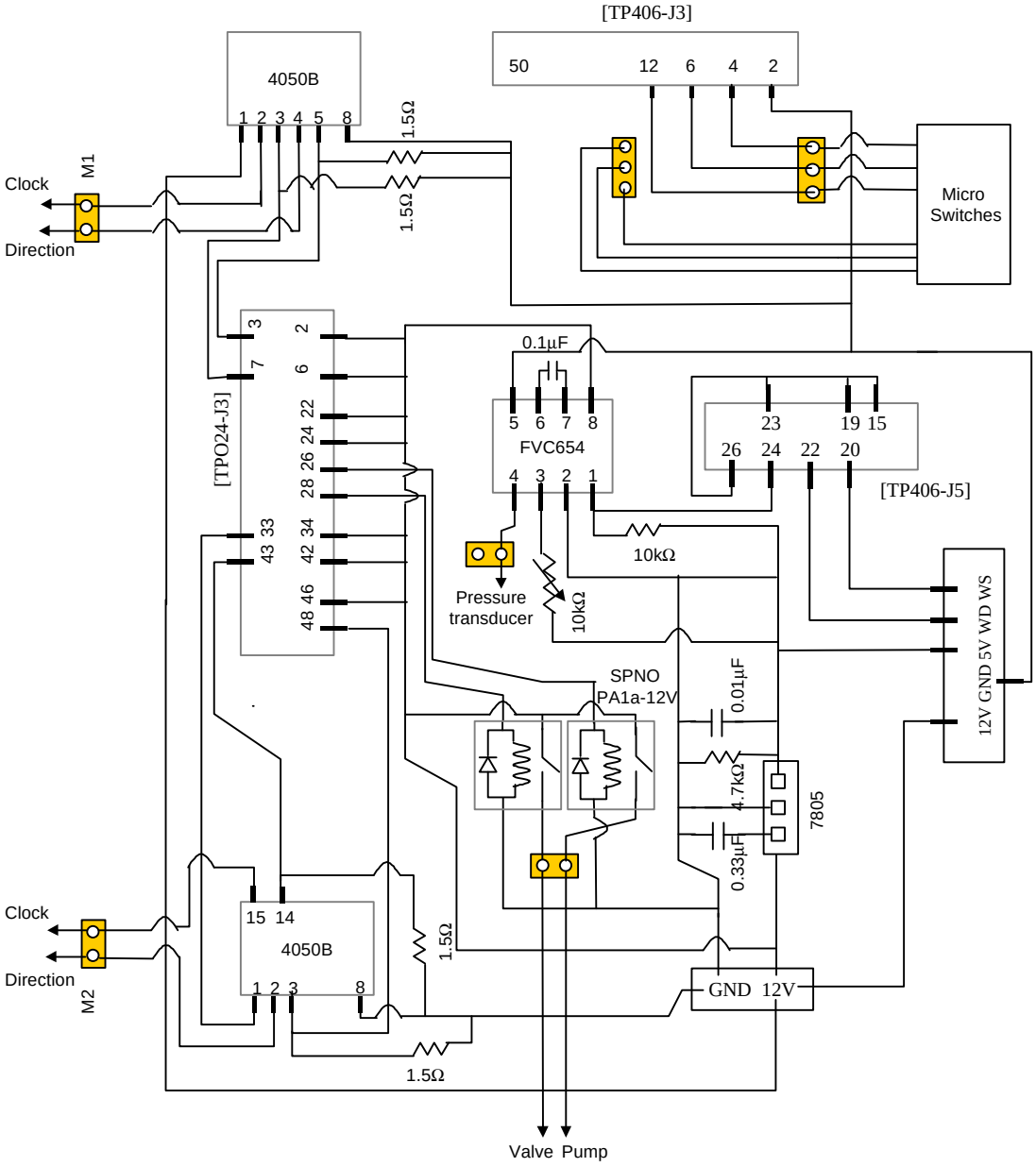

Fig.3-15: The electric circuit of the Main board.

