Università degli Studi di Genova
Scuola Politecnica
Dipartimento di Meccanica e Costruzione delle Macchine

Disarmadillo: a small, low-cost demining robot.
Remote control improvement.

Candidato: Edoardo Del Bianco

Relatori: Emanuela Elisa Cepolina, Matteo Zoppi

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Contents

1 Few words about landmines

1.1 What landmines are

According to the Anti-Personnel Mine Ban Convention (also known as Ottawa Treaty) dated December 1997 [7]:

"Mine" means a munition designed to be placed under, on or near the ground or other surface area and to be exploded by the presence, proximity or contact of a person or a vehicle.

Landmines are used to deny access to a specific and strategic area, causing death or injury of people who try to cross it. They are simple and low cost, but their localization and removal is time and money consuming. They have been largely used, during the last 50 years, by many armed groups in guerilla-type conflicts.

The biggest problem about this war instrument and the main reason behind its ban through the Ottawa treaty is that landmines cannot be directed toward the enemy: they indiscriminately kill or injure soldiers, civilians, peacekeepers, workers or animals who accidentaly activate them.

The Treaty defines the difference between Anti Personnel (AP) and Anti Tank (AT) landmines:

"Anti-personnel mine" means a mine designed to be exploded by the presence, proximity or contact of a person and that will incapacitate, injure or kill one or more persons. Mines designed to be detonated by the presence, proximity or contact of a vehicle as opposed to a person, that are equipped with anti handling devices, are not considered anti personnel mines as a result of being so equipped.

As a result:

- Anti Tank (AT) landmines are designed to detonate when a vehicle drives over them: they ate activated by high force (major than 100kg), magnetic influence or remote control. They contain from 5kg to 10 kg of explosive charge so they are quite big. AT landmines are usually located in unsealed roads or potholes.
- Anti Personnel (AP) landmines are designed to detonate in presence, contact or proximity of a person: they are activated by low force (from 3kg to 20kg) directly exerted on them or by pulling tripwires. They contain from 80g to 500g of explosive charge, therefore they are small (from 7cm to 15cm of diameter). AP landmines are usually buried into or just laid on the ground.

There are more than 700 known types of AP landmines; each of them belongs to one of the two following categories:

- Fragmentation mines, which propel metal fragments out at a high velocity to a radius up to 100m and are actuated by tripwires.
- Blast mines, which destroy the foot and the leg of a person that walks over them.

1.2 The current landmine problem and Snail Aid approach

An up to date report on landmine contamination and demining efforts around the world is provided by the International Campaign to Ban Landmines [8]. They report:

- Every year approximately 4000 people get injured or killed.
- Approximately 60 countries are contaminated by landmines.
- Landmines deprive families and communities of land that could be used for agriculture.
- 36 countries haven't signed the Ottawa Treaty. Stockpiles of landmines are kept in China, Russia, United States, India, Pakistan, whereas some countries still produce them (including India, Myanmar, Pakistan, and South Korea).
- Landmines are still used. For example, Myanmar/Burma government has persistently continued laying landmines over the years. Libya (under Gheddafi) and Syria used landmines during recent conflicts.

There are many Private Voluntary Organizations (PVOs) currently working on the problem on different sides:

- Inviting all the states to join the Treaty and destroy their stockpiles.
- Helping in clearing the soil from landmines.
- Assisting victims of landmines and educating people to avoid access to mine areas.

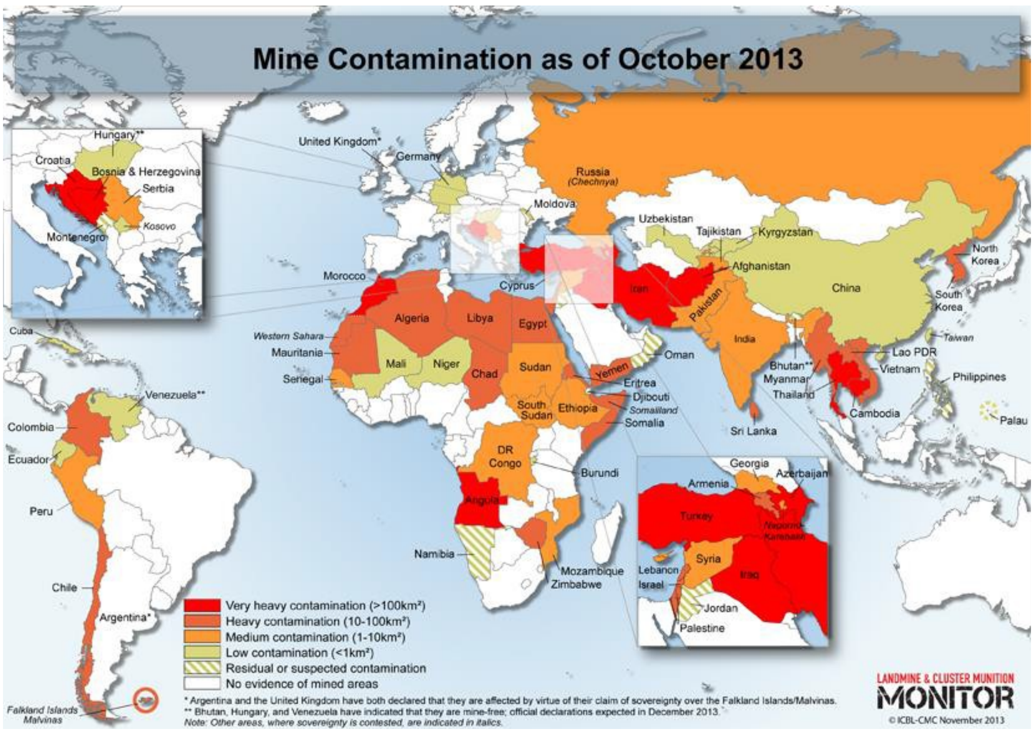

Fig. 1.2 1: The mine contamination as of October 2013, provided by ICBL.

Another complete view of the situation is provided by [4]. The most significant aspects are reported below.

With the exception of cases of items of Explosive Remnants of War (ERW) left over from the World Wars in Europe, the problem of landmines and ERW occurs exclusively in developing countries, where 85% of conflicts since the end of the Second World War have taken place and keep on proliferating.

As research and development facilities in developing countries are usually scarce or non existent, technical solutions for landmine clearance come from Western countries, where research is either carried out in academic institutions or private companies selling demining equipment.

As a result, these kinds of technologies generally belong to one of two types: complex, high-tech types, whose justification and funding come from the need to produce high level state of the art research or simple to use but very expensive types, produced by commercial companies that sell in a very small market without enough competition. Sometimes, technologies are also developed locally, by Non Governmental Organizations (NGOs) who have good field facilities and technicians able to adapt existing technologies such as construction machines to the demining purpose.

In all cases, technologies for humanitarian demining are not designed together with local communities who might contribute consistently to the achievement of a good result with their first hand experience of the problem.

Local communities could also gain useful skills that can be used later on for upgrading old technologies and starting their own innovation process.

Indeed, economic and human development would require that technical capacities suffuse the entire society, from the bottom up. In any developing countries, home-grown technologies would be needed to satisfy local needs in areas ranging from energy production and use, construction, natural hazards mitigation, disease control and agricultural production as well as humanitarian demining.

Therefore, a new methodology to design technology in a participatory way together with local end-users has been conceived by Snail Aid - Technology for Development (Snail Aid) and used to design several tools for mine action.

Fig. 1.2 2: The Snail Aid official logo.

Snail Aid - Technology for Development [13] is a no profit social enterprise researching and implementing technologies for sustainable development, both in Italy and abroad, especially in developing countries.

For what concerns machines, Snail Aid has been working at developing low cost technology using local resources, adapting already available agricultural technology to demining tasks pursuing the idea that leveraging mature technology would allow the exploitation of local knowledge already acquired through decades of use. Moreover, skills acquired in modifications of agricultural technologies to demining applications, could be used later on to increase agricultural production. Technological innovation in the field of agriculture is one of the major contributors to development.

The participatory approach used empowers local communities by increasing their technical knowledge while making use of their own experience and skills.

Using this approach, Snail Aid helped developing together with other key partners (i.e. the University of Genova) two demining machines: LOCOSTRA and Disarmadillo.

Fig. 1.2 3: The LOCOSTRA demining machine

LOCOSTRA [10] is a big, low cost tractor at the moment under development within the context of the TIRAMISU (Toolbox Implementation for Removal of Anti-personnel Mines, Submunitions and UXO) [11] project, funded by the European Commission, of which both Snail Aid and the University of Genova are partners. In the context of TIRAMISU project, Snail Aid is working on a new participatory tool for Mine Risk Education (MRE) called Billy Goat Radio for Mine Risk Education [12].

1.3 Traditional demining processes and machines

Even though most demining machines are usually tested in an open lane specifically prepared for the task, humanitarian demining is usually performed in conditions far from ideal.

In fact, minefields usually:

- are located far from basic infrastructure;
- are occupied by thick vegetation and obstacles that hamper big deminig systems;
- require tools for vegetation removal, and landmines sensing, prodding, digging and manipulating;
- are affected by extreme weather conditions that make difficult the maintenance of any mechanical system.

Demining operations are mostly conducted manually: the tools are hand held vegetation cutters, metal detectors and excavation tools. The Database of Demining Accidents (DDAS) [9] reports that the majority of the accidents occur while digging to uncover a device or while cutting vegetation.

Therefore, the introduction of demining machines to process the ground before conducting manual demining operations slightly reduces the possibility of accidents.

Despite this, after the demining process has been performed by a machine, a follow up ground check process has to be carried out thoroughly in order to release a field as cleared. This process in conducted manually and again involves some risk.

As reported in [17], demining machines are divided into three categories.

- Machines designed to detonate hazards: these machines destroy hazards, reducing or in some cases eliminating the necessity of a follow up clearance.
- Machines designed for ground preparation: these machines remove obstacles and improve the efficiency of demining operations. They can perform: vegetation cutting and clearing, tripwires removal, soil loosening, metal contamination removal, debris removal.
- Machines designed to detect hazards: they use different detection technologies in order to detect mines either physically or with detectors.

Some machines are designed to perform more than one activity, they hence belong to more than one category.

The demining machines can be intrusive, if they perform their purpose inside the minefield, or non intrusive, if they remain outside the minefield. Intrusive machines can be remotely controlled or on board driven.

Fig. 1.3 1: The MineWolf Bagger, a machine for ground preparation.

Fig. 1.3 2: The Bozena 4, a machine designed to detonate hazards.

Regardless the category to whom a machine belongs, a problem common to all the demining machines in current production is the fact that they use a very sophisticated technology, often military derived, which costs much (from 250000USD to 1800000USD). Therefore in many cases demining organizations can not afford to buy one of them and conduct all the operations manually.

In order to overcome this problem, Snail Aid and other demining organizations have begun developing demining machines derived form mature and reliable agricultural technology.

2 Disarmadillo

Disarmadillo is a small and low cost remotely controlled intrusive machine derived from an agricultural powertiller, designed to be used to help manual deminers in areas contaminated by AP mines only.

Disarmadillo is designed to be equipped with different tools, such as tools for exposing mines or vegetation cutting tools. Therefore it can be classified as a machine designed to detect hazards and as a machine for ground preparation.

A key factor in Disarmadillo's effectiveness is the capability of being remotely controlled, making work much safer for manual deminers. In the context of this thesis I have analyzed and improved the Disarmadillo remote control system.

Fig. 2 1: The Disarmadillo official logo

2.1 Demining machines: Disarmadillo

Disarmadillo is the second design iteration of the PAT machine, developed by Snail Aid – Technology for Development in close collaboration with the PMARlab of the University of Genova.

It is a low cost machine built around a power tiller (a small two wheel tractor) designed to be low cost and locally sustainable in developing countries. Its aim is to provide manual deminers a machine to help processing the ground, lifting on soil surface landmines or cutting vegetation, depending on the tool it is equipped with.

Unlike other machines available on the humanitarian demining technology market, Disarmadillo is designed to be a manual deminer companion. With a cost of the same order of magnitude of the one of other deminer appliances such as metal detectors (costing on average 3000USD), Disarmadillo is intended to work close to manual deminers making their job safer and easier.

Except for LOCOSTRA, the majority of demining machines aim to be mine clearance devices, being designed to detonate the biggest possible number of landmines. Although they get near to 100% destruction capacity in test lanes their performance in the field is greatly reduced by environmental and other factors, such as: aged not functioning mines, hard ground, stones and roots.

The fact that in the field, the area processed by demining machines is always rechecked by manual deminers is the main driving idea behind the conceptualization of Disarmadillo and LOCOSTRA, two machines designed to accompany manual deminers.

Disarmadillo and LOCOSTRA are designed not to substitute the people but to integrate their work.

They are designed to somehow lower requirements that allow substantial power saving and improvement of efficiency. Moreover, Commercial Off The Shelf (COTS) components can be used, leading to easier maintenance.

Therefore, Disarmadillo is assisting manual deminers reducing the time and the danger related to their vegetation cutting and ground processing activities.

Disarmadillo is designed to allow end-users to become owners of its core technology; they shall understand the way it has been built, in order to reproduce the machine locally and use it to speed up demining. Snail Aid will lead this integration.

One important aspect of Disarmadillo is the fact that it can be reused. When demining is complete, the tractor can be reconverted to its original agricultural purpose, helping people to overcome the poverty brought by the war.

The design of Disarmadillo answers the following requirements:

- small dimensions and weight (maximum 1.5m * 5m; 1000kg)
- simplicity of use and maintenance
- safety of operation, with a remote control system
- low cost (maximum 10.000€)

Therefore, some constraints are put to Disarmadillo capabilities. In order to work properly, it requires:

- low vegetation
- soft soil (solid cohesion C = 10kPa, angle of internal friction = 30) such as: Sri Lanka, Jordan, Western Sahara
- small, plastic, anti-personnel blast landmines (maximum explosive content of 50g) such as: P4-Mk1, Type72AP, VS-50, Tangan 99, Jony 95.

Fig. 2.1 1: The Type72AP

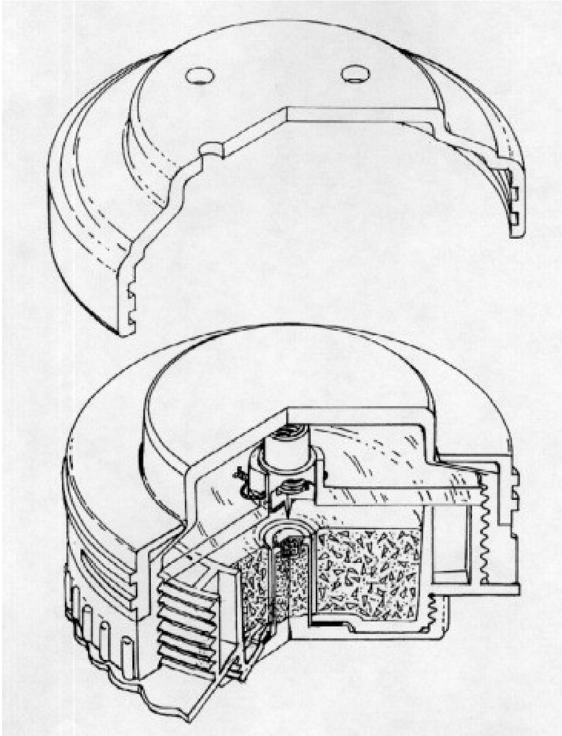

Fig. 2.1 2: The P4-Mk1

Fig. 2.1 3: The VS-50

2.2 Disarmadillo in the past

The consultancy of the Italian patent office pointed out that some of the ideas that inspired the design of Disarmadillo had been patented a long time before the begin of PAT for humanitarian demining project. I will show two significant cases.

The most interesting case is the French patent N° 904.245 dated 1946: "Dispositif et engins pour le déminage des terrains." The inventor was Hervé Mativet. He presented a demining machine similar to a tractor which could change the main demining tool, just as the PAT machine and Disarmadillo can. Among the many demining tools presented by Mativet, we can find a soil smoother very similar to the one developed for the PAT machine and Disarmadillo. The figure below shows the original patent illustration.

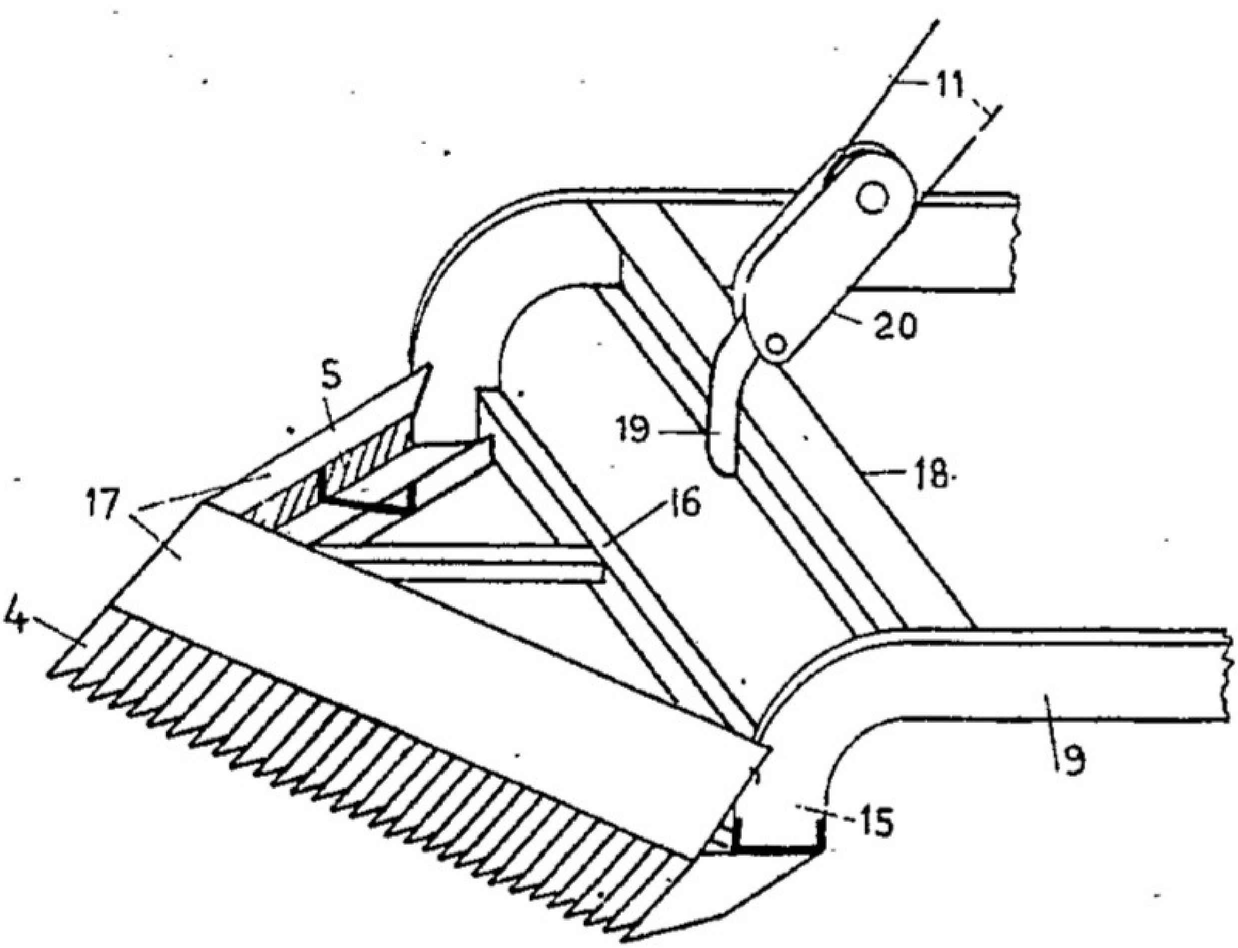

Fig. 2.2 1 French patent N° 904.245, detail of a tool.

As it can be seen, this tool seems just a different version of Disarmadillo ground processing tool. Its design is different in the details, but provides the same functions: the tool lifts the ground while the tractor moves forward. It can be put on the ground and lifted up mechanically (whereas the PAT machine / Disarmadillo version uses a winch) and it is supposed to move the mines to the sides of the tractor.

Fig. 2.2 2: The Disarmadillo ground processing tools immersed into the soil.

Another really important case is the French patent N°1.071.122 dated 1952: “Perfectionnements aux tracteurs pour l'agricolture.” The inventor was Paul Gardette. Gardette presented many improvements to power tillers, and one of them was the modification of the frame for installing tracks.

Despite the substantially different design of the frame, which extends backwards respect to the two wheels of the power tiller whereas the PAT machine / Disarmadillo frame extends frontwards, it is an undeniable fact that the idea of improving traction capabilities of a power tiller with tracks was yet experienced by Gardette.

The existence of these patents denies the PAT machine / Disarmadillo design to be patented, neither now nor in the future. But this is no concern for Snail Aid or the designers of Disarmadillo. In fact, patenting the design of Disarmadillo would be against the inspiration of the Snail Aid design approach: as it was pointed out before, Disarmadillo is designed to allow end users to become owners of its core technology, understanding the way it has been built in order to reproduce the machine locally. As a result, there is no place for patent exploitation. This is an important point that should never be forgotten by those who either support or work on the Disarmadillo project.

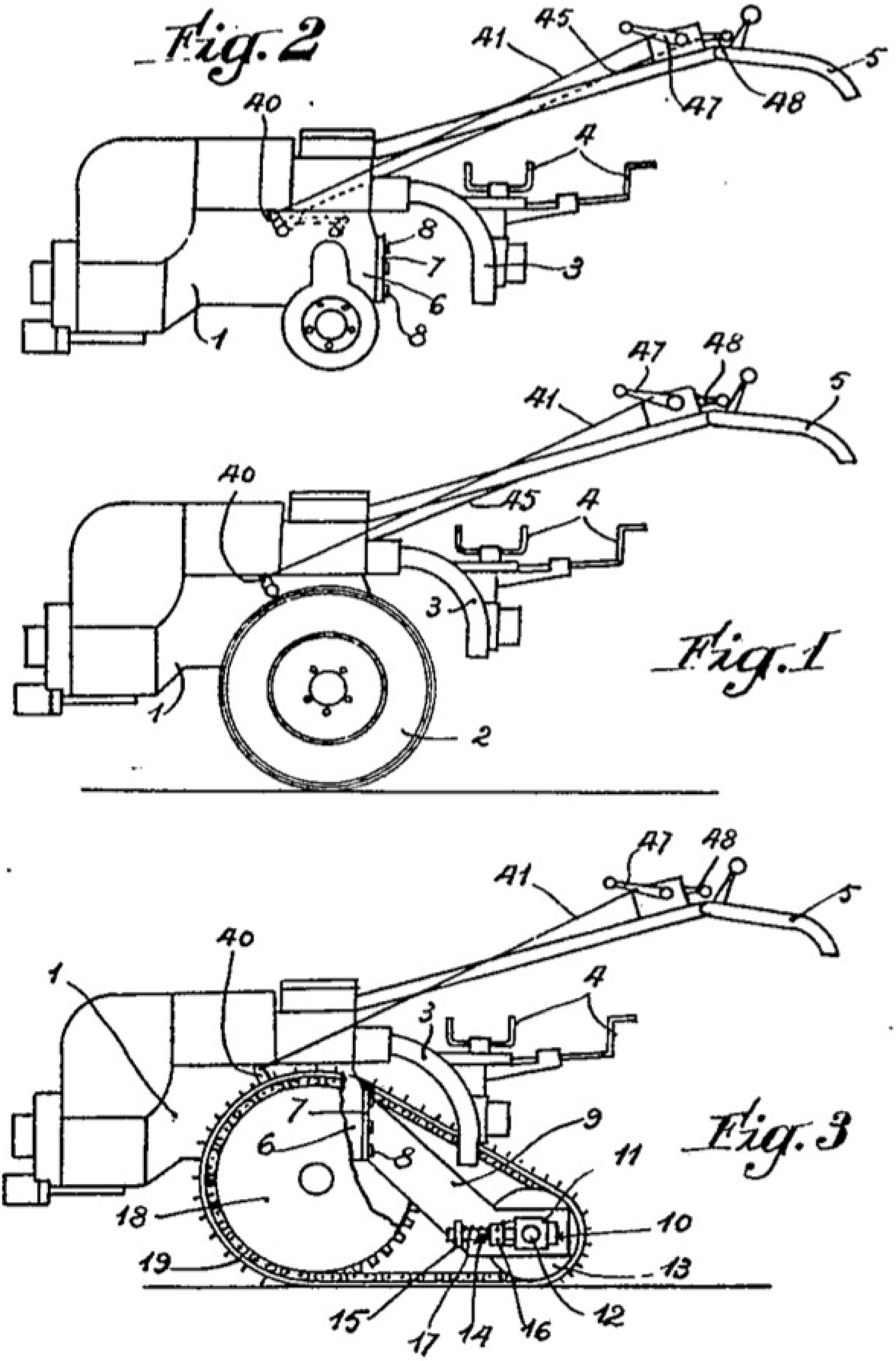

Fig. 2.2 3: French patent N°1.071.122, installation of caterpillars.

2.3 Disarmadillo detailed description

The idea of a designing a compact deminer machine starting from a power tiller was born with the PAT for humanitarian demining machine. The PAT machine was developed by Emanuela Elisa Cepolina in the context of her thesis for the degree of Doctor of Philosophy in the Faculty of Engineering of the University of Genova.

The power tiller used during the PAT machine design was a Pasquali Tipo PL CV10 (built in Italy in1944), which best resembled the type of power tillers currently available in Sri Lanka, country on which the project initially focused.

The PAT machine design has substantially been inherited by Disarmadillo. The main differences in the design of Disarmadillo respect to the PAT machine are in the remote control chain. The PAT machine remote control was provided with pneumatic actuators and disk brakes, whereas Disarmadillo uses electric actuators and more reliable mechanical brakes.

The PAT for humanitarian demining project naturally turned into the Disarmadillo project when Grillo S.p.a. decided to provide Snail Aid with a brand new power tiller for free.

A complete description of PAT for Humanitarian demining project can be found on the project web pages: http://www.dimec.unige.it/PMAR/demining/.

Disarmadillo has been developed at Istituto Professionale per l'Industria e l'Artigianato (I.P.S.I.A.) Attilio Odero in Genova, under the supervision of Prof. Gigi Acquilino with constant support and consultancy of Snail Aid members.

The power tiller on which Disarmadillo is built is a Grillo G131, now in production. The G131 was kindly provided by Grillo S.p.a. for free.

The G131 has a Lombardini 3LD510 diesel engine. Its displacement is 510cm3, its power is 12,2 hp (9kW). It is air cooled and has an oil bath air filter. The differential can be manually locked, it has four gears in forward direction and two in backward direction. It weights 215kg and has a 5.3l fuel tank.

The modifications to the tractor include the redesign of the frame, the installation of two tracks (provided for free by Minitop S.r.l.) and the installation of two band brakes (provided for free by Isibond S.p.a.). It is also present a winch, used to control a ground processing tool. Despite the modifications to the frame, the power take off can still be used.

As mentioned before, the remote control is electrically actuated. At the beginning of my thesis, the most of the work on the actuators was done, whereas the work on the logic of the remote controller was just begun.

The project web pages regarding Disarmadillo are available on the Snail Aid's web site: http://www.snailaid.org/index.php/Disarmadillo/.

Different tools have been developed for the PAT machine and Disarmadillo.

The first is a ground processing tool, which aims to smooth the soil up and expose landmines, moving them to the sides of the tractor. This tool requires the winch. It has been developed by Emanuela Elisa Cepolina as a part of the PAT for humanitarian demining work. It has been made and it is ready for use.

The second tool is a vegetation cutter, which aims to make easier and safer the activity of preparing the field for demining operations. The tool is connected to the power take off of the power tiller. It has been designed by Paolo Silingardi during the work for his master degree thesis. Its design is complete, but the tool is still to be made.

Fig. 2.3 1: The PAT for humanitarian demining.

Fig. 2.3 2: Disarmadillo at the beginning of my work. Notice the ground processing tool attached to the front of the frame.

2.4 The Disarmadillo existing remote control chain: analysis, strong and weak points

2.4.1 Analysis of the manual commands of Disarmadillo and definition of the remote commands available

The design of the remote control system begun analyzing the commands available to operate the power tiller. For this purpose, the manual of the power tiller was essential [16]. Two photos (provided by Grillo S.p.a) help defining which is the operation performed by each command.

Fig. 2.4.1 1: The G131 power tiller, side view.

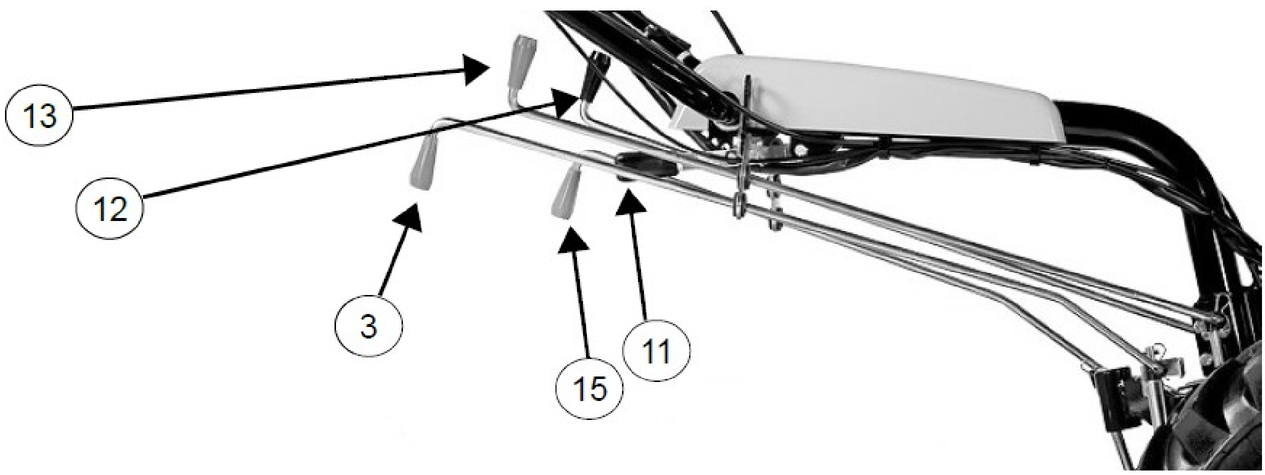

Fig. 2.4.1 2: Detail of gearbox levers.

The commands necessary to drive Disarmadillo are:

1) Clutch control lever (actuates a steel wire)

3) Reducer control lever

9) Ignition key (actuates an electric contact)

12) Differential lock lever

13) Speed selection lever

14) Gas throttle (actuates a steel wire)

15) Power Take Off Lever

The power tiller provided for the Disarmadillo project also included two drum brakes integrated into the original wheels. As their braking momentum is not enough to contrast the traction provided by the tracks installed on Disarmadillo, they are used for safety parking brakes.

Two band brakes were therefore installed, with their cables and wires chosen of the same type of the clutch cable and wire.

The power tiller should be stopped manually by closing the diesel valve, located on a side of the engine.

Some decisions were taken by the original designers of the remote control system in order to choose which manual commands should be remotely controlled. As the reducer control lever, the differential control lever, the speed selection lever and the power take off lever can be set before starting the work with the remote control and are not supposed to be operated while the machine is moving, the designers decided that the remote commands available should be the clutch control lever, the ignition key, the gas throttle, the band brakes wires and the diesel valve.

The designers also decided that the original manual controls must be preserved. The clutch is therefore remotely actuated by pulling/releasing the wire with a motor in parallel with the manual lever, the throttle lever is remotely actuated with a motor by a gear that can be manually disengaged in order to restore manual control. The remote control ignition contact is linked in parallel with the original one and the diesel valve is moved by a motor that does not forbid the manual operation.

2.4.2 Analysis of the existing actuators

The actuators that were installed on Disarmadillo at the beginning of my work were seven:

- Three electric linear motors, model Mecvel ALI1-F/0050/M03/24/C02/AR0/P1/A2, with adjustable limit switches (so that the stroke can be adjusted) and anti rotation devices, used to pull and release the right and left brakes and the clutch wires.
- Two automotive purpose 12V electric motors used to actuate the throttlen wire and the diesel valve lever.

  The throttle motor is a power window motor, whereas the diesel valve motor is a linear motor originally installed in the ignition system of a car. These two motors have been chosen among the many generic 12V in current production for their availability worldwide, their reliability and their relatively low cost.

  Two limit sensors are installed in the throttle mechanism and another two are supposed to be installed on the diesel valve mechanism.
- One electric winch motor.
- One electric starter motor, yet installed on the power tiller by the manufacturer.

These electric motors can be set to move in forward or backward direction by reversing the power supply. They all need 12V of tension; the Mecvel ones, which are the most powerful, adsorb 2A (it is not specified if it is a RMS value or a peak value).

The battery originally mounted on the G131 power tiller (which had a capacity of 19Ah) was replaced by one with higher capacity (70Ah), in order to provide more power to the actuators of the remote control system.

The Mecvel motors automatically switch off once they have reached the limit of their stroke, thanks to integrated limit switches. By the other side, the automotive purpose ones do need custom limit switches.

All the actuators were installed on the frame in a way that made possible to preserve the manual control. The throttle, the clutch, the starter and the diesel valve have their original command modules, but the two brakes can only be controlled by the linear motors, due to the high strength required. Therefore a switch system, supposed to be installed on the handlebar, is required to operate the linear motors manually.

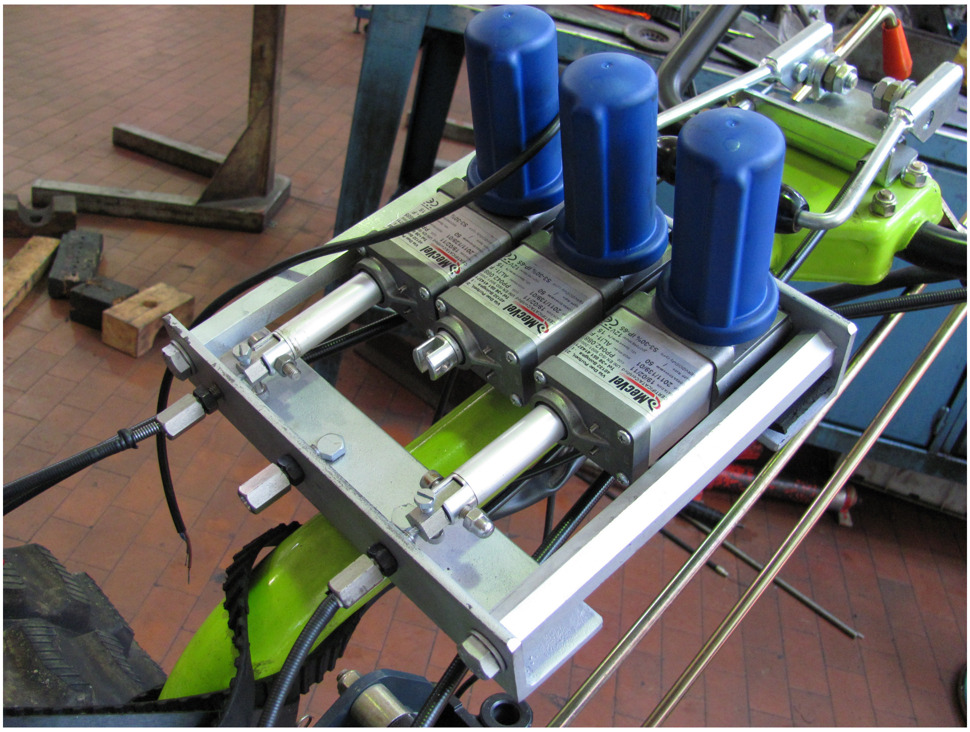

Fig. 2.4.2 1: The Mecvel electric linear motors. From the left: the right brake, the clutch and the right brake motors.

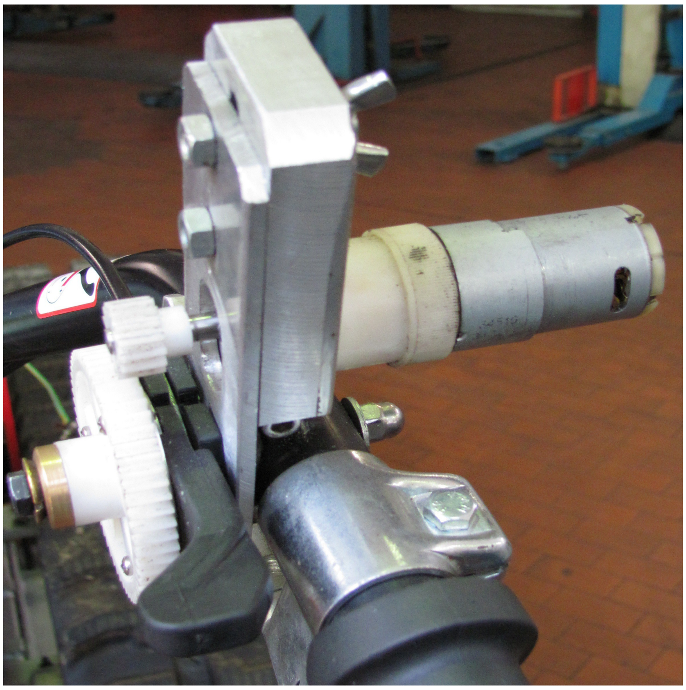

Fig. 2.4.2 2: The power window 12V motor adapted to the throttle cable.

2.4.3 Analysis of the existing remote control system

At the begin of my work, the remote control system consisted of:

1. the box containing the electronic devices
2. the relay group (identified as RELAY)
3. the voltage level converter circuit (identified as CIRCUIT)
4. the Arduino MEGA 2560 R2 board (identified as ARDUINO)
5. the digital receiver (identified as RECEIVER_RELAY and RECEIVER_CABLE)
6. the digital transmitter.

I disassembled the remote control system and analyzed all its components.

The components of the input chain were the digital transmitter and the digital receiver (with its relays and its cables); the components of the output chain were the voltage level converter circuit and the relay group, which provided high power to the actuators using a low power input signal.

The logic controller which interpreted the input and returned the correct outputs was the Arduino board.

The connections between these elements are summarized in the tables below. The numbers and the tags or the colors reported match the ones observed at the moment of disassembly, the identifiers of the components are the ones reported before.

RECEIVER RELAY	RECEIVER CABLE	ARDUINO INPUT PIN
1	ORANGE	31
3	YELLOW	33
4	GREEN	35
11	BLUE	37
12	PURPLE	39
THROTTLE_LIMIT_SW_1	GREY	41
THROTTLE_LIMIT_SW_2	WHITE	43
5	RED	45
6	BROWN	47

ARDUINO OUTPUT PIN	CIRCUIT	RELAY
22	1	LEFT_BRAKE+
24	2	LEFT_BRAKE-
26	3	RIGHT_BRAKE+
28	4	RIGHT_BRAKE-
30	5	CLUTCH+
32	6	CLUTCH-
34	7	THROTTLE_POWER
36	8	THROTTLE+
38	9	THROTTLE-
40	10	WINCH_POWER
42	11	WINCH+
44	12	WINCH-
46	13	DIESEL_VALVE_POWER
48	14	DIESEL_VALVE+
50	15	DIESEL_VALVE-

The Arduino board, the voltage level converter circuit, the relay group and the digital receiver were all powered by the battery of the tractor.

A more detailed scheme of the whole circuit is shown in the figure below, provided by the PMARlab.