<Sensor board>

Functions:

- A connection between the anemometer, the wind vane and the main board.
- Convert the output voltage from the wind vane into frequency by VFC654

Electric circuit:

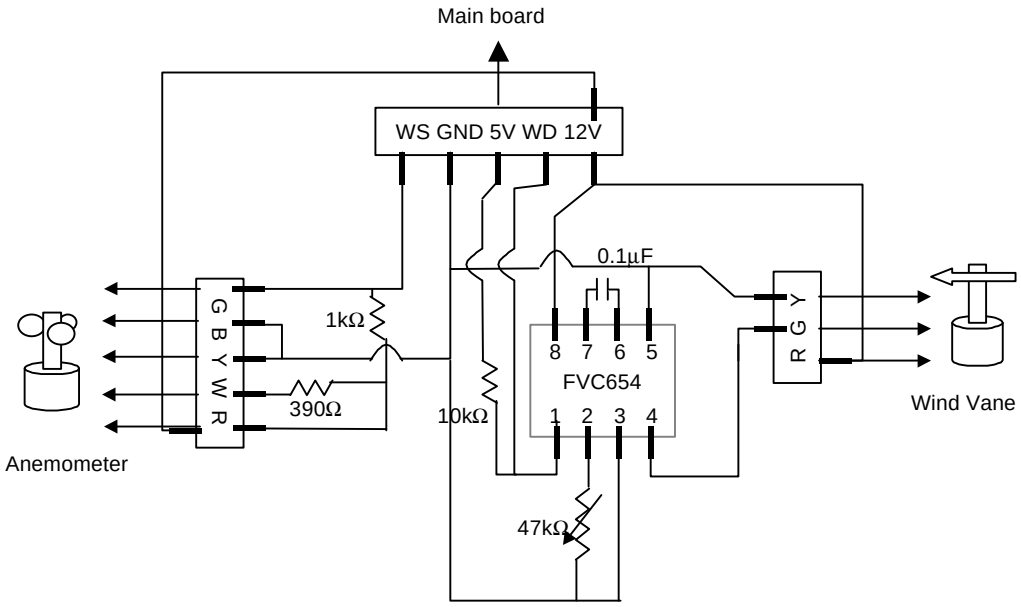

Fig.3-16: The electric circuit of the sensor board.

<PC connector board>

To transfer the data, Wind Speed, Wind Direction, Pressure, Travelling Distance, Trajectory and Sector angle, COM1 is connected to an external computer to save them.

Function:

- To adjust the connector of PC/104 to PC as shown below.

Electric circuit:

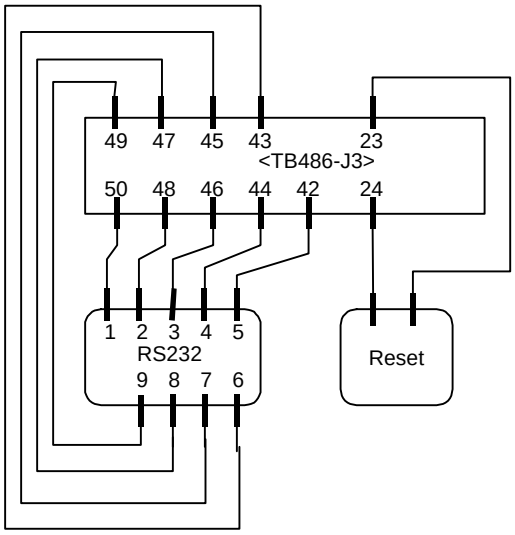

Fig.3-17: The electric circuit of the PC connector board.

b) Motor driver box

It includes two motor driver boards, 4-Phase Unipolar Stepper Motor Drive Board 332-098 (from RS) whose details are described in 3.1.2 and a regulator board which converts 24V to 15V.