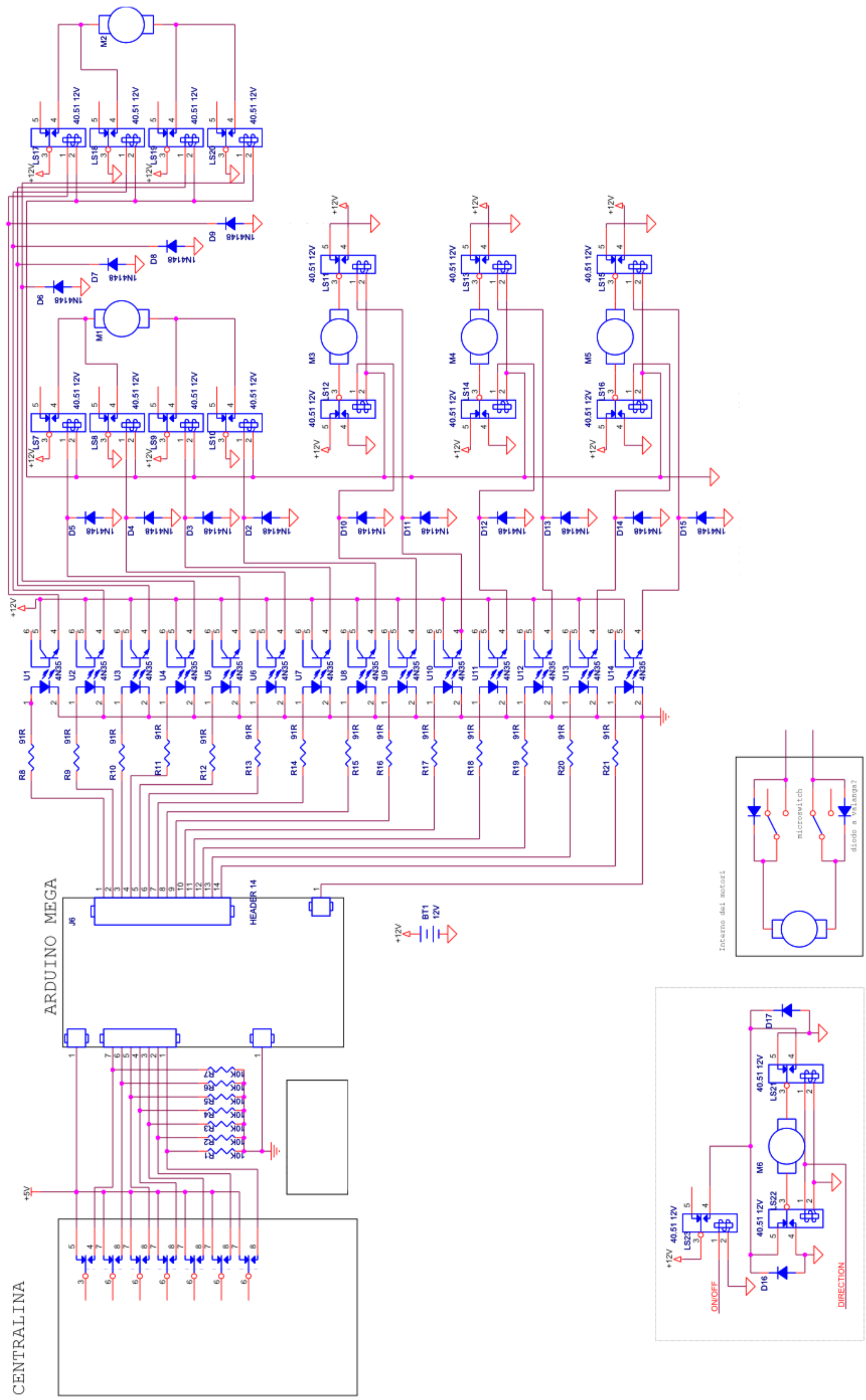

Fig. 2.4.3 1: The existing remote control scheme.

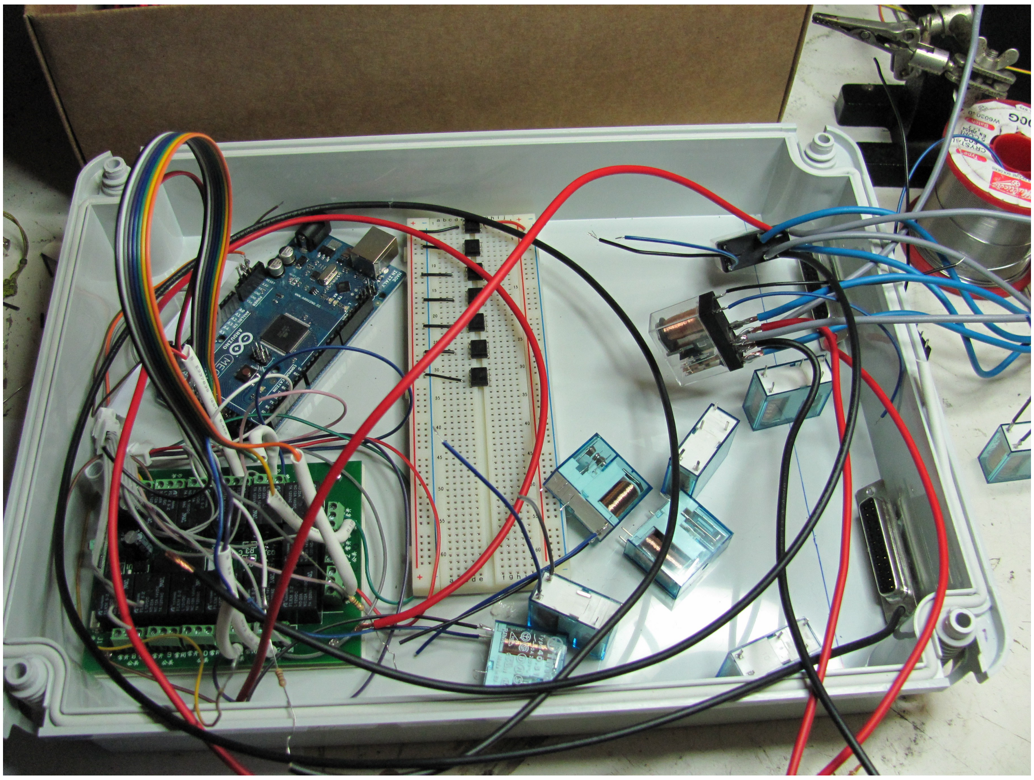

Fig. 2.4.3 2: An early version of the existing remote control system. Notice the breadboard for testing the circuit. The Arduino board can be seen on the top left.

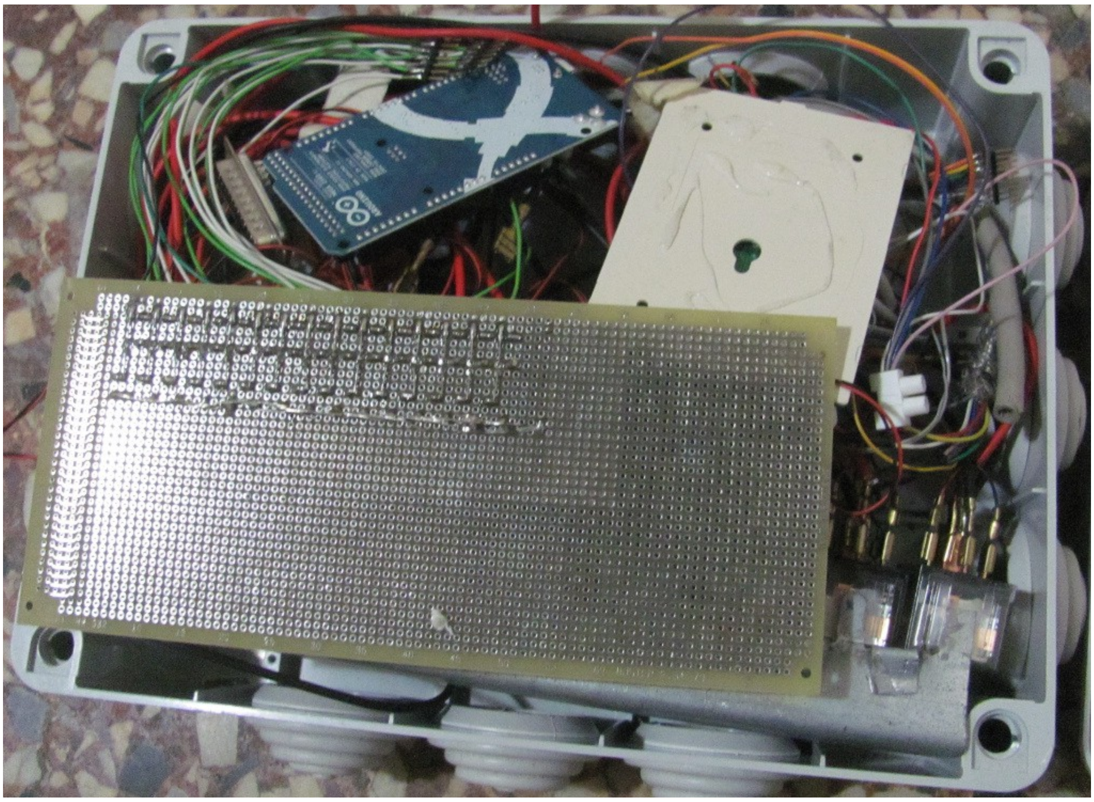

Fig. 2.4.3 3: The remote control system at the beginning of my work, with the voltage level converter circuit soldered on a prototyping purpose stripboard.

In order to plan a remote control improvement, I made a detailed analysis of every single device, pointing out its function and its specifications. I insisted on those characteristics which can limit the final reliability of the remote control system.

1. Box containing the electronic devices

This box aimed to protect the delicate electronic devices from dust, moisture and mine fragments.

This box is a GEWISS GW44009 coded as IP55. This means that it can resist dust and water jets. Internal available measures are circa 260mm * 180mm.

Reliability evaluation: this box seems adequate to its purpose, therefore it can be reused. It must be installed in a place protected from explosion fragments.

2. Relay group

The relay group aimed to have a reliable and high current resistant automatic switches to activate the motors.

The relays used were marked as 12V 80A and have been produced by Univang, with model name JD 80125.

All the connections were realized with non insulated Faston connectors.

The relays delivered power from the battery to the motors when the coil was excited by the signal received from the circuit board.

The relays identified as THROTTLE_POWER, WINCH_POWER and DIESEL_VALVE_POWER were used to cut the power supply to the respective motors.

Reliability evaluation: the relays chosen have a current limit much higher than the motors maximum absorption and they are very reliable models, installed on many of the automobiles in current production. They seem the best choice for Disarmadillo and therefore they will be reused, possibly with insulated Faston connectors.

3. The voltage level converter circuit board

It was a homemade circuit, installed on a stripboard for circuit prototyping, aimed to adapt to the relays the signal coming from the Arduino board. It included diodes for counter current blockage, resistances and transistors for tension level switching. They were soldered to the board.

Its purpose was to convert 5V signals coming from Arduino output pins to 12V signals adequate for driving the 12V relays of the output relay array.

The power supply was the tractor's battery.

Reliability evaluation: I made some research about practical electronics basics in order to better determine the reliability of this circuit. I used [14] and [15]. As I have determined, a stripboard circuit is never as reliable as a big production circuit, and this is due to the soldering process, which is manual and can lead to the risk of damaging the semiconductors or obtaining unnoticed “cold joints” that can come apart in time. As reported in [14], big production circuits are obtained by gluing with a solder paste the components to the board and than heating it in a second time, obtaining a much more controlled soldering process. Therefore it is advisable, if possible, in order to reach a higher level of reliability, to substitute the personalized circuit with a big production one or a different type of control system that does not require a voltage level converter. The same advice extends to any electronic device of the improved system: in order to get the maximum reliability, it must be a big production device.

4. Arduino MEGA 2560 R2 board

Its characteristics are determined from the official web site of the Arduino project, [14].

I understood the Arduino's principle of operation with [3], and then analyzed its program (which is reported in the appendix for reference) and determined clearly which commands were to be executed by the remote control.

This board was the core of the Disarmadillo remote control system. It received the signals coming from the digital receiver, elaborated them and sent new signals to the voltage level converter circuit.

All the connections were made with single inline connectors.

It was powered by the battery and it provided the 5V power supply. This power supply was used by the digital receiver to send signals to the Arduino board.

Reliability evaluation: The Arduino boards are all produced with high quality standards in the Italian Arduino factory. They reach a level of reliability that fits the Disarmadillo requirements. The only drawback of the Arduino board is the fact that it requires 5V inputs and outputs, which means that a voltage level converter circuit is necessary for the Arduino board to work on Disarmadillo.

5. Digital receiver

This board could receive a maximum of 12 signals from the digital transmitter and send them to the Arduino board.

It worked like a normal relay group, with the activation of the relays controlled by the transmitter.

The power supply for signals going to Arduino was taken by the Arduino 5V internal power supply.

It was available a specifications paper which reported: Power supply 5V; Absorption 200mA, 6mA in sleep mode; Frequency 433MHz; Number of channels 12; Relays output 10A; Maximum Dimensions 75mm * 52mm * 28mm.

Reliability evaluation: From the comments of the precedent users about this receiver, it seems that its transmission precision is not adequate to the requirements of Disarmadillo. A new antenna or a completely different transmission system is therefore advisable for the new remote control system.

6. Digital transmitter (remote controller)

It was the first component of the control chain, and its key mapping is determined by the program loaded on the Arduino board.

At the moment of my analysis the mapping was:

Key	**Action performed**
1	Go forward
3	Turn left
4	Turn right
11	Wind the winch
12	Unwind the winch

The battery required was a 27A 12V alkaline battery, commonly used in remote controllers.

Reliability evaluation: The reliability of the digital transmitter is strongly correlated to the reliability of the receiver.

2.4.4 The strong and weak points of the existing remote control chain

The strong points of the analyzed remote control system are:

- The low cost of the electronic devices, costing in total less than 300EUR.
- The cheapness of the electric motors, being much more affordable than the ones used in traditional robotics applications, for total cost of less than 700EUR.
- The fact that the Arduino board is an open-source project, made to be easy understandable and usable by nearly everyone. This is conform to the Disarmadillo inspiring principles.

The weak points of the remote control system are:

- The scarce reliability of actual electric connections in case of vibrations due to work on unpaved, irregular terrain.
- The vulnerability of non insulated electronic connectors, which need isolation with at least some specific tape.
- The scarce reliability of the voltage level converter circuit, which has not the reliability of the big production circuits due to the manual soldering process required to realize it.
- The low range of the antenna and the scarce precision of the digital transmission.
- The impossibility to make an immediate and reliable safety arrest of the engine.
- The weakness of the box, that can not resist to explosion fragments if not installed in a safe position.

The things to be done to improve the existing remote control circuit are:

- Overcome the scarce reliability of the internal connections and of the voltage level converter circuit.
- Overcome the safety lack by creating a remote button that cuts the power supply to the engine.
- Improve the digital transmission.
- Install a low fuel level sensor to warn the user when the fuel level is too low.
- Improve the generic motor limit sensors.

2.4.5 Improvements plan

It is easily understandable that these modifications will end up with a cost increase. But the Disarmadillo budget is very low. In order to overcome the cost problem, Snail Aid gives me the possibility to use some parts of the previous (now dismissed) remote control systems of the LOCOSTRA deminer.

As I need to operate without the voltage level converter circuit, I analyzed the available PLCs (Programmable Remote Control). A PLC will indeed give me the chance to remove the personalized circuit.

The available PLCs are 2:

- a Siemens LOGO! 12/24RC with eight inputs and four outputs, that were not enough for remote controlling Disarmadillo (as the actuators are seven);
- a FATEK FBs-60MAT with 36 inputs and 24 outputs, which are enough for remote controlling Disarmadillo.

There is only one digital transmitter and receiver available:

- a Hetronic NOVA-M originally programmed by the manufacturer to work with the LOCOSTRA deminer developed by the PMARlab.

I also obtained, for reference, the master degree thesis in Robotics Engineering written by Michał Przybyłko: LOCOSTRA, a small-size fully teleoperated tractor: improvement of the remote control system.

In the context of this thesis Michał Przybyłko improved the LOCOSTRA remote control system with the same devices I am now using: the FATEC FBs-60MAT and the Hetronic NOVA-M.

3 My work on Disarmadillo

3.1 Additional band brakes

3.2 Remote control system improvement

3.2.1 Chosen devices description

The Programmable Logic Controller (PLC)

This PLC is produced by FATEK, and its model name is FBs-60MAT. It has 60 terminals: 36 inputs and 24 outputs. The manufacturer provides updated manuals and the free software WinProLadder, a tool to program the PLC with the ladder language.

Fig. 3.2.1 1: The FATEK FBs 60MAT PLC.

FATEK also provides a communication protocol, available with USB, RS-232, RS485 and Ethernet interfaces. Our PLC has no off-the-shelf communication cable, our cable was made by the previous programmer of the PLC and I had to solder again its terminals as some of them were broken. For simplicity of build and maintenance, the RS-232 interface and a USB to serial adapter were used. The detailed connection scheme is provided in the appendix.

The FBs-60MAT comes with its own 36W power supplier with 12V DC input. There is one 24V DC power output available to the user. The power supplier model name is SPW24-D12.

A scheme of the input and output connectors of the FBs-60MAT is reported in the figure below.

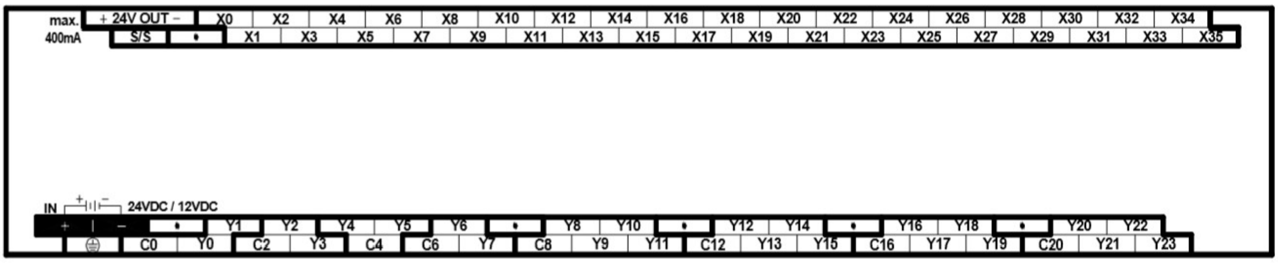

Fig. 3.2.1 2: FBs-60MAT connectors scheme

The 24V DC digital input circuits of FBs-60MAT are available for medium and low speed signals. The circuit structure is the same but the response speed are different: for inputs X0,1,4,5,8,9,12,13 speed is 20kHz (HHSC); for inputs X2,3,6,7,10,11,14,15 speed is in total 5kHz (SHSC); for inputs from X16 to X35 speed is 0.47ms and the limit of input speed is 10kHz. In order to save input terminals, one end of all input connectors must be connected to the connector S/S, whereas the other end of each input must be connected to the corresponding terminal. This structure is called single end input. If S/S is connected to 24V+ (positive power supply output) and all the external input wiring are connected to 24V- (negative power supply output) the circuit serves as sink input (named SINK). In the reverted situation the circuit serves as source input (named SRCE). Two figures show two sample situations.

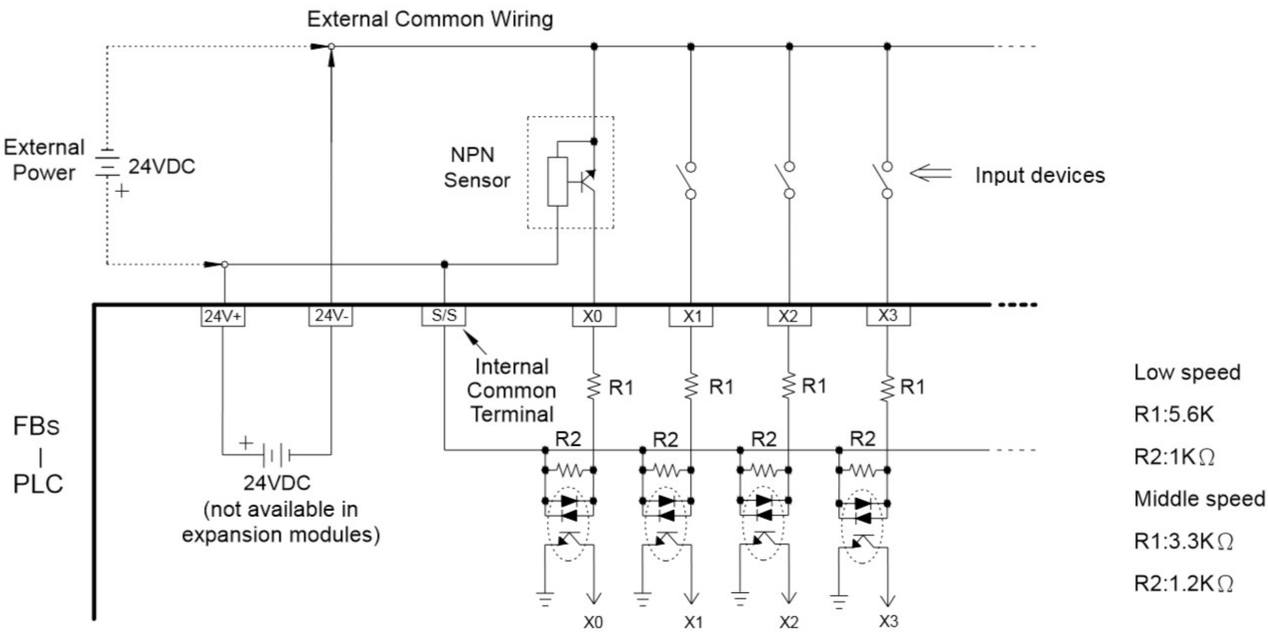

Fig. 3.2.1 3: Single end SINK input wiring

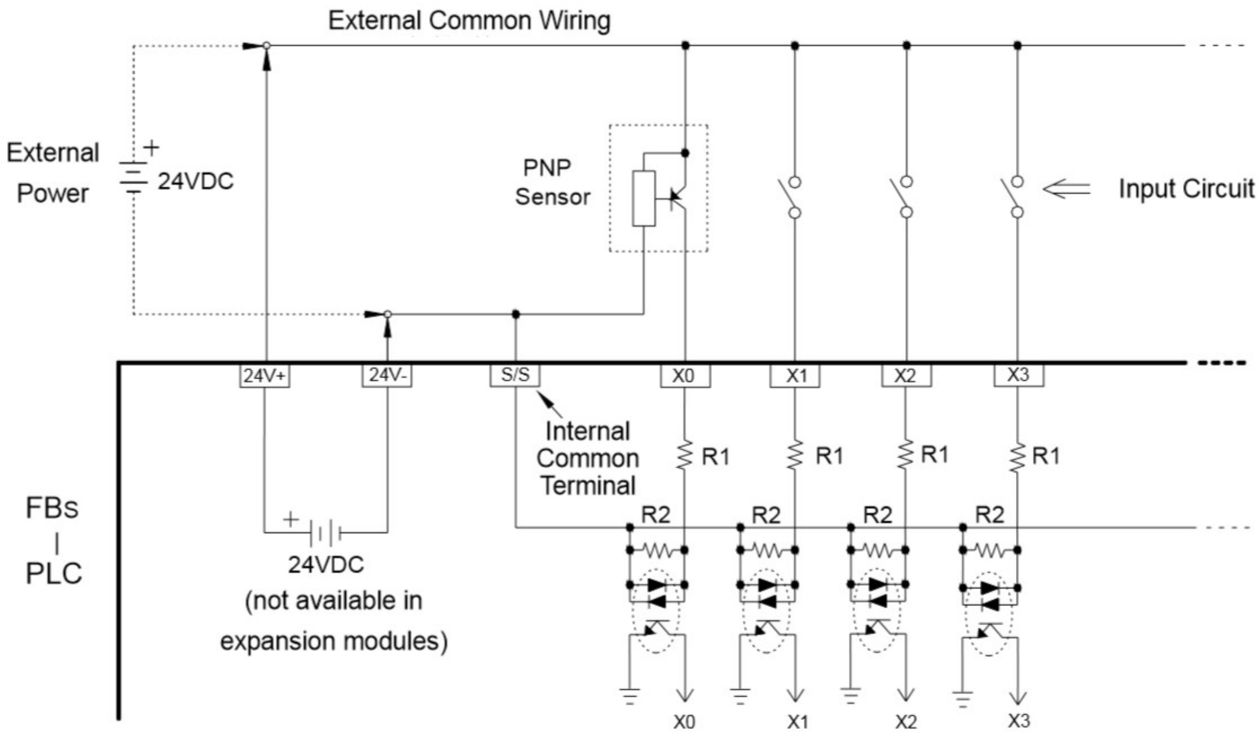

Fig. 3.2.1 4: Single end SRCE input wiring.

In FBs-60MAT, the digital output is performed by transistors. The circuits do not provide over current protection, attention must be payed by the users. They allow 0.5A current. Digital output circuits are available for medium and low speed loads. The circuit structure is the same but the response speeds are different: for outputs form Y0 to Y7 speed is 20kHz, for outputs from Y8 to Y23 speed is low and not specified. In order to save output terminals, terminals are organized in 8 blocks. Each block is identified by the minimum terminal marking number. In order to realize the connection, one end of each output connector must be connected to one Yn terminal. The other end of that output connector must be connected to the common connector Cm of its block, where m is the block number. The connection method is more clear by viewing the figure below. This structure, again, is called single end input. Due to the presence of transistors, connections can not be made indifferently as source or sink outputs. In our FBs-60MAT connections must be made as source, as the mark SRCE on the PLC specifies. Therefore, the positive +12V DC pole coming from the battery must be connected to each common Cm connector and each load must be connected to the Yn connector. The figure below shows a sample source connection.

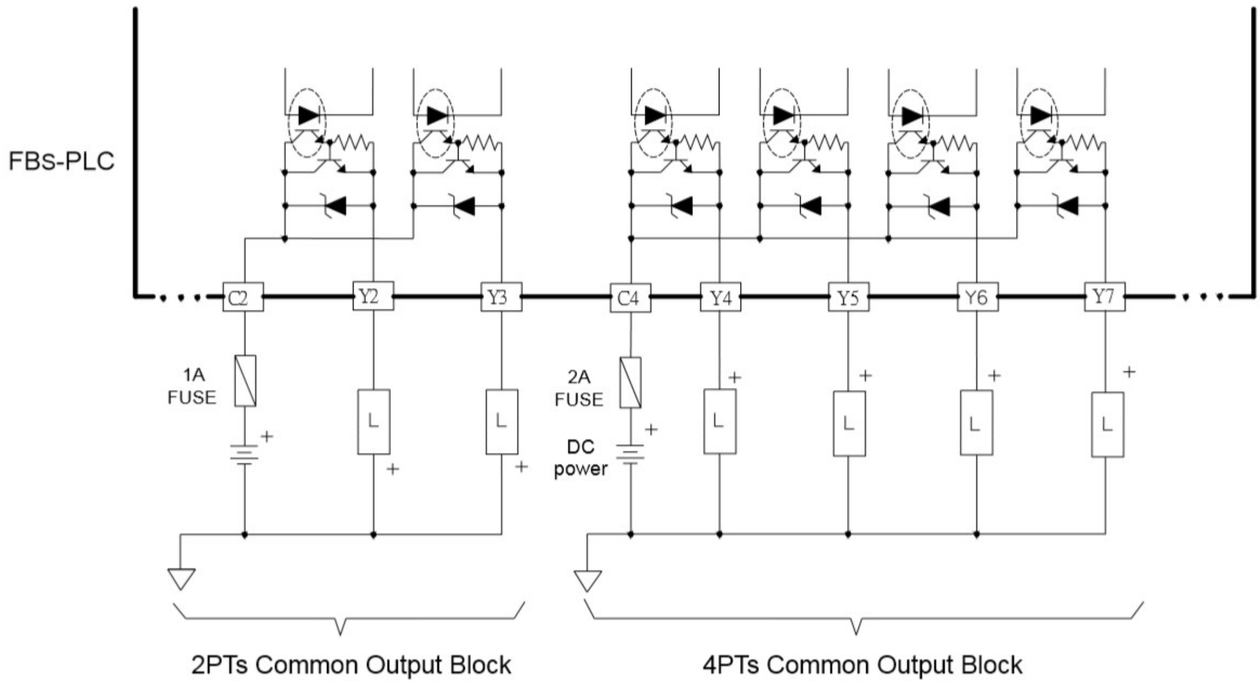

Fig. 3.2.1 5: Single end SRCE output wiring.

The FATEK FBs-60MAT PLC can be connected to the PC with a serial port RS-232. As modern PCs do not have a serial port, I use a serial to USB adapter to connect to a portable PC.

The automotive purpose relays

All the devices in Disarmadillo operate at 12V but the PLC requires 24V inputs. Therefore some coil relays, powered with the PLC's power outputs, are required to adapt input signals. Furthermore, the electric motors used as actuators adsorb high current (more than 2A). Therefore we need some coil relays to power the actuators. For their reliability, automotive purpose relays are the best choice. For their availability, 12V 80A relays will be used.

The upper part of the figure shows the physical structure of the relays, whereas the bottom part shows the terminals arrangement on the bottom side of the relays. The N.O. (Normally Open) relay disconnects terminals 30 and 87 when no potential is given to terminals 86 and 85 and connects terminals 30 and 87 when the 12V potential is given to terminals 86 and 85. The N.C. (Normally Closed) relay connects terminals 30 and 87 when no potential is given to terminals 86 and 85 and disconnects terminals 30 and 87 when the 12V potential is given to terminals 86 and 85.

In fact, the relays I use are different. They are represented in the third figure from left: they can be used either as normally open or normally close. But they can serve for another important function: as they are built to connect terminals 30 and 87a when no potential is given to terminals 86 and 85 and to connect terminals 30 and 87 when 12V potential is given to terminals 86 and 85. I will operate the relays in this way to switch the power supply to the motors and change their direction of rotation.

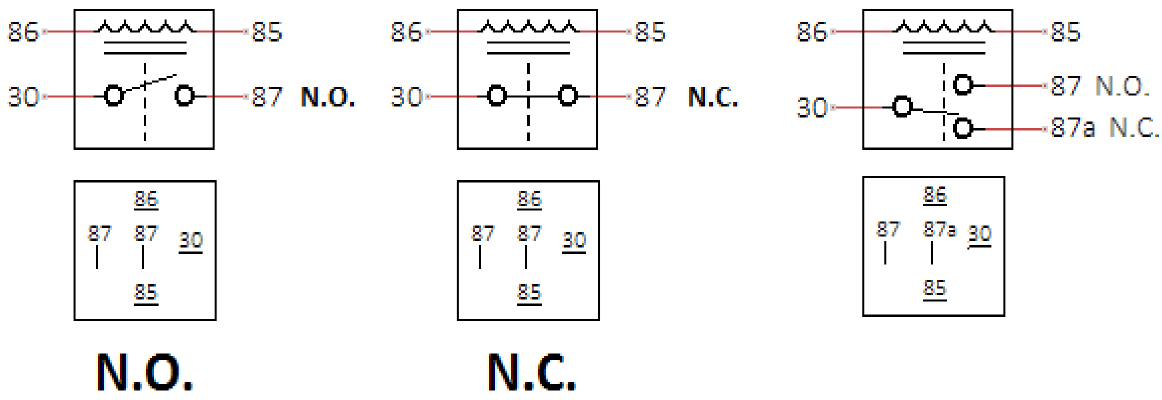

Fig. 3.2.1 6: Structure and terminals' arrangement of relays.

The wires

The most powerful motors adsorb 2A of current with a 12V tension. Using a safety factor of 2.5 in the calculations, the wires are to be dimensioned for a maximum current of I = 5A.

The maximum voltage drop allowed into a wire is selected at U = 0.01V, as such a small voltage drop won't affect neither the relays' nor the motors' operation and is negligible for the PLC's or the receiver's power supplies.

Therefore, according to the Ohm's law, the maximum resistance allowed in a wire is R = U/I = 0.002ohm

The resistance R of a wire is related to its length L, to its section S and to the electrical resistivity p of the material on which it is made with the formula: R = pL/S.

The minimum length of a conductor in the Disaradillo remote control system will be of 100mm = 0.100m.

I assume that the wire is made on copper and remains at ambient temperature (p = $1,68*10^{-8}$ohm*m at 20°C).

Therefore the minimum area of the wire should be: S = pLI/U = 0.84mm^2.

The widely available 1.5mm^2 wire is therefore chosen for all the circuit.

The complementary devices

Low fuel level sensor

The low fuel level sensor is a traditional resistive fuel sensor with a switch circuit for the fuel reserve. I use that switch to control an input relay for the PLC.

Limit switches

The only modification to the existing actuators is the installation of limit switches to the diesel valve motor. They are chosen of the same kind of the throttle motor's limit switches.

The transmitter and the receiver

The transmitter and the receiver have been produced by Hetronic and has been bought in Italy. Their commercial name is NOVA-M. The receiver and the transmitter were specifically adapted and programmed for being used with the tractor LOCOSTRA, developed by Snail Aid. The Hetronic company has now been reorganized and the Italian seller is no longer available. As a result, it is not easily possible to reprogram either the receiver or the transmitter. This limitation will lead to an effort to adapt the current configuration to the Disarmadillo needs. This makes the presence of the PLC crucial for the remote control system.

A design drawing of the transmitter is provided by the manufacturer and reported below. The Q1 hand wheel turns the controller on, S4 and S5 press buttons are used for analog joystick work adjustment. The joystick S2 moves in all directions (with a spherical joint) and activates the wireless circuit of a PWM controller. Switches S1 and S6 have three positions; in both of them the front (T) position is momentary. The central position is the normally open one. Switches S5 and S7 have two positions. The rear position is the normally open one. S8 is a press button normally open. S0 is a safety stop push button (red colored): when pressed, it locks itself and for unlocking it has to be rotated clockwise. Its default position is normally close. There are three light indicators: FB1, red; FB2 and FB3, both green. There also is a light indicating the transmitter's battery status.

When establishing connection between the transmitter and the receiver, after turning the transmitter on, the first command to be given is the START signal. This command is performed by pushing the S1 switch in frontward direction. After receiving the START signal, the transmitter allows all the other commands to be given.

Each command to the transmitter activates the wireless circuit of a digital contact (named DKn, where n is the contact number to be read on the transmitter design drawing). This powers up one output wire of the receiver with a +12V DC potential. The receiver has 23 output wires, 6 of which are ground connections and 2 of which are the power contacts.

The receiver performs four PWM (Pulse With Modulation) outputs. They are activated by the joystick and their aim was to control the movement of the LOCOSTRA tractor. Nevertheless, the Disarmadillo band brakes should not be actuated with modulated force: band brakes should be used only in completely released or pulled positions. Half pulled positions would lead to a premature wear of the brake. On the other hand, the accelerator does not require modulation because Disarmadillo always work with the same gear (gear change can not be performed with remote control). Furthermore, as seen in the control activity flowchart paragraph, we prefer to send three simple signals to control the Disarmadillo: FORWARD, LEFT, RIGHT. Therefore, I have to convert the PWM signals as they were digital ones and force (with PLC programming) the employment of only three positions of the joystick: frontward, left and right. As the PWM outputs can activate simple automotive purpose relay, the conversion from PWM to digital signals is not a problem: I only have to connect the relays to the PWM outputs as they were digital outputs.

The transmitter comes with two 3.6V DC 1.2A batteries. The battery charger is a transformer with these characteristics: input 10-30V DC output 300/780mA. Its connector to power supply is a ANSI/SAE-J563 12V cigar lighter plug, size A. The Disarmadillo will provide a cigarette lighter receptacle to power the battery charger with its battery. The receiver needs a +12V DC power supply.

A cabling scheme describing the wireless connections from the transmitter to the receiver and the receiver's internal connections is provided by the manufacturer. It is also provided a scheme describing the wiring output from the receiver. They are reported in the images below.

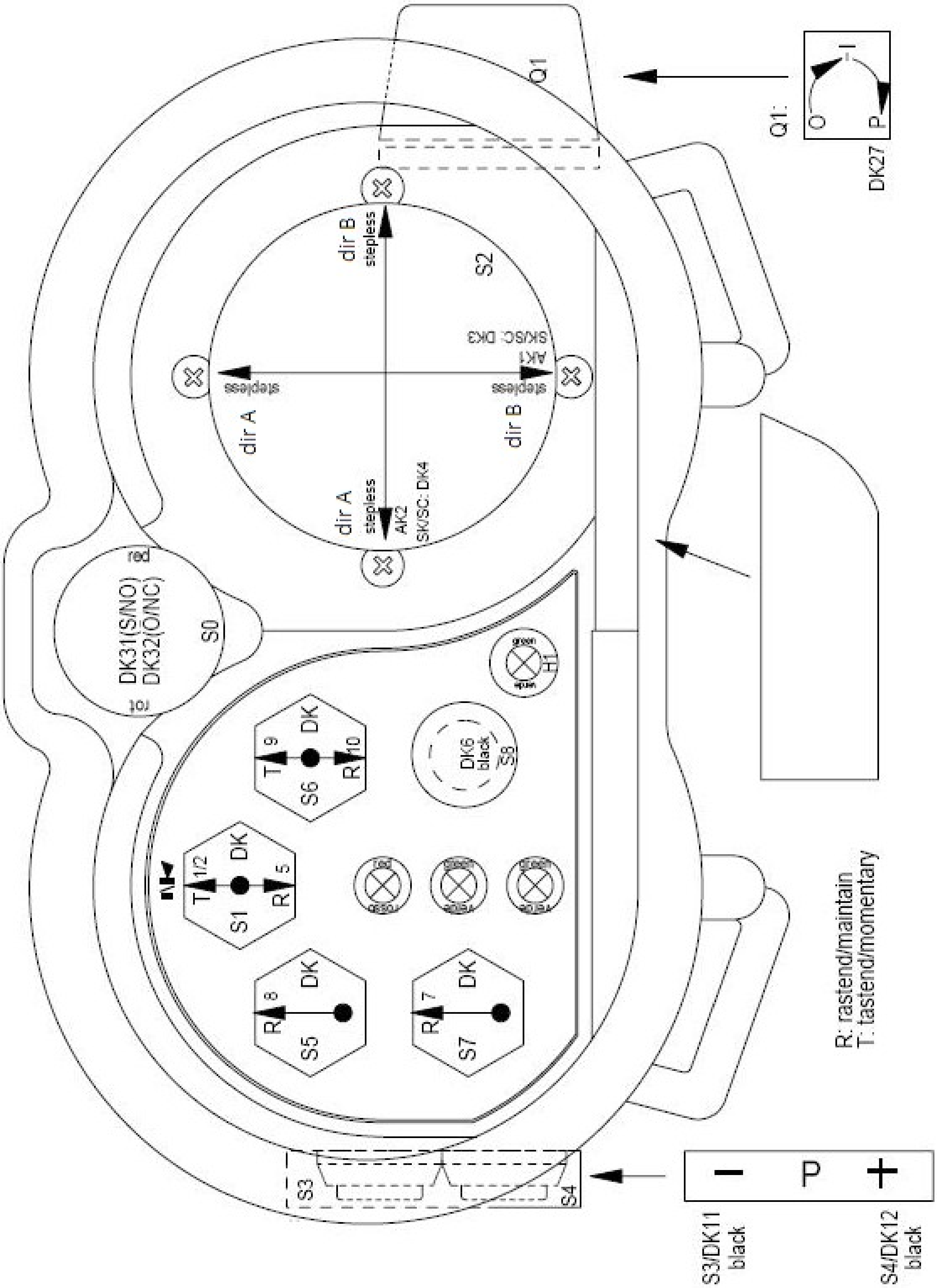

Fig. 3.2.1 7: Transmitter design drawing.