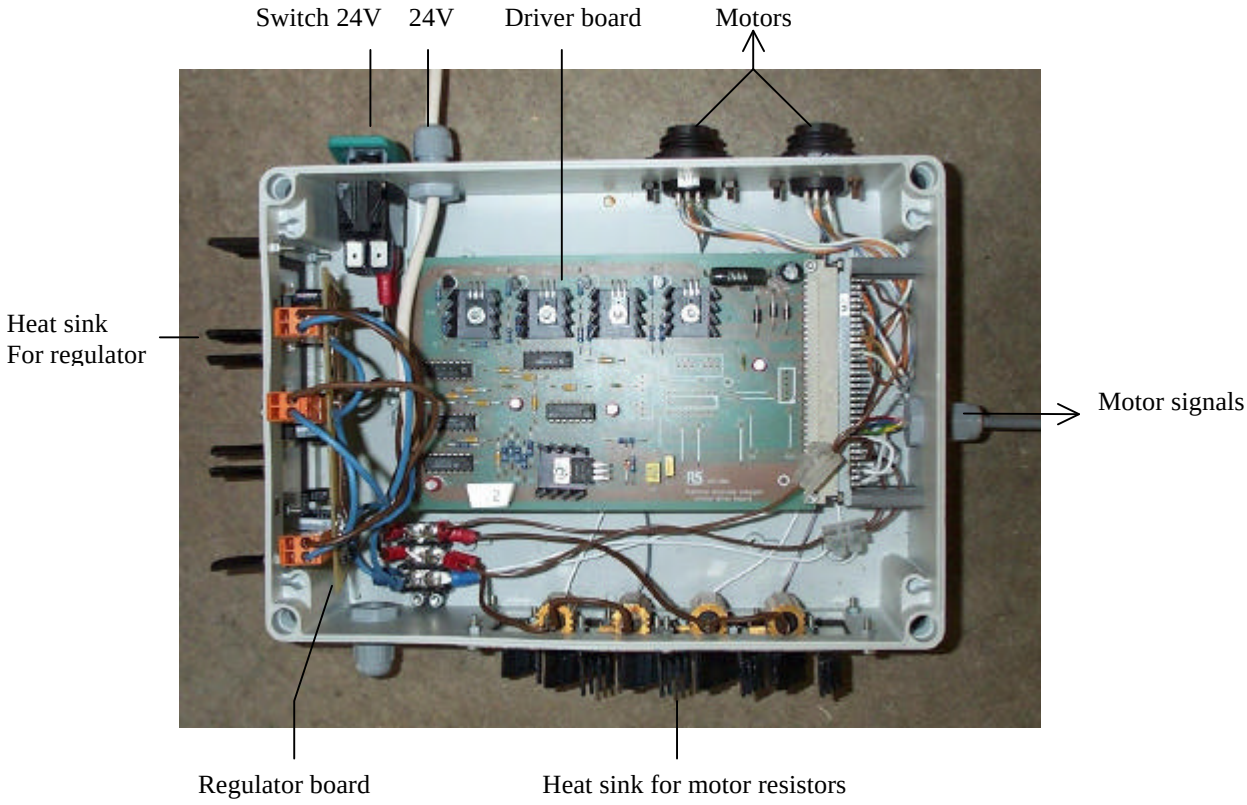

Fig.3-18: Driver board

<Motor drivers>

All of the details are referred to Section 3.2.1.

<Regulator board>

Function:

- The input voltage 24V is regulated to be 15V fed into motor drivers and motors.