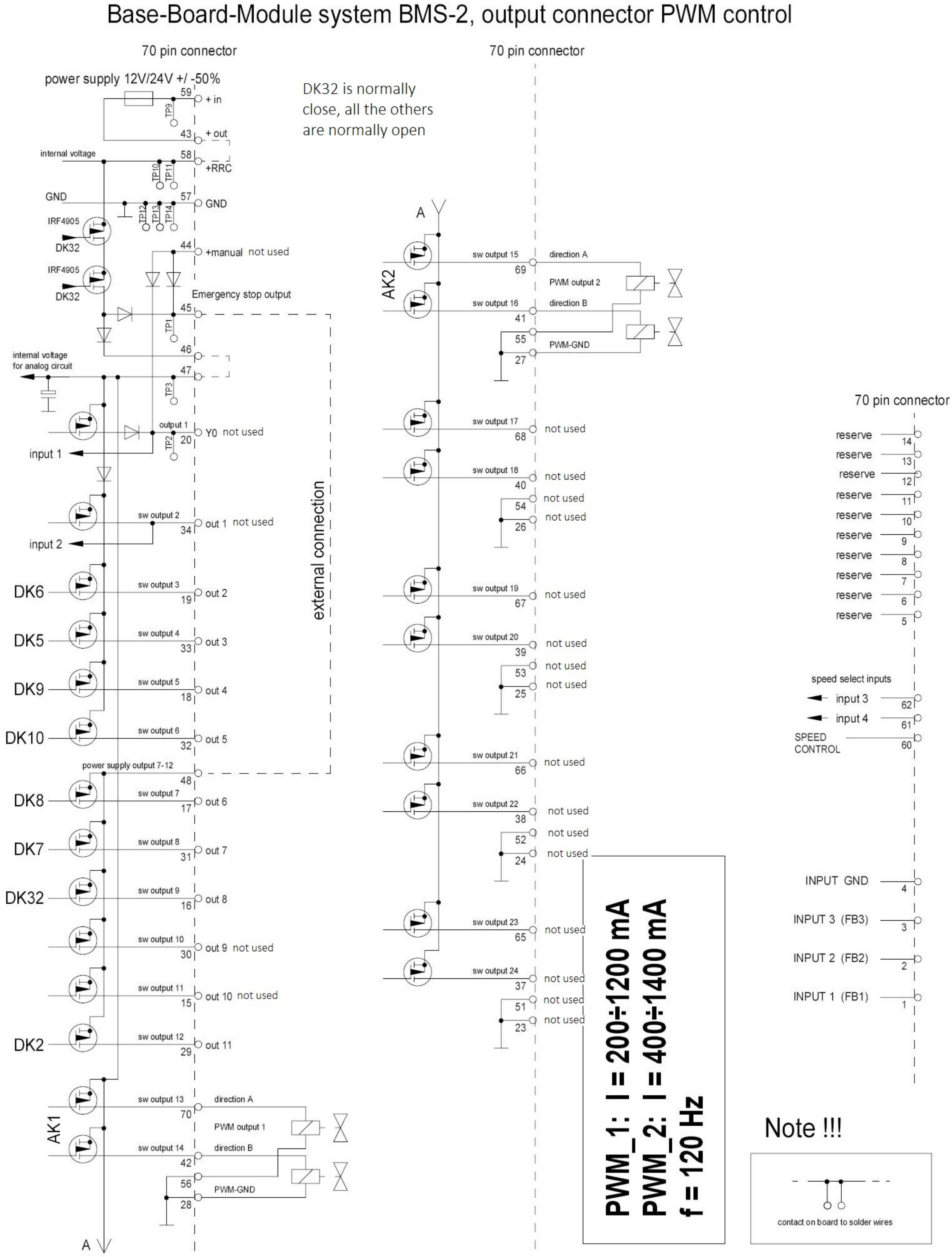

Fig. 3.2.1 8: Wireless connections from the transmitter to the receiver

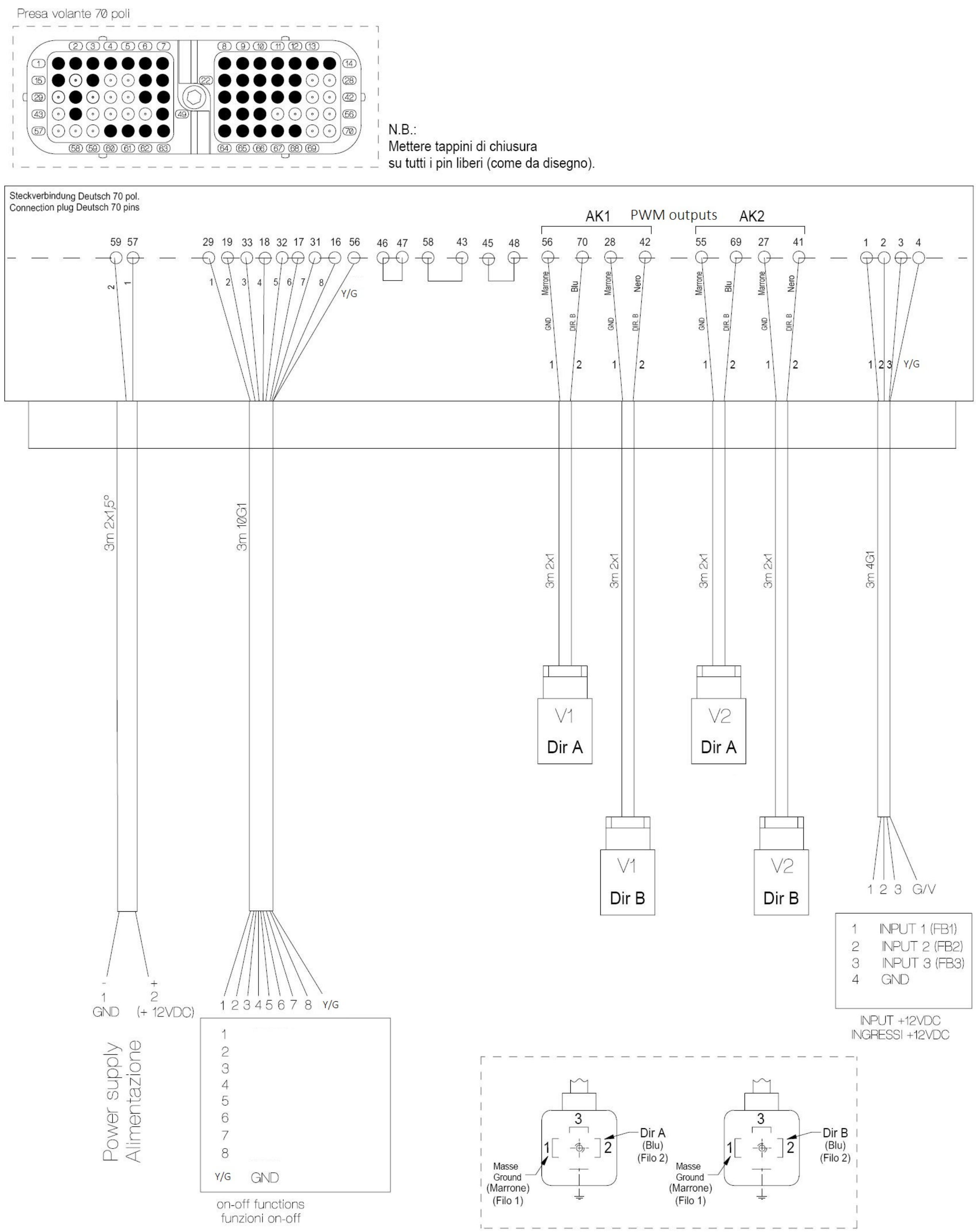

Fig. 3.2.1 9: Receiver output wiring

Fig. 3.2.1 10: The Hetronic NOVA-M receiver.

Fig. 3.2.1 11: The Hetronic NOVA-M transmitter.

3.3 Improved remote control detailed design

3.3.1 Conceptual design of the improved remote control

Definition of the control activity flowchart

This section aims to define the algorithms used in the Programmable Logic Controller (PLC) to remotely control the Disarmadillo.

This effort will make possible to have a scheme defining how the control operates. This scheme should be easy to understand without knowing any programming language.

Flowcharts are a widely used way to model a work flow, graphically describing tasks to carry and their sequence.

Each block can have a different form:

- begin and end blocks >> rounded rectangles
- input and output blocks >> parallelogram
- decision blocks >> rhombus
- processing blocks >> rectangles.

To create flowcharts I used the open source application:

Dia 0.97.2 – http://live.gnome.org/Dia

The input signals, coming from the receiver to the PLC, are:

1. turn the engine off (OFF)
2. turn the engine on (ON)
3. activate the electric starter (in case of accidental turn off) (STARTER)
4. go forward (FORWARD)
5. go right (RIGHT)
6. go left (LEFT)
7. wind the winch (WIND)
8. unwind the winch (UNWIND)
9. safety Disarmadillo stop (STOP)

The output signals, coming from the PLC and performed by actuators, are:

1. pull the left brake (LB_PULL)

2. release the left brake (LB_RELEASE)
3. pull the right brake (RB_PULL)
4. release the right brake (RB_RELEASE)
5. pull the throttle (TH_PULL)
6. release the throttle (TH_RELEASE)
7. pull the clutch (CL_PULL)
8. release the clutch (CL_RELEASE)
9. open the diesel valve (DIESEL_OPEN)
10. close the diesel valve (DIESEL_CLOSE)
11. start the starter engine (START)
12. wind the winch (WINCH_UP)
13. unwind the winch (WINCH _DOWN)

Each output signal is performed until the simple task it defines is completely done by the actuators. It usually requires a little time to be performed.

As the input signals require more tasks to be done than just activating a relay, a PLC is required to perform needed tasks.

The Disarmadillo standard condition must be the safest possible, with both brakes pulled, clutch pulled and throttle released. In order to realize this condition, a complex task must be performed at the start of the remote control system and at the end of any other task, as a safety control cycle. This is the Disarmadillo standard task.

All other complex tasks alter the Disarmadillo standard one just for the time that the input signal is received.

As a result, the list of all complex tasks is:

1. turn the engine off (OFF)
2. turn the engine on (ON)
3. activate the electric starter (in case of accidental turn off) (STARTER)
4. go forward (FORWARD)
5. go right (RIGHT)
6. go left (LEFT)
7. wind the winch (WIND)
8. unwind the winch (UNWIND)
9. safety Disarmadillo stop (STOP)

as the input signals require, plus the safety standard one:

10. Disarmadillo standard (STANDARD)

For each complex task I realized a flowchart.

The task named STANDARD must be perpetually performed by the PLC, so it doesn't have the END block: it ends when the remote control system is shut off. As you can see, only after having restored the safest condition the Disarmadillo can accept a new task. The other tasks are OFF, ON, FORWARD, RIGHT, LEFT, WIND, UNWIND, STARTER, STOP. These tasks all have BEGIN and END blocks, as they must not be performed perpetually.

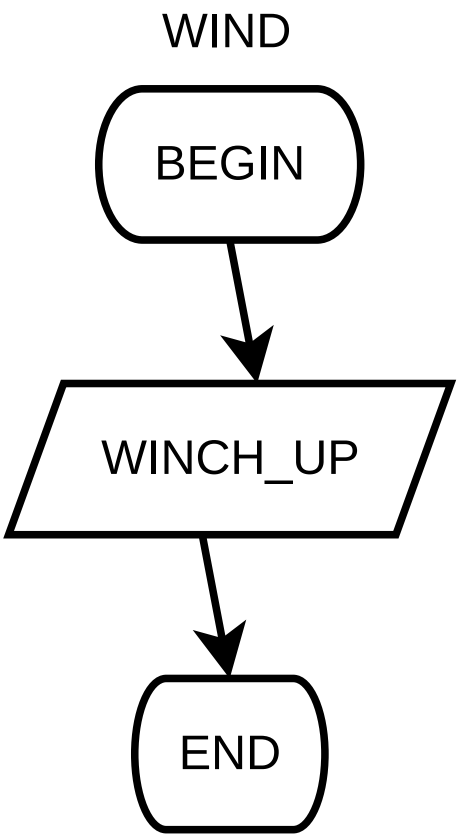

Fig. 3.3.1 1

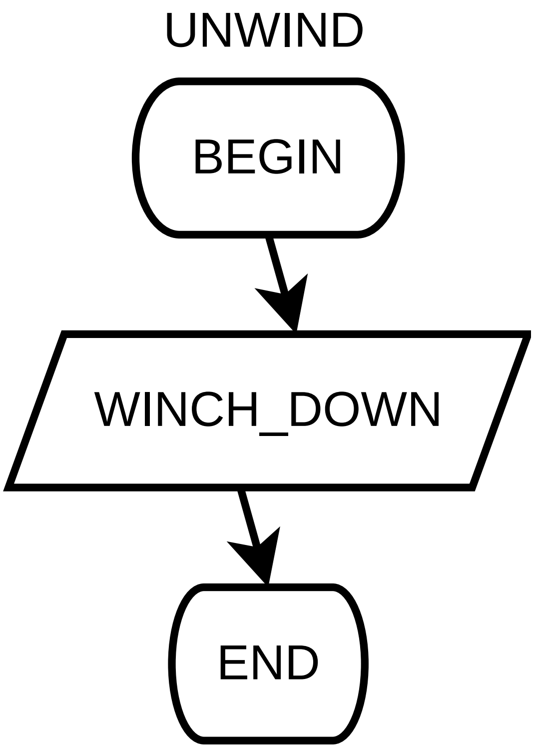

Fig. 3.3.1 2

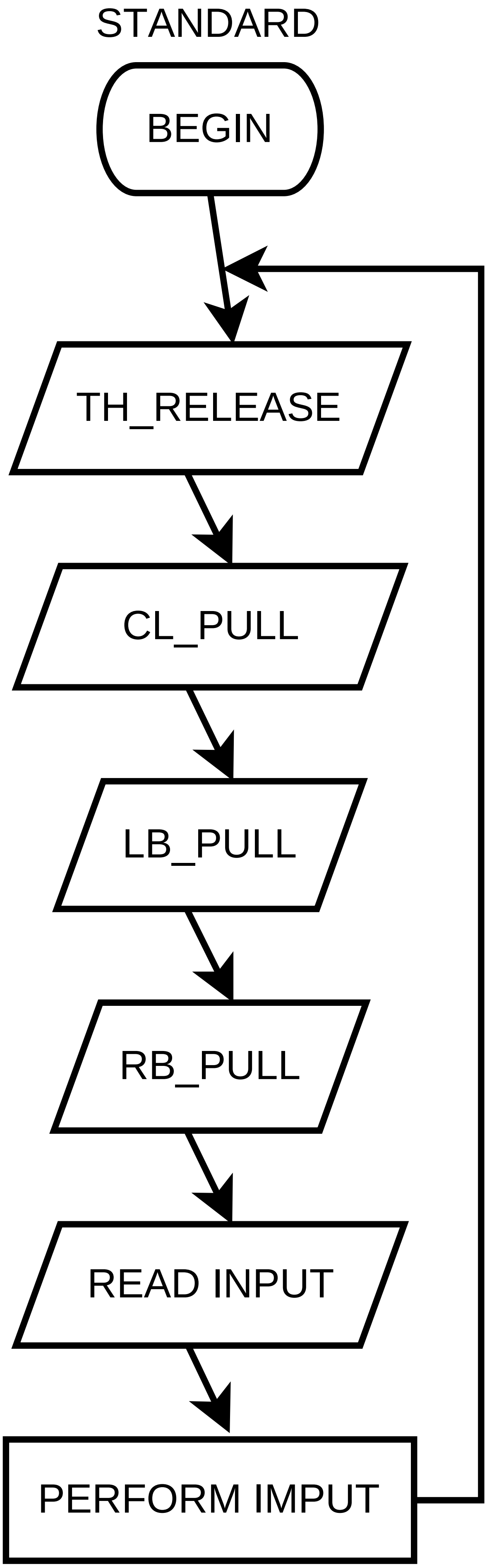

Fig. 3.3.1 3

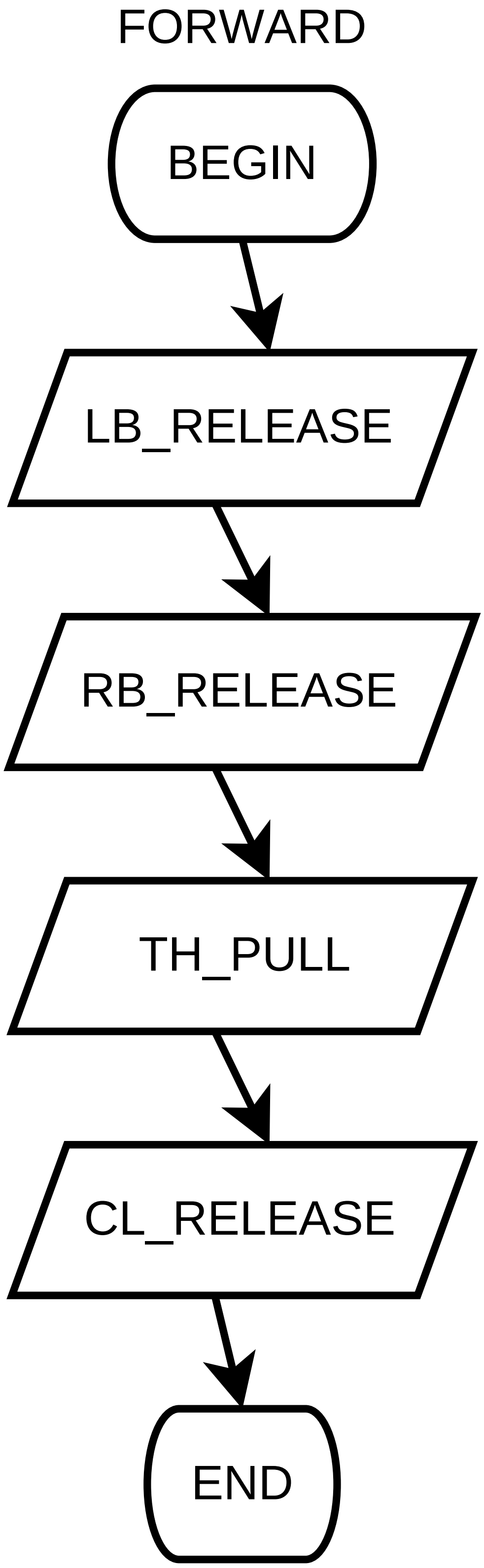

Fig. 3.3.1 4

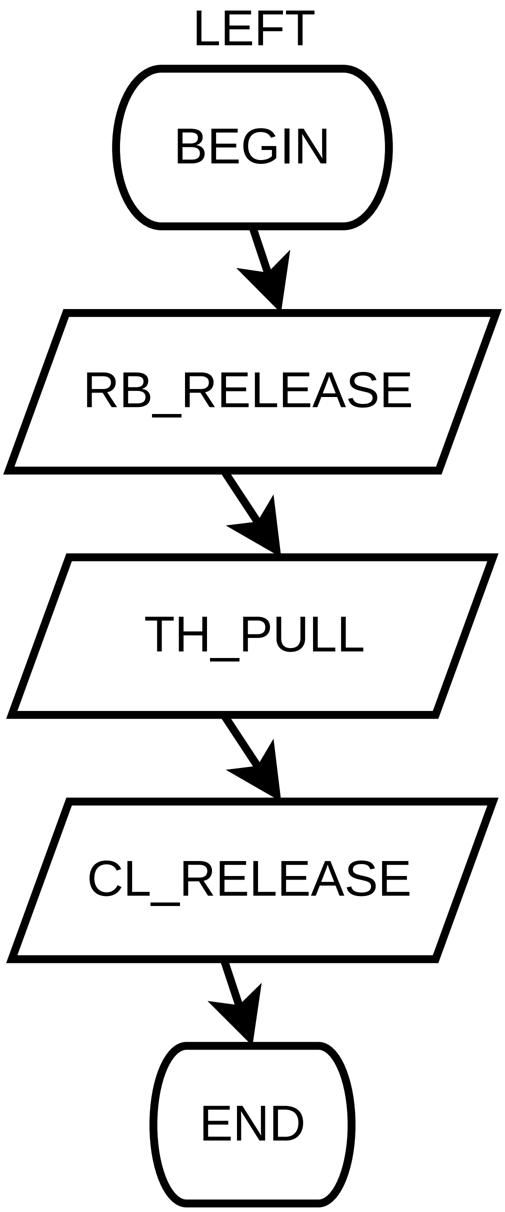

Fig. 3.3.1 5

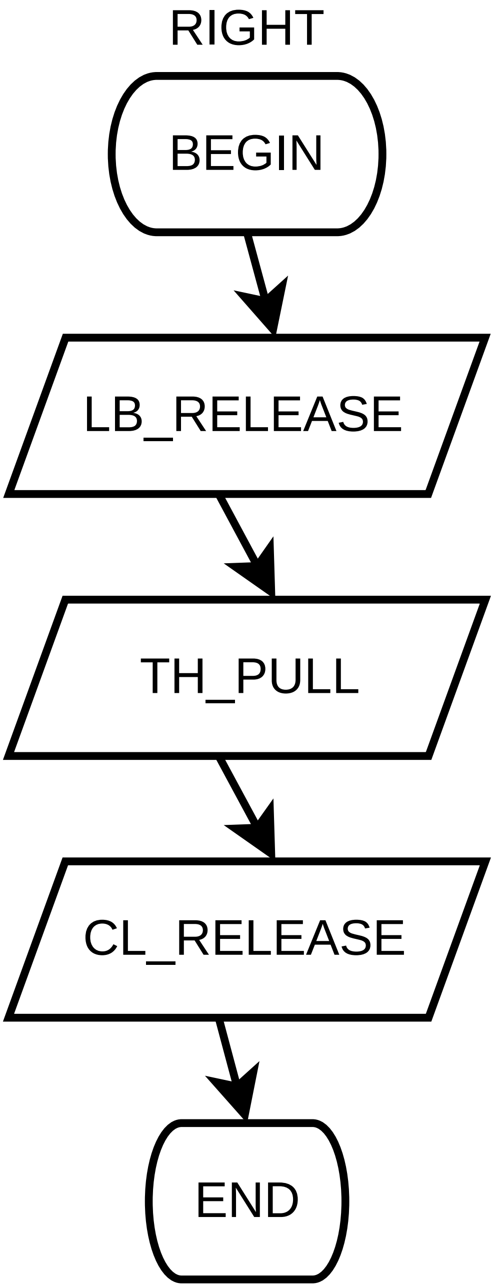

Fig. 3.3.1 6

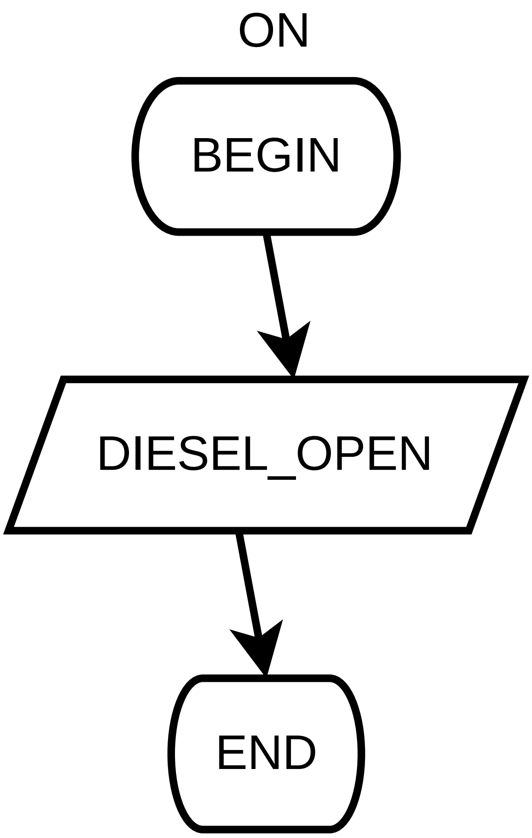

Fig. 3.3.1 7

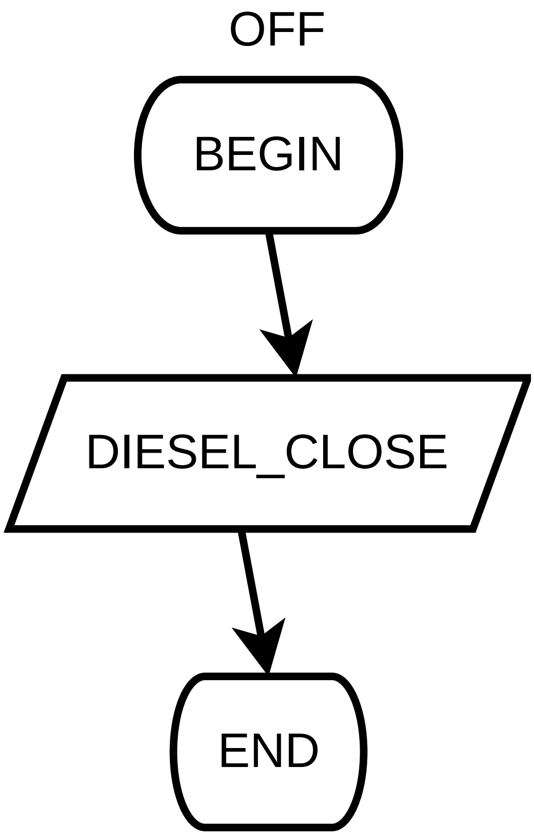

Fig. 3.3.1 8

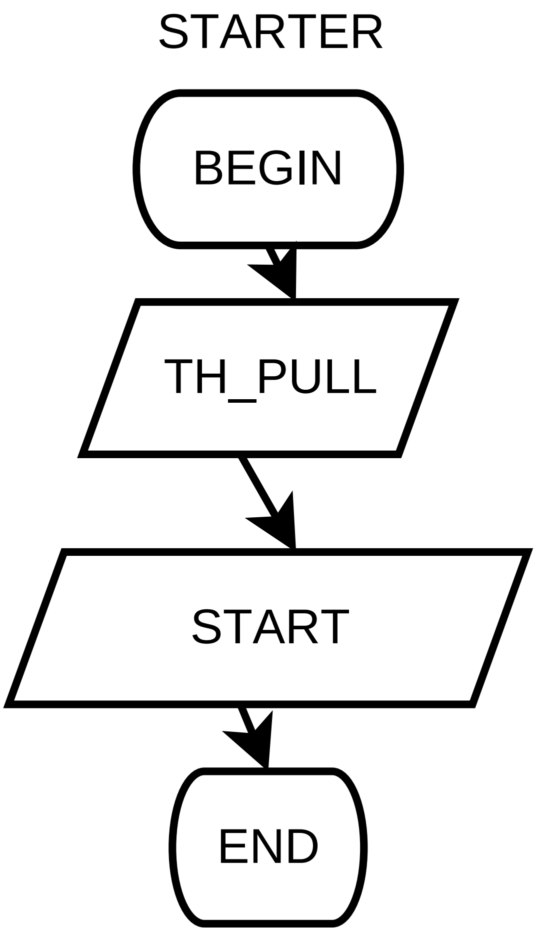

Fig. 3.3.1 9

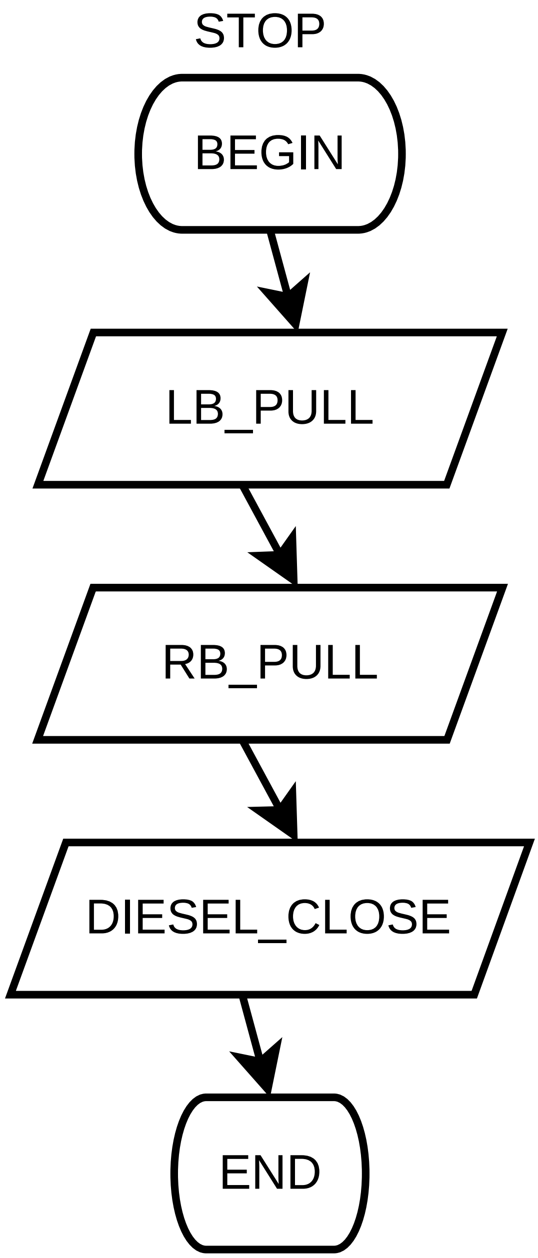

Fig. 3.3.1 10

Safety requirement satisfaction

The very first aim of the Disarmadillo remote control design is to make an actually safe deminer.

The best way to accomplish this task is to setup the PLC to pull the brakes and stop the engine when the safety stop red push button is down. The transmitter output 8 receives a +12V DC potential in normal working conditions (push button up) and no potential in safety stop condition (push button down). A relay can be connected to output 8 and Y/G ground to give the PLC the input signal to perform safety stop tasks.

If the remote control goes out of battery or if the connection between the transmitter and the receiver is lost, the receiver will perform a safety stop signal, as if the red push button were down.

While the Disarmadillo remote control is in the safety stop condition, it is possible to act on the manual control of the brakes.

Therefore, before starting the remote control it is imperative that the manual control of the brakes it is set to pull the brakes: otherwise the Disarmadillo will release the brakes when it enters the safety stop condition.

In the normal working conditions, with no other input apart from the one coming from the receiver red push button up, the Disarmadillo standard task seen in the control activity flowchart must be performed.

Another thing that can be done to make Disarmadillosafer is to connect a low fuel level sensor to the PLC. The PLC can than be programmed to light up the red light FB1 on the transmitter, by sending an output signal to the input 1.

3.3.2 Detailed design of the improved remote control system

Transmitter mapping

As a result of the Remote control flowcharts and the Chosen devices description, I decided to map the remote control in the way shown in the figures below. Because there are only 8 tasks that must be performed after a remote command, some switches are unused.

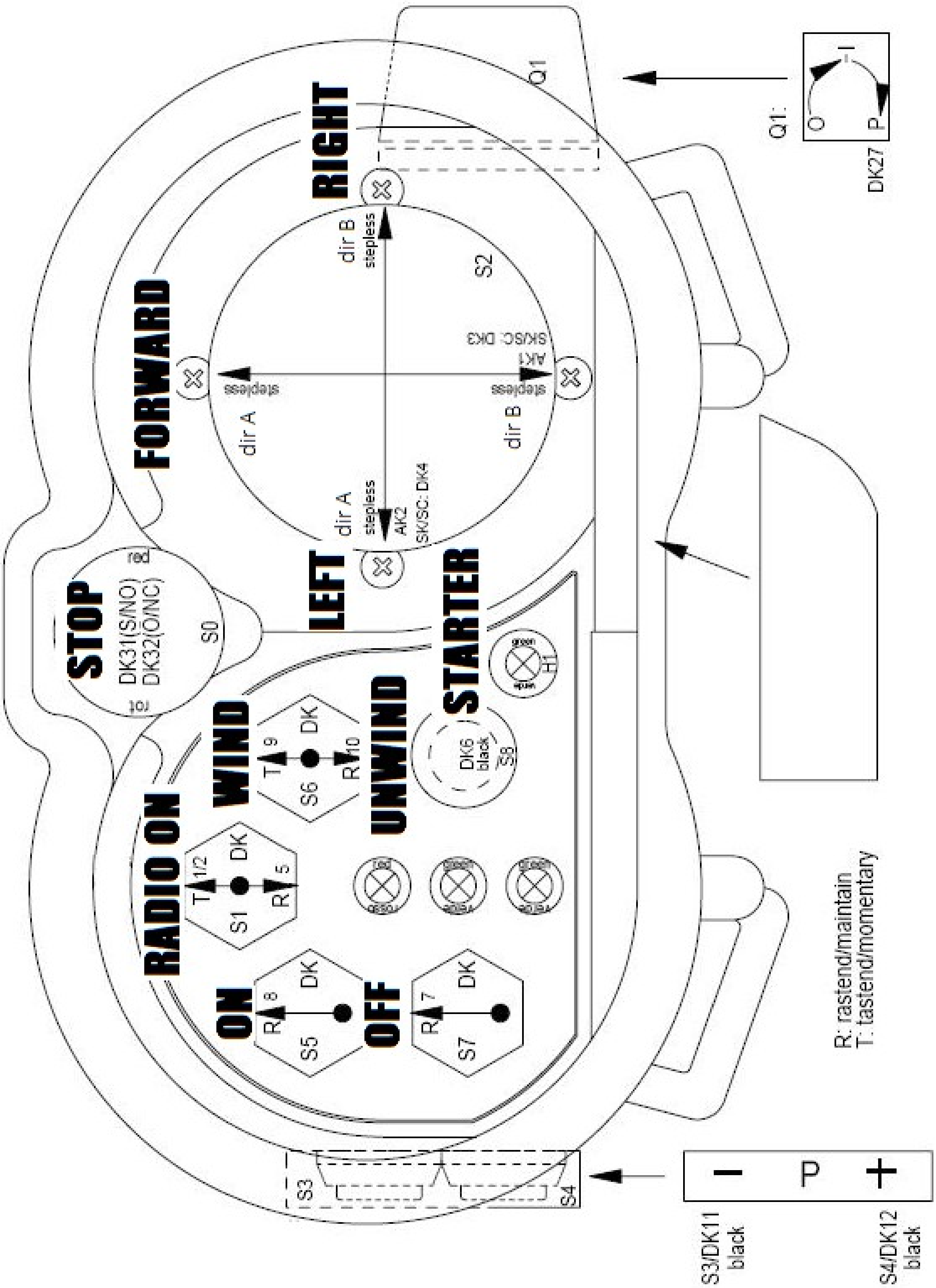

Fig. 3.3.2 1: The new transmitter switch mapping

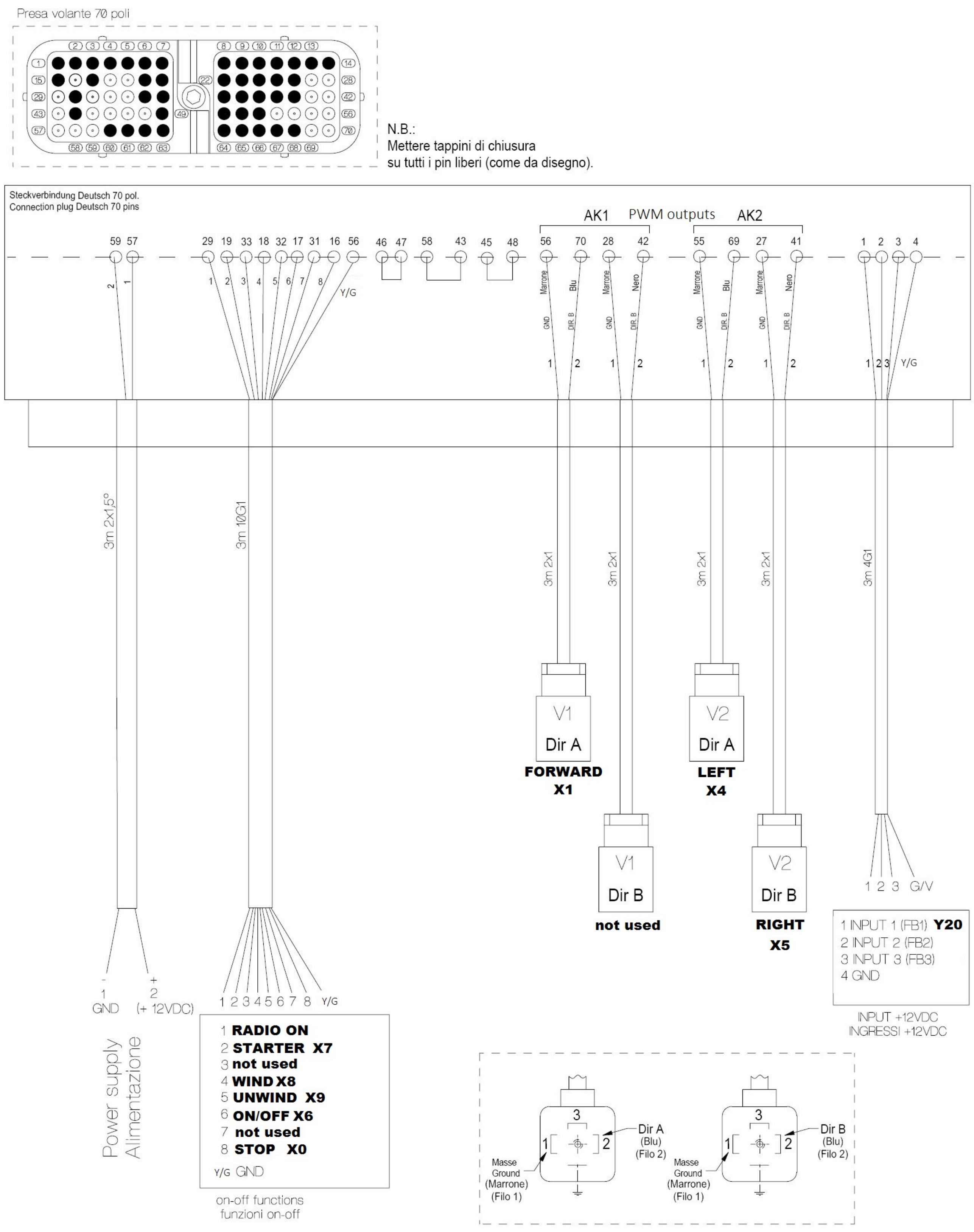

Fig. 3.3.2 2: The new receiver connections mapping

As seen in the figures, a RADIO ON command is present: it is a signal check command that must be given before any other. As a result, the starting procedure of the remote control is:

1. start the controller with the round switch on the right side;
2. switch to RADIO ON for some seconds.

Generic electric motors limit switches

The limit sensors of the throttle generic electric motor are now used to power off the motors using the Arduino board. As they are simple switches, a more simple and reliable solution it is needed.

Limit switches can be used to give potential to a normally close relay. The relay, when potential is given, can cut the power to the electric motor. The wiring scheme in the image below is quite simple and can be easily understood.

Two limit switches, of the same type of the ones installed in the throttle motor, should be installed in the diesel valve motor.

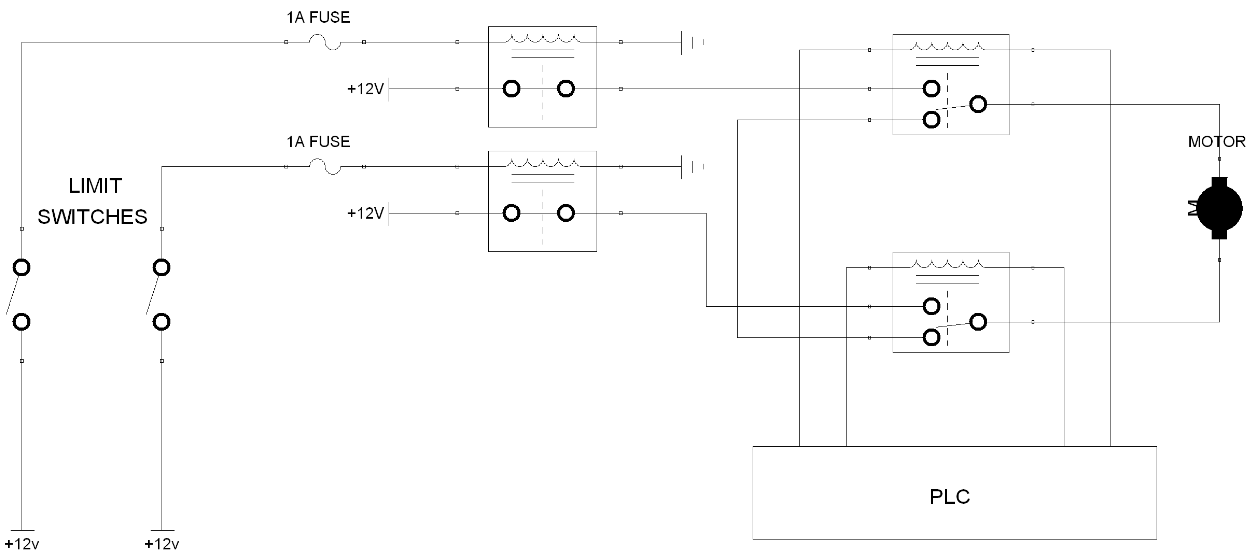

Fig. 3.3.2 3: The limit switches' electric scheme.

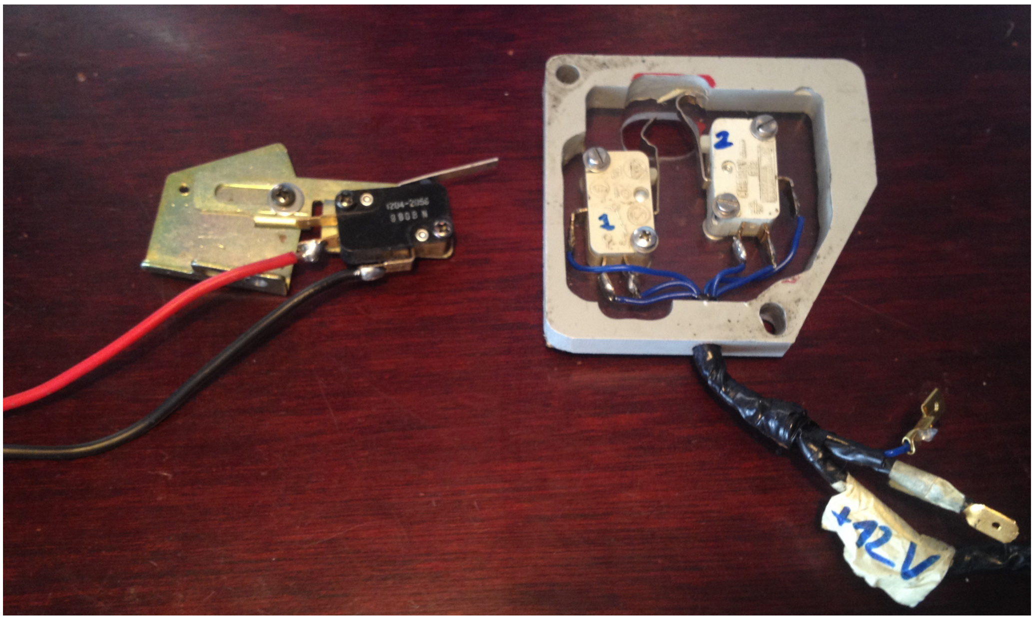

Fig. 3.3.2 4: The limit switches and their supports after soldering the wires.

Wiring scheme

To send the input signals from the receiver to the PLC, I connected the receiver outputs to some relays, used to adapt to +24V DC the signals. Another relay is used to adapt to +24V DC the signal coming from the low fuel sensor to the PLC.

The wires coming from the PLC towards the motors' relays are properly connected as SRCE output I have put some fuses to ensure that the very delicate PLC's transistors are safe, as described in the PLC manual. The fuses must be put before he common output Cn and must be 1A for the outputs related to two Yn outputs and 2A for the inputs related to four Yn outputs.

One 1A fuse also protects the fuel switch, while another 1A fuse protects the receiver input 1 (FB1).

The throttle and diesel valve motors are connected to the battery though the limits switch circuit. Although it has been analyzed separately, the wiring scheme is shown again. The limit switches are protected with some 1A fuses.