Electric circuit:

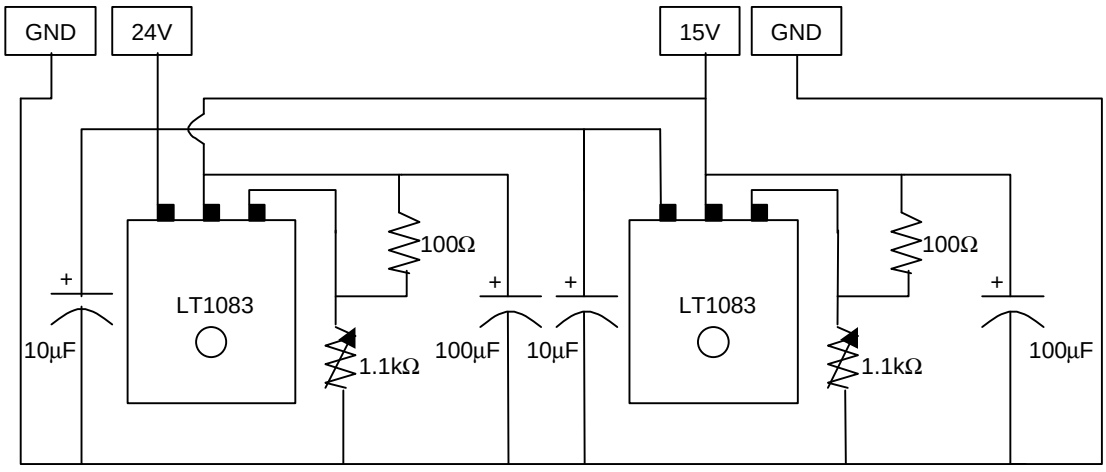

Fig.3-19: The electric circuit of the regulator board.

- Heat sink:

Three heat sinks are set on the opposite of the regulators between which an aluminum plate is installed instead of the plastic one. Fig. 3-19 shows the features.

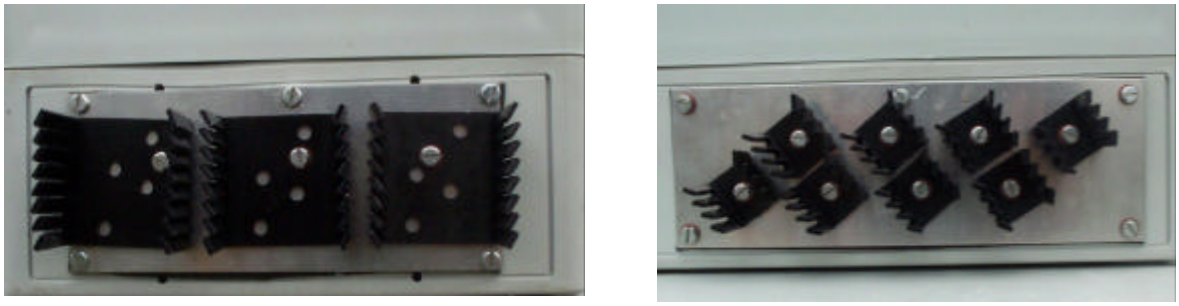

Fig.3-20: Heat sinks for regulators (right) and motor resistors (left).

3.4 *Position*

3.4.1 Dead reckoning

To count the pumping cycles of the hydraulic motor in order to know the position of the sprinkler, a micro switch is set to attach to the lever of the sprinkler wheel as shown in Fig.3-30. This micro switch is Single sealed miniature micro switch V3SYR Series from Burgess. The mechanism of this micro-switch is totally enclosed to IP67. The equation of travelling distance is,

$$[\textit{Travelling distance}] = [\textit{Counted value}] * 0.07 \text{ (m)} \quad (3.4)$$

Fig.3-21: Wheel micro switch

3.4.2 DGPS

DGPS stands for Differential GPS which allows users to obtain increased accuracy from the GPS system. In some projects, DGPS has been tried applying to Agricultural machinery so far.
Thereby, incorporating DGPS to this system which is redesigned to be larger in an actual huge field, it must be useful in order to know the global position of the sprinkler. Further, by comparing the dead reckoning data with that of DGPS, this positioning system will become more reliable. An example of DGPS is shown below.

Leica Inc. MX 9400N