To operate the brake motors manually, two simple switches have been installed on Disarmadilloand connected to the PLC.

All the connections are shown in the figures below.

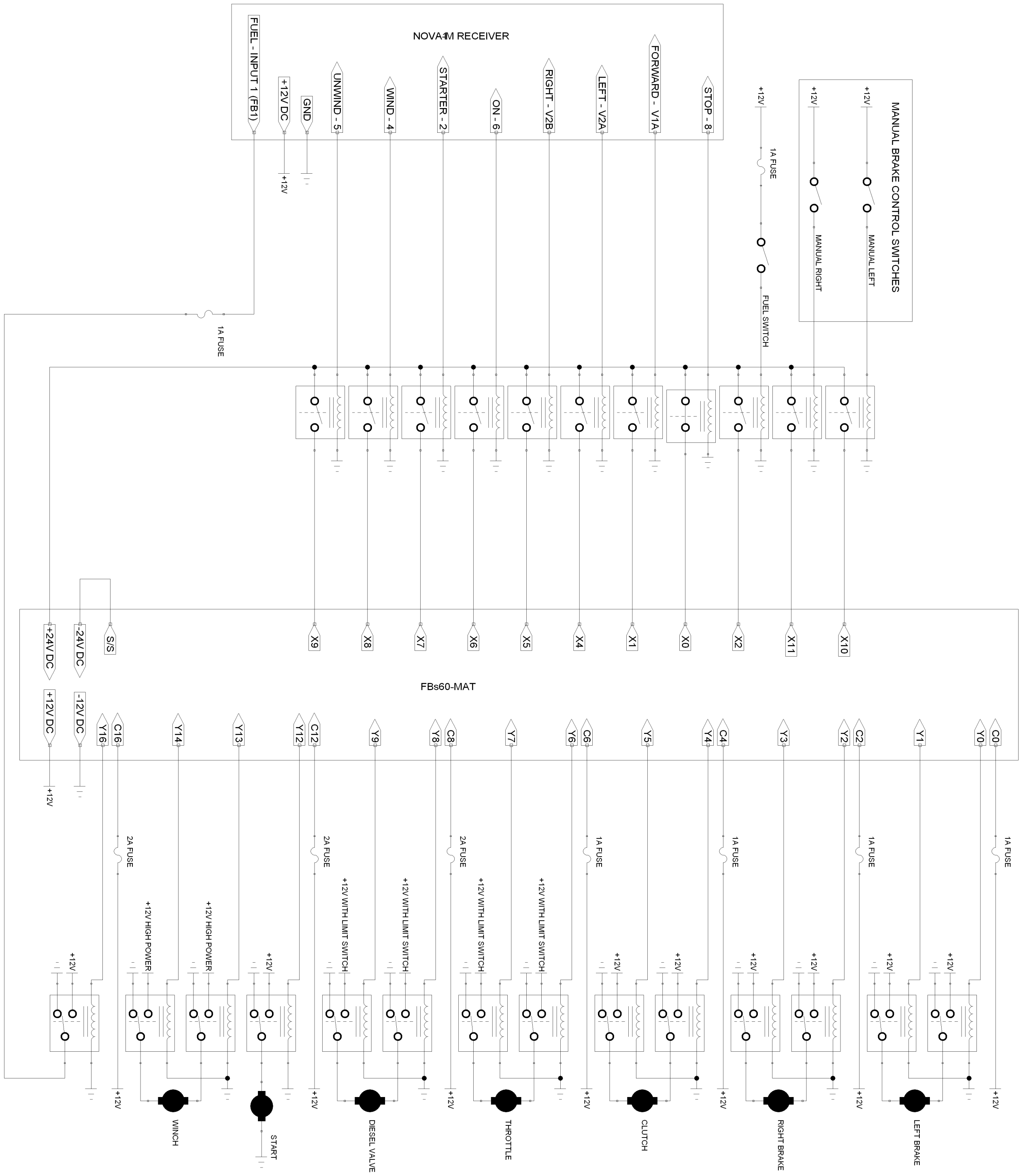

Fig. 3.3.2 5: The new wiring scheme

PLC programming

The software used to program the PLC is WinProLadder 3.23, provided by FATEK. It comes with a very complete user manual.

WinProLadder allows the users to operate with the ladder diagram: a graphical programming language. It is the oldest and most popular language for remote control systems. Using the ladder diagram means to actually draw a circuit with input contacts, output coils, timers, counters and many other additional elements. The many elements can be combined in series or in parallel.

The image below represents a circuit that can be fully drawn with the ladder language.

X0, X3 and X4 are momentary push buttons normally open; X1 and X2 are momentary push buttons normally close. They are the inputs of the system. The loads Y0, Y1 and Y2 are the output coils of the system. The standard condition is the one presented in the figure. X0 is open therefore Y0 is off, if X0 is pushed Y0 turns on. X1 is closed therefore Y1 is on, if X1 is pushed Y1 turns off. X2 and X3 are linked in parallel: the current can pass in X2 but is stopped by X4, which is open. Therefore the load Y2 is off. If X4 is pressed with the same conditions (X2 and X3 untouched) Y2 turns on. But if X2 is pushed (with X4 pushed and X3 untouched) Y2 turns off again. A press of X3 (with X2 and X4 both pushed) would turn Y2 on again.

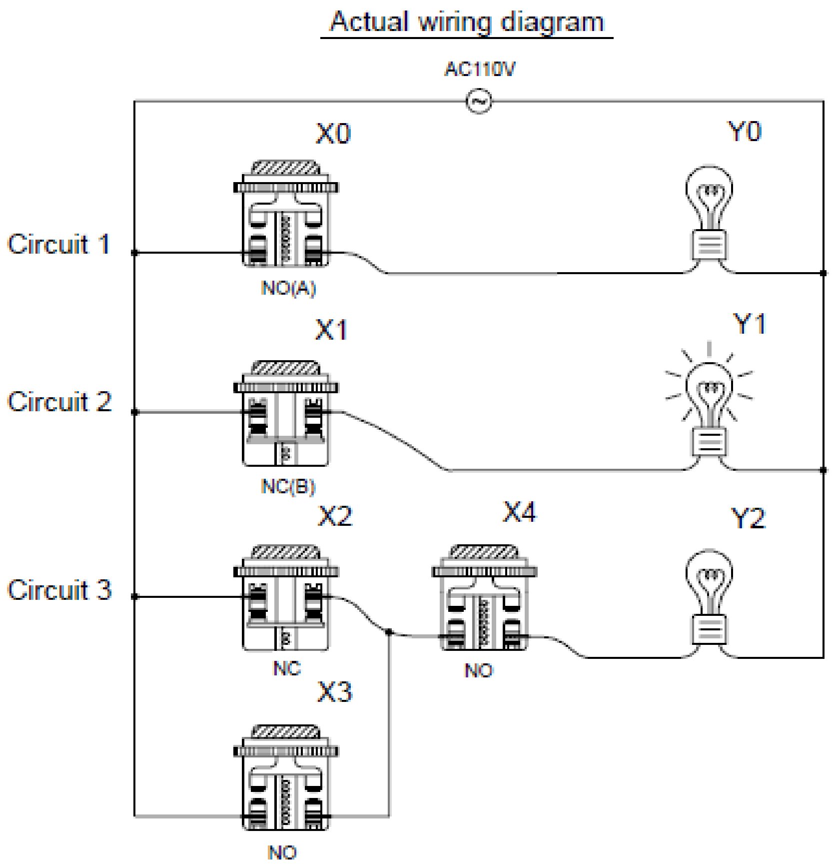

Fig. 3.3.2 6: A wiring diagram that the ladder language can reproduce.

In the figure below, a comparison between an actual ladder diagram of the circuit shown before and the WinProLadder version of the same circuit is presented.

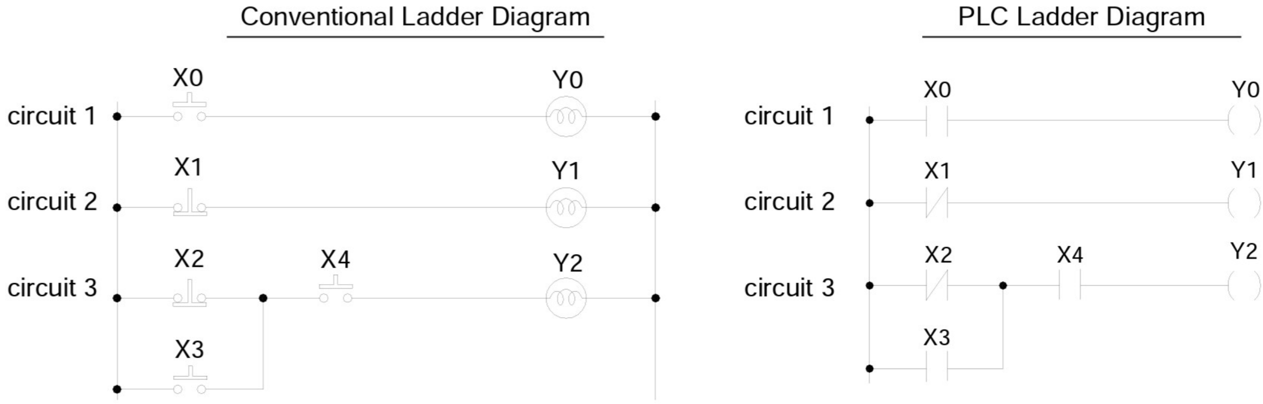

Fig. 3.3.2 7: A comparison between the conventional ladder language and the FATEK language.

In WinProLadder the diagram is divided in 88 small cells. Each cell can accommodate one element. I will analyze only the elements of the WinProLadder language I used in the PLC program for the Disarmadillo remote control.

The Input Contact it is an element with open circuit (A type) or short circuit (B type) status. Its status reference from the external signals. It is marked with X.

The Output Contact is an element with open circuit (A type) or short circuit (B type) status. Its status reflects the status of a relay coil. It is marked with Y.

The Internal Relay is an element with open or short status. It can be used either as input or output as if it were a Contact. Its status reflects the status of a memory register. It is marked with M.

By combining these three elements, I got a fully working PLC program.

In the figure below it can easily be seen what is the complication respect to flowcharts: the Output Contact must be unique for each physical output. So I must specify which input requires a certain output, instead of specifying which output requires a certain input (as I did when I drew the flowcharts). As a result, each section of the program reflects one actuator instead of one task.

Particular attention must be payed to the manual control of the brakes: it can be activated only when the safety stop red button is pressed, which means that the remote control is not operating. As a consequence, the Disarmadillo brakes must always be pulled before starting remote control, so that they are pulled again when the remote control is off.

3.4 Improved remote control test

Before the installation of the new remote control system, I carried out some extended tests. The tests were three:

- the test of proper connection functioning of each wire;
- the test of power polarity of output connections in the safety standard condition;
- the test of the power polarity of output connections in working conditions, testing the proper reaction of the system to each command.

The first test was carried out with the power source disconnected from the system, whereas the others were carried ut with the system fully powered by a desktop power supply.

Conductivity and polarity were tested with a common digital multimeter.

During the two latter tests the reactions of the PLC were monitored by the PLC program running on a portable PC connected to the PLC.

All the tests gave good results, hence the remote control was installed on Disarmadillo.

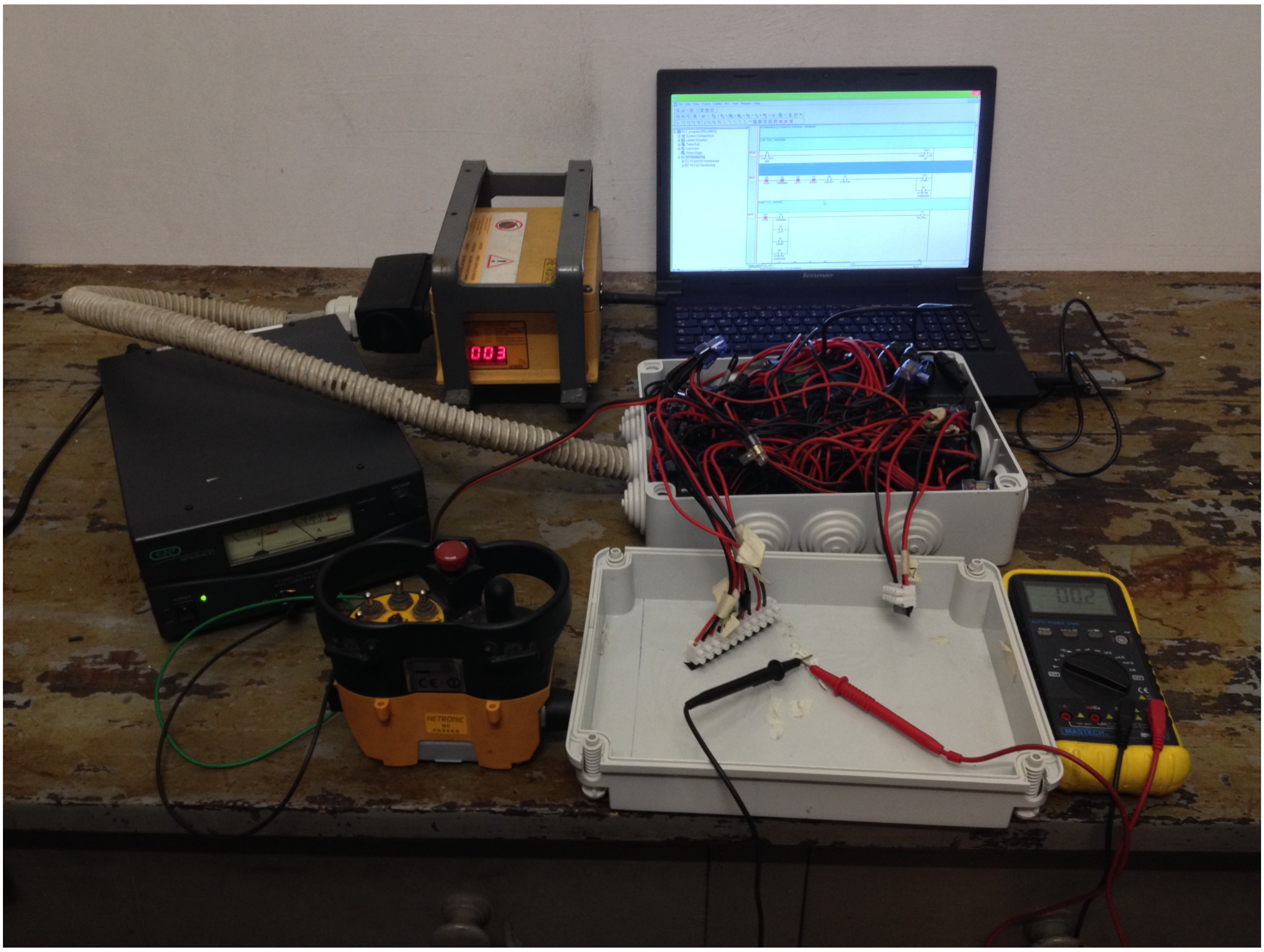

Fig. 3.4 1: The whole system being tested in the laboratory of the University.

4 References

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2. Hetronic NOVA-M datasheet
3. Massimo Banzi – Getting started with Arduino, O'Reilly Media (February 2009)
4. Emanuela Elisa Cepolina – Powertillers and Snails for Humanitarian Demining: Participatory Design and Development of a low cost Machine based on Commercial Agriculture Technology (May 2008)
5. Michał Przybyłko – LOCOSTRA, a small-size fully teleoperated tractor: improvement of the remote control system. (September 2011)
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7. Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction, also known as “Ottawa Treaty” or “Mine Ban Treaty”, signed on 18 September 1997 in Ottawa (Ontario, Canada)
8. International Campaign to Ban Landmines [online] (www.icbl.org)
9. Database of Demining Accidents (DDAS) [online] (http://www.ddasonline.com/)
10. The LOCOSTRA project web page [online] (http://www.snailaid.org/index.php/LOCOSTRA)
11. The TIRAMISU (Toolbox Implementation for Removal of Anti-personnel Mines, Submunitions and UXO) project web page [online] (http://www.fp7-tiramisu.eu/)
12. The Billy Goat Radio for Mine Risk Education project web page [online] (http://www.snailaid.org/index.php/Billy_Goat_Radio_for_Mine_Risk_Education)
13. Snail Aid – Technology for Development [online] (www.snailaid.org)
14. The Arduino official web page [online] (www.arduino.cc)
15. Charles Platt – Make: Electronics, Maker Media, Sebastopol, California, USA (2009)
16. Grillo S.p.a. G131 Operator's manual
17. IMAS International Mine Action Standards, 9.50

5 Appendix

5.1 The PLC program in detail

All the parts of the program are designed so that the Disarmadillo standard condition is restored at the end of each action.

I will analyze each part of the program, describing what it does, in order to better understand its scheme. This description is to be read after analyzing the figure.

Low fuel warning: if FUEL_SENSOR is on: set FUEL_LIGHT on.

This lights the fuel sensor light on the receiver when the fuel level is low.

Starter consent and starter control: if STOP is on and FORWARD and LEFT and RIGHT are off and ON/OFF and STARTER are on: set START, STARTER_CONSENT on.

This starts the starter motor and writes on the memory register STARTER_CONSENT the high state, in order to use the register as an input for the throttle (remember that Disarmadillo needs the throttle to be pulled to start).

Throttle control: if STOP is on and FORWARD or LEFT or RIGHT or STARTER_CONSENT are on: set TH_PULL on; if STOP is on and FORWARD and LEFT and RIGHT and STARTER_CONSENT are off: set TH_RELEASE on; if STOP is off, set TH_RELEASE on.

This pulls the throttle when moving Disarmadillo and when starting the engine.

Left brake control: if STOP is on and FORWARD or RIGHT are on: set LB_RELEASE on; if STOP is on and LEFT is on or FORWARD and LEFT and RIGHT are off: set LB_PULL on; if STOP is off and MAN_LEFT is on set LB_RELEASE on; if STOP is off and MAN_LEFT is off: set LB_PULL on.

This pulls the right brake when moving forward or left and when the manual control requires it.

Right brake control: if STOP is on and FORWARD or LEFT are on: set RB_RELEASE on; if STOP is on and RIGHT is on or FORWARD and LEFT and RIGHT are off: set RB_PULL on; if STOP is off and MAN_RIGHT is on set RB_RELEASE on; if STOP is off and MAN_RIGHT is off: set RB_PULL on.

This pulls the right brake when moving forward or right and when the manual control requires it.

Clutch control: if STOP is on and FORWARD and LEFT and RIGHT are off: set CL_PULL on; if STOP is on and FORWARD or LEFT or RIGHT are on set CL_RELEASE on; if STOP is off set CL_RELEASE off.

This releases the clutch when moving Disarmadillo.

Diesel valve control: if STOP is on and ON/OFF is on: set DIESEL_OPEN on; if STOP is on and ON/OFF is OFF set DIESEL_CLOSE on; if STOP is off set DIESEL_CLOSE on.

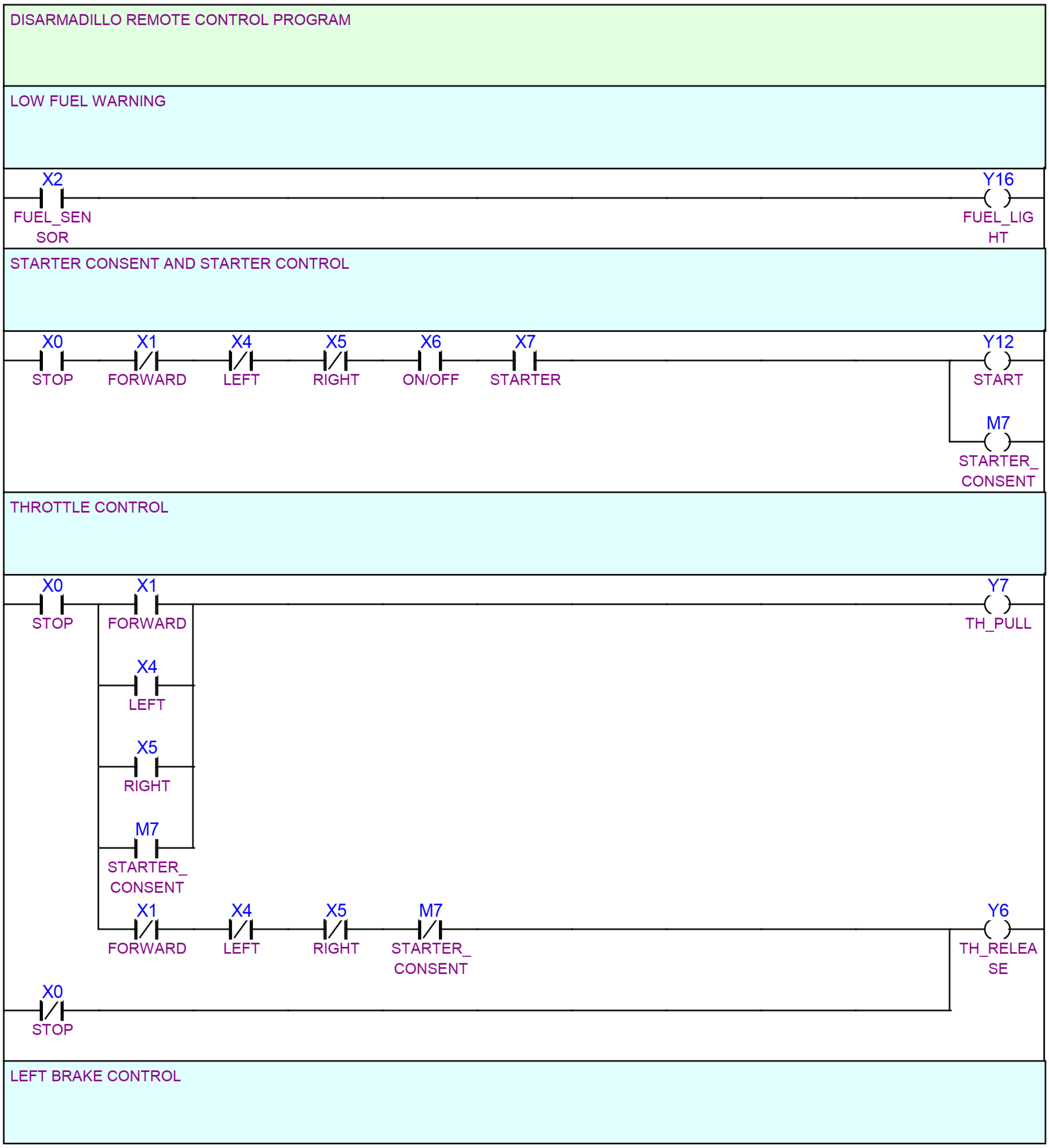
This opens the diesel valve when required by the operator.

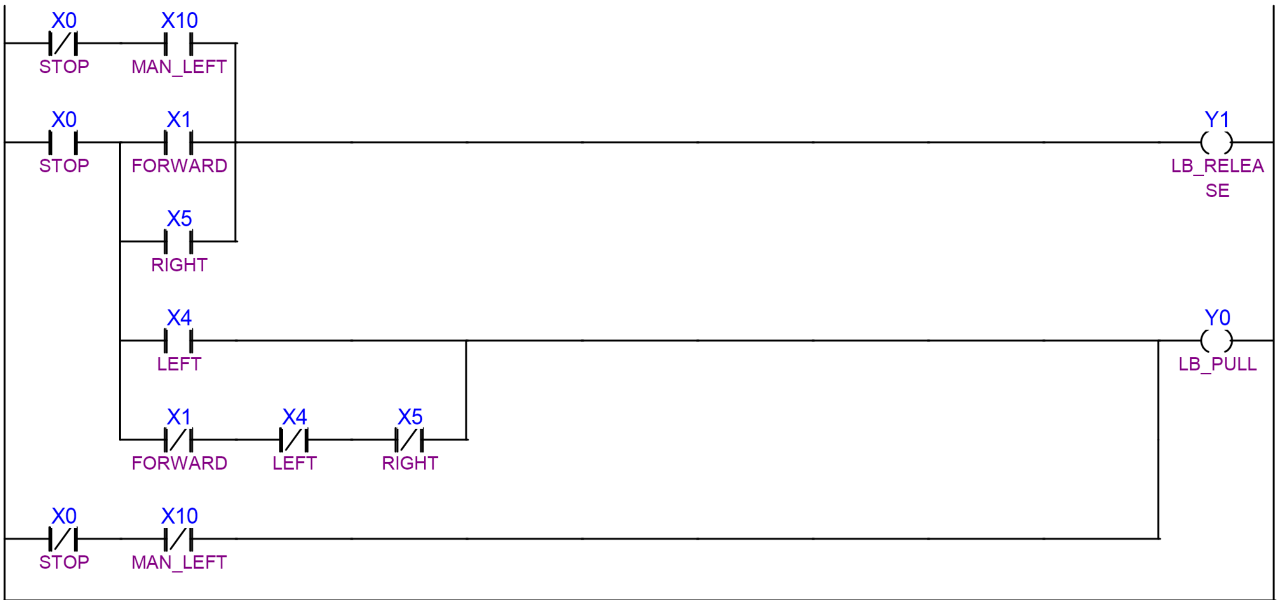
Winch control – up: if STOP is on and WIND is on: set WINCH_UP on.

This winds the winch when required.

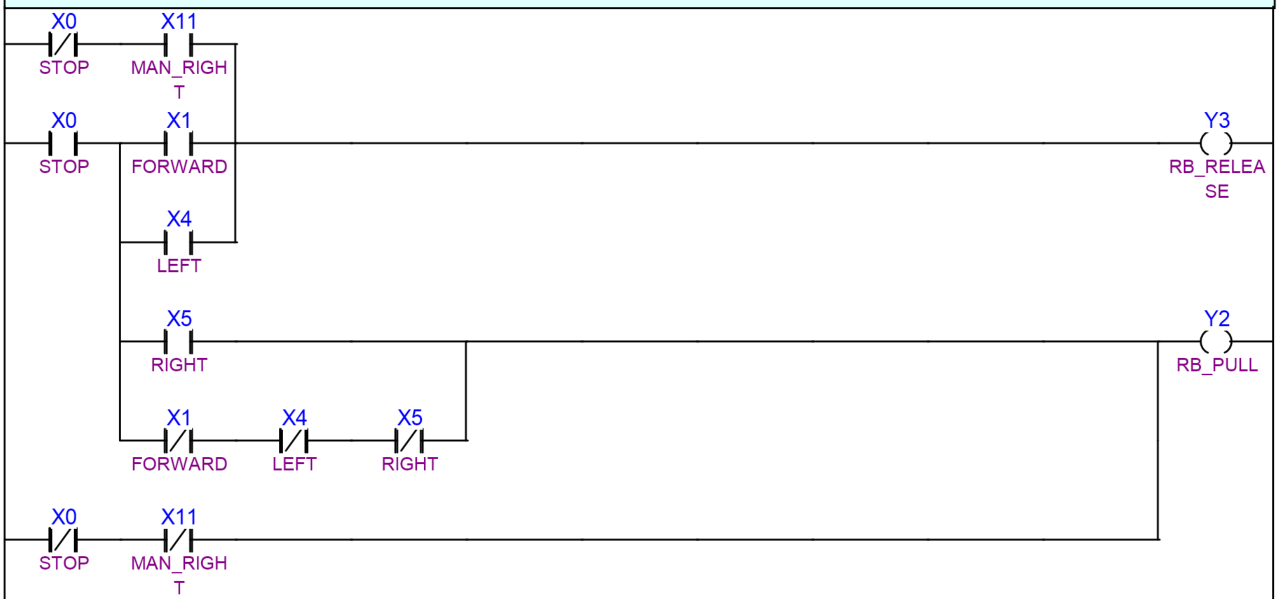
Winch control – down: if STOP is on and UNWIND is on: set WINCH_DOWN on.

This unwinds the winch when required.

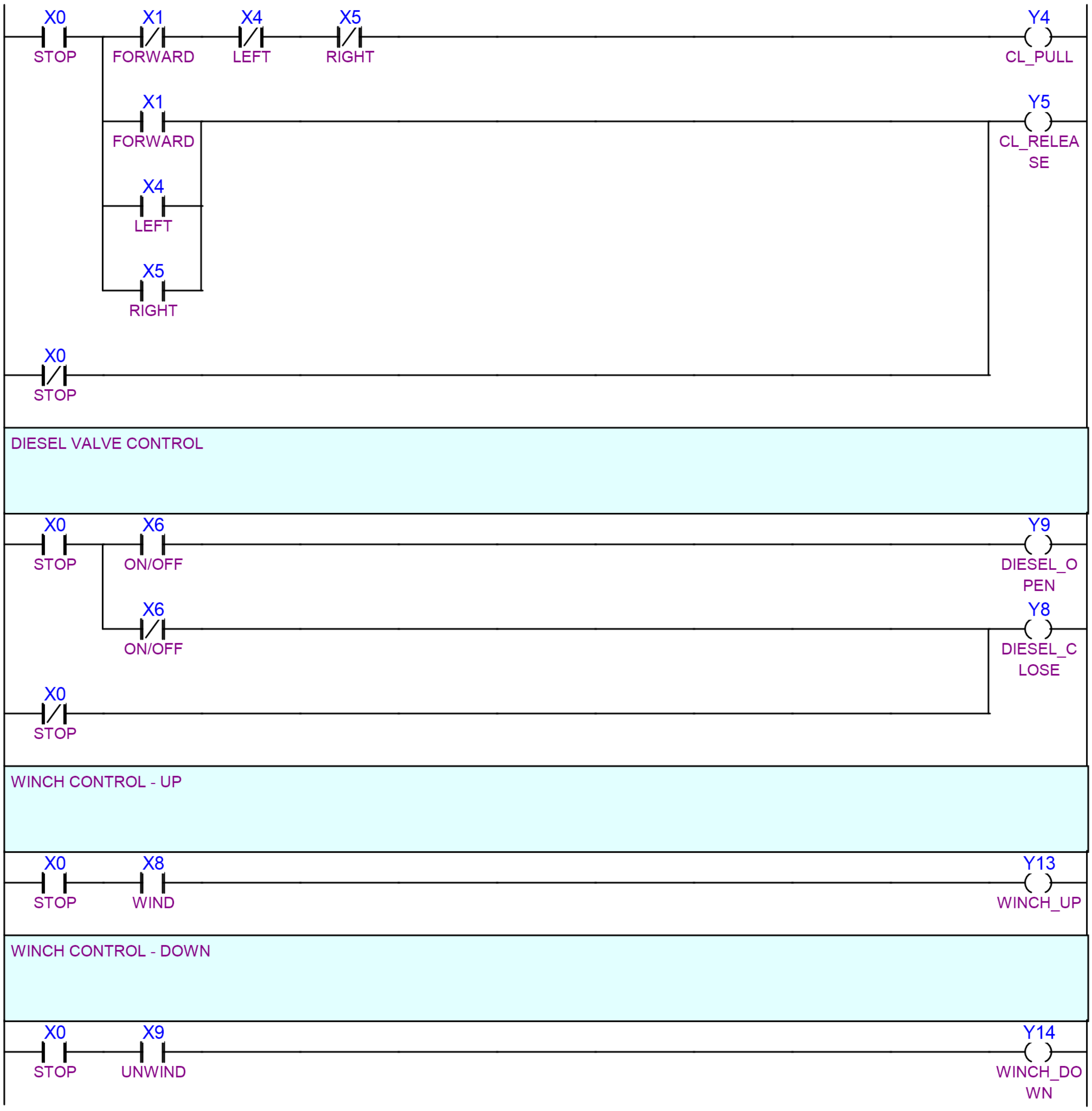




RIGHT BRAKE CONTROL



CLUTCH CONTROL


X0
STOP
X1
FORWARD
X4
LEFT
X5
RIGHT
Y4
CL_PULL
X1
FORWARD
Y5
CL_RELEA
SE
X4
LEFT
X5
RIGHT
X0
STOP
DIESEL VALVE CONTROL
X0
STOP
X6
ON/OFF
Y9
DIESEL_O
PEN
X6
ON/OFF
Y8
DIESEL_C
LOSE
X0
STOP
WINCH CONTROL - UP
X0
STOP
X8
WIND
Y13
WINCH_UP
WINCH CONTROL - DOWN
X0
STOP
X9
UNWIND
Y14
WINCH_DO
WN

5.2 The PLC – to - PC communication cable

The PLC must be connected to the PC with the PORT0 interface, found on the top of the PLC box.

The PORT0 requires a male Mini-DIN 4 pin (MD4M) connector, the same as the one used in S-VIDEO cables.

The connection to the PC can be realized with a RS-232 9 pin D-sub female (DBF9) connector.

The cable used to realize the connections was a regular 4 wires USB cable marked as: 28AWG/1P+28AWG/2C.

The wiring diagram can be found on the PLC's manual provided by FATEK. The following figure shows the way to solder each pin of the connectors.

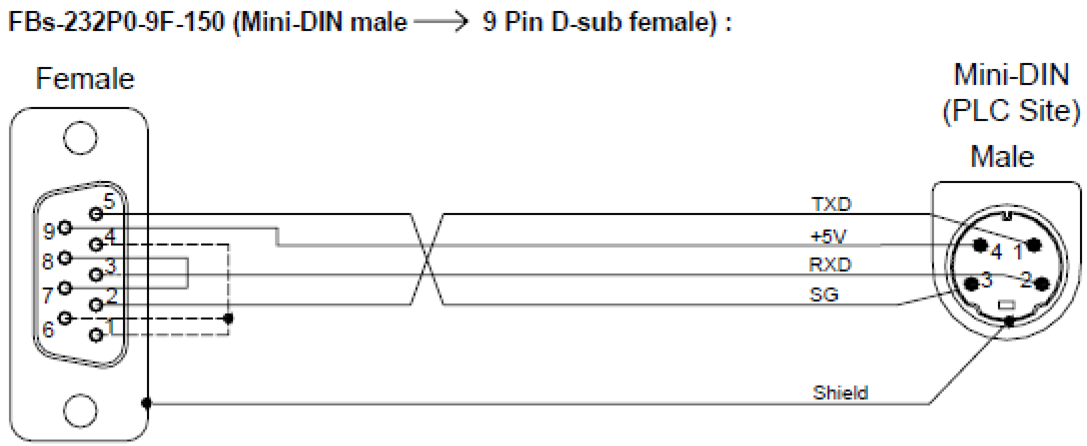


Fig. 5.2 1: The communication cable wiring diagram.

5.3 The Arduino code loaded on the analyzed Arduino board

As mentioned before, the original (incomplete) remote control system installed on Disarmadillo worked with an Arduino board in order to process the input signals. As I studied deeply the characteristics of the original Arduino program in order to improve them with the new (PLC controlled) remote control system, I decided to report (for reference) the Arduino code I analyzed.

For understanding the (very simple) programming language I used the book written by the creator of the Arduino project, Massimo Banzi [3].

```
/* Code for the Arduino to control the Disarmadillo machine


Input signals come from a simple wireless board with 4 channels
Output signals are sent to optoisolators connected to relays
which control X motors to action accelerator, left and right
brakes, clutch, shutdown and power on*/

/*Commands*/

/*The command has 12 channels, normally ground connected,
which turn on a relay only for the time the button being pushed.
Each button shall be pushed separately, in case of simultaneous
pushing, less dangerous action will be performed.
The command activates an arduino channel, which will activate
several actions on the output to the engines*/

  int A = LOW;  //Accelerator
  int C = LOW;  //Clutch
  int F = LOW;  //Power ofF
  int L = LOW;  //Turn Left
  int N = LOW;  //Power oN
  int R = LOW;  //Turn Right

void setup() {

  Serial.begin(9600);  //Comunicazione su porta seriale

  pinMode(31, INPUT);  //A
  pinMode(33, INPUT);  //L
  pinMode(35, INPUT);  //R
  pinMode(37, INPUT);  //N
  pinMode(39, INPUT);  //F
  pinMode(41, INPUT);  //SA0
  pinMode(43, INPUT);  //SA1

  pinMode(38, OUTPUT); // Accelerator  (HIGH, pulled)
  pinMode(40, OUTPUT); // Decelerator  (HIGH, pulled)
  pinMode(24, OUTPUT); // Left brake (HIGH, pulled)
  pinMode(26, OUTPUT); // Right brake (HIGH, pulled)
  pinMode(28, OUTPUT); // Clutch (HIGH, pulled)
  pinMode(30, OUTPUT); // Gas on (HIGH, pull)
  pinMode(32, OUTPUT); // Gas off (HIGH, pull)

  pinMode(13, OUTPUT); // LED per debug

}
```

```
void loop() {

  int A = digitalRead(31);
  int L = digitalRead(33);
  int R = digitalRead(35);
  int N = digitalRead(37);
  int F = digitalRead(39);
  int SA0 = digitalRead(41);
  int SA1 = digitalRead(43);

/*1 Accelerator
Accelerator shall let the brakes and clutch and pull
accelearator*/
if (A == HIGH)
{
  Serial.println(1, DEC);  //SERIAL TEST
  digitalWrite(40, LOW);  //Decel Let
  digitalWrite(24, LOW);   //Left brake let
  digitalWrite(26, LOW);   //Right brake let
  Serial.println('SA1'); //Verifica lettura SA1

  while (SA1==LOW&&A==HIGH){
    SA1=digitalRead(43);
    digitalWrite(38, HIGH);  //Accel pulled
    A=digitalRead(31);
    Serial.println(11);
    }
  digitalWrite(38, LOW);   //Accel let
  digitalWrite(28, LOW);   //Clutch let

 }
/*3 Turn Left
Let right brake, let clutch and pull accelerator*/
else if (L==HIGH)
{
  Serial.println(3, DEC);  //SERIAL TEST  digitalWrite(40,
LOW);  //Decel Let
  digitalWrite(24, HIGH);   //Left brake pulled
  digitalWrite(26, LOW);   //Right brake let
  while (SA1==LOW&&L==HIGH){
    digitalWrite(38, HIGH);  //Accel pulled
    SA1=digitalRead(43);
    L=digitalRead(33);
  }
  digitalWrite(38, LOW);   //Accel let
  digitalWrite(28, LOW);   //Clutch let

}
/*4 Turn Right
Let left brake, let clutch and pull accelerator*/
else if (R==HIGH)
{
  Serial.println(4, DEC);  //SERIAL TEST
  digitalWrite(40, LOW);  //Decel Let
  digitalWrite(24, LOW);   //Left brake let
  digitalWrite(26, HIGH);   //Right brake pulled
  while (SA1==LOW&&R==HIGH){
    digitalWrite(38, HIGH);  //Accel pulled
    SA1=digitalRead(43);
    R=digitalRead(35);
```

```
  }
  digitalWrite(38, LOW);   //Accel let
  digitalWrite(28, LOW);   //Clutch let

}
/*11 --> Power On
Start the poweron engine and pull the gas for some secs */
else if (N==HIGH)
{
  digitalWrite(40, LOW);  //Decel Let
  digitalWrite(24, HIGH);   //Left brake pulled
  digitalWrite(26, HIGH);   //Right brake pulled
  while (SA1==LOW){
    digitalWrite(38, HIGH);  //Accel pulled
    SA1=digitalRead(43);
  }
  digitalWrite(38, LOW);   //Accel let
  digitalWrite(28, HIGH);   //Clutch pulled

  digitalWrite(30, HIGH);   //Gas on pulled
  delay(2000); //time to let the gas reach the top
  digitalWrite(30, LOW);   //Gas on let
  Serial.println(5, DEC);  //SERIAL TEST
}

/*12 --> Power Off
Dare tensione a motorino di spegnimento*/
else if (F==HIGH)
{
  digitalWrite(38, LOW);  //Accel let
  digitalWrite(24, HIGH);   //Left brake let
  digitalWrite(26, HIGH);   //Right brake let
  while (SA0==LOW){
    digitalWrite(40, HIGH);  //Decel pulled
    SA0=digitalRead(41);
  }
  digitalWrite(38, LOW);  //Accel let
  digitalWrite(28, HIGH);   //Clutch let
  digitalWrite(32, HIGH);
  delay(2000);
  digitalWrite(32, LOW);

}
/*Default

Machine is normally blocked
Both brakes are pulled clutch is pulled acelerator is let
If no input, pull brakes and clutch*/
else
{
  digitalWrite(38, LOW);  //Accel let
  while (SA0==LOW){
    digitalWrite(40, HIGH);  //Decel pulled
    SA0=digitalRead(41);
    Serial.println(9,DEC);
  }
  digitalWrite(40, LOW);  //Decel let
  digitalWrite(38, LOW);  //Accel let
  digitalWrite(28, HIGH);   //Clutch pulled
  digitalWrite(24, HIGH);   //Left brake pulled
```

```
  digitalWrite(26, HIGH);   //Right brake èulled
  Serial.println(10, DEC);  //SERIAL TEST
  Serial.println(digitalRead(41),DEC);
  Serial.println(digitalRead(43),DEC);
}

/*Actuators

3 Mcvell with 2 microswitches each (brakes, clutch) (L, R, C)
1 Relay for Power On (N)
1 Piston engine for Poweroff (F)
1 engine for accelerator (A)
*/

/*Arduino Input
5 relays from board
2 microswitches for accelerator
*/
}
